# TEHNIČKI GLASNIK

# TECHNICAL JOURNAL

**CONTENT**                                                                                                           I

# 9th European Congress on **Computational Methods in Applied Sciences and Engineering**

## 3-7 JUNE 2024, LISBON (PORTUGAL)

# Effects of COVID 19 on Electrocardiographic Parameters: Healthy ECGs vs COVID 19 ECGs

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**Abstract:** The coronavirus disease (COVID-19) started in 2019 and became a pandemic by infecting many people all over the world. It is known that COVID-19 affects the heart as well as the respiratory system, and the changes it causes on the electrical activity of the heart are among the common research topics of recent studies. The electrical activity of the heart is measured by Electrocardiography (ECG). While some ECG devices give the ECG signal directly as numeric vector format, others draw the signal on paper or give results as an image. ECG images drawn on paper are usually only visually examined by the doctor, and detailed analysis is mostly attempted with low-accuracy machine learning methods. In this study, a new approach that converts ECG images drawn on paper into signals is proposed. The proposed approach was used to convert the ECG images recorded from COVID-19 and healthy people in an open source ECG image database into signals, and the obtained ECG signals were analysed in detail with signal processing methods and compared statistically between COVID-19 and healthy group and with similar studies in the literature. Results showed that, ECG characteristics were significantly changed with the COVID-19.

**Keywords:** COVID-19; Electrocardiography (ECG); Feature Extraction; image-to-signal conversion

## 1 INTRODUCTION

Coronavirus Disease 2019, commonly known as COVID-19, is a disease that emerged in China at the end of December 2019, and spread all over the world [1]. COVID-19 is caused by Severe Acute Respiratory Syndrome-Coronavirus-2 (SARS-CoV-2) virus and The World Health Organization (WHO) had to declare a pandemic in 2020 due to the spread of the virus. Two years have passed since the emergence of the virus, and the total number of cases and deaths in worldwide have reached over 450 million and 6 million, respectively [2]. The clinical indications of the coronavirus are mostly manifested by respiratory system symptoms (cough, fever, shortness of breath, fatigue, etc.). With sudden changes in the respiratory system, pneumonia and acute respiratory diseases are observed in individuals. It is known that many patients have also persistent symptoms after COVID-19 [3]. According to studies, it has been observed that individuals with cardiovascular diseases face COVID-19-related problems more frequently and have higher mortality rates compared to the others [4].
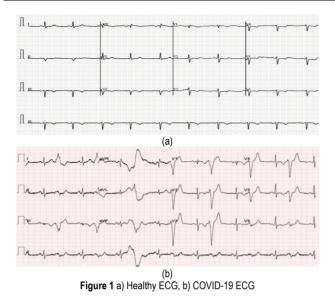
In general, the damages caused by SARS-CoV-2 infection in the respiratory tract, heart and lungs are observed with computed tomography (CT) and x-ray scans. Recent reports show that COVID-19 triggers diseases such as myocarditis and hypertension in the heart [5]. Recently, researchers focused on electrocardiographic (ECG) observations of individuals, since it is a more cost effective approach compared to CT and X-ray scans to obtain information from heart. In addition to that, it is possible to have more information of heart physiology using ECG. Therefore, studies using ECG have increased to observe the effects of COVID 19 on heart [6-7].

In a recent study with a shared COVID-19 ECG database, researchers observed the effects of COVID-19 on ECG [8]. This dataset contains 1937 ECG recordings obtained from distinct patients using 'EDAN SERIES-3' ECG device from different health care facilities across Pakistan. The team of senior medical professionals with experience of ECG interpretation reviewed the data using Telehealth ECG diagnostic system. The researchers distinguished the healthy and COVID-19 ECG images after the manual interpretation and 859 of the images belong to healthy people while 250 of the images belong to COVID-19 patients. Using the same database, different studies used convolutional neural network (CNN) models to classify ECG images [9-14]. Each of these studies exhibited a deep learning-based approach through imagery. However, since not having a signal dataset, it is impossible to make a precise ECG signal analysis over this important database. In this study, ECG paper images of this COVID-19 ECG database were converted into digital vector arrays using image-processing techniques. During this process, low quality or corrupted images were also eliminated and finally, a high quality Lead-II ECG signal dataset consisting of 118 COVID-19 patient and 156 healthy individual ECGs were obtained. Furthermore, converted signal dataset was analysed using signal processing techniques and their features were extracted. Results were statistically analysed and distinguishing features in ECGs between COVID-19 patients and healthy individuals were revealed. The results were compared with the studies using the images of the same dataset.

## 2 MATERIALS AND METHOD
### 2.1 Database

In this study, the COVID-19 ECG database consisting of COVID-19 patients' and healthy individuals' ECGs shared by Khan et al [5] were used. ECG recordings of that dataset were obtained using a 12-channel ECG device with a sampling frequency of 500 Hz and recorded on thermal paper using the built-in thermal array recorder. Shared 859 healthy individual ECGs were directly saved as jpeg image by the device while 250 COVID-19 patient ECGs were saved by scanning the paper output. Sample recordings of a COVID-19 patient and a healthy individual are given in Fig. 1.

(a)

(b)

**Figure 1** a) Healthy ECG, b) COVID-19 ECG

## 2.2 Preprocessing

Since healthy and COVID-19 ECG images exhibit different image formations, different methodology were applied for each of them. Firstly, healthy individual ECG images were processed. These images were directly recorded by the device and all of them were in the same formation as given in Fig. 1a. In each image, the signal at fourth raw corresponds to Lead-II ECG data and a square wave at the beginning of this signals shows the zero line of the signal together with its amplitude and time information. Quick visual inspection showed us that the Lead-II data varies between ±3 mV and all of them have at least 9 seconds duration. Thanks to all Lead-II data were at the same location of the recorded images, an image mask was constructed by calculating the corresponding corner pixels to be extracted and applied to all healthy group dataset.

Similar procedure was applied for the extraction of Lead-II ECG images of COVID-19 patients. But, since the recorded images were obtained via scanning or photographing the ECG papers, Lead-II data in each of them have different locations as well as different aspect ratios. Therefore, each of the data were manually investigated and zero line of the signal was determined using the square wave indicator at the beginning of each Lead-II image. After detecting the corresponding corner pixels for ±3 mV range and 0-9s duration for each image, Lead-II images were extracted from the recordings and saved for further processing. Sample extracted images for a random ECG Lead-II data are given in Fig. 2.



**Figure 2** Extracted Lead II ECG

After extracting all Lead II derivation images from recordings, they were converted to vectoral signal format using image and signal processing techniques. Firstly, a binary mask was applied to image using a threshold to get rid of background paper and leave only ECG pattern on the image. Then, the amplitude and time value of each pixel on the extracted images was calculated and they converted into the ECG signal values.

The generalized formulation for the vectoral conversion used are as follows:

$$d = (a - b) / h / sqr / \text{mV} \tag{1}$$

Here, $d$ corresponds to the potantial value of the converted ECG signal, while $a$ is the pixel number of the extracted ECG pattern in vertical axis (amplitude of ECG – $y$ axis), $b$ is the pixel number corresponds to the baseline of square indicator in vertical axis, $h$ is the total number of pixels of the extracted image in vertical axis, $sqr$ is the number of squares the extracted image has along vertical axis, and mV is the millivolts value of each square in ECG paper, as seen in Fig. 3.



**Figure 3** Demonstration of ECG graph conversion parameters

After obtaining all ECG Lead-II data as numeric signals, the analysis phase was started. The first part of the analysis was to filter the signals to remove unwanted noises that embarrass them during analysis. Wavelet transform-based filtering using Debuchies 6 wavelet was utilized as proposed in [15].

After filtering the signals, characteristic points of the signal, the onset, peak and offset points of P, QRS complex and T waves, were determined numerically using wavelet transform based algorithms proposed in [15] and [16].

Furthermore, the scalogram of each signal was calculated as explained in [15] and [16] and energy values of each wave was obtained for both groups.
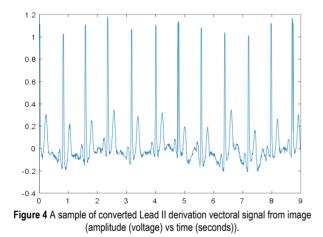
By using the obtained characteristic points and scalogram data, following parameters given in Tab. 1 were calculated from each ECG signal and stored for statistical analysis.
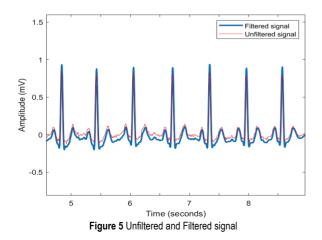
As a descriptive statistical result, mean and standard deviations of the calculated parameters were obtained using a statistical package program. The normality of variables and the homogeneity of variances were evaluated with the Kolmogorov-Smirnov test. In data analysis, independent 2 group t-test (Student's t-test) was used for the comparison of two groups, while the relationship between two continuous variables was evaluated with the Pearson Correlation Coefficient. The significance level of the tests was accepted to be $p < 0.05$.

**Table 1** Description of obtained ECG parameters [17]

| ECG Parameter | Information |
|---|---|
| RR interval | The duration between two consecutive R peak points, in milliseconds |
| ST interval | The duration between end of T wave and end of the previous QRS complex, in milliseconds |
| ST segment | The duration between onset of T wave and end of the previous QRS complex, in milliseconds |
| QT interval | The duration between end of T wave and onset of the previous QRS complex, in milliseconds |
| PR (or PQ) interval | The duration between onset of QRS complex and onset of previous P wave, in milliseconds |
| QRS complex interval | The duration from beginning to end of an QRS complex, in milliseconds |
| QRS complex amplitude | Amplitude difference between R peak and S deflection downwards point of a QRS complex, in millivolts |
| T wave amplitude | Amplitude difference between peak and offset points of a T wave, in millivolts |
| P wave amplitude | Amplitude difference between peak and offset points of a P wave, in millivolts |
| $QTc$ | $QTc = QT\_interval/(RR\_Interval)^{\frac{1}{3}}$ |
| ECG Scalogram | Energy content of the signal obtained from Scalogram analysis [20] |

# 3 RESULTS
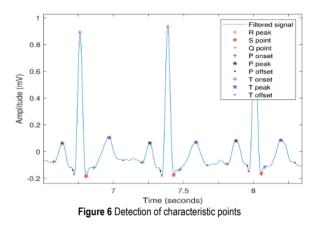
Fig. 4 shows a sample signal converted from extracted image using Eq. (1) as described in section 2.2.



**Figure 4** A sample of converted Lead II derivation vectoral signal from image (amplitude (voltage) vs time (seconds)).



**Figure 5** Unfiltered and Filtered signal

Extracted ECG signal was filtered using a 30 Hz low pass filter and the signal was removed from recording and conversion noises. Unfiltered and filtered signals are given in Fig. 5 and signal became ready for further analysis.

Detection of ECG characteristic points was performed using the technique proposed in [15] to calculate analysis parameters. Fig. 6 shows detected characteristic points on a digitized and filtered Lead-II signal.



**Figure 6** Detection of characteristic points

After detecting the characteristic points of ECG, all analysis parameters together with PED values were obtained from all ECGs and stored.

Calculated analysis parameters were first statistically analyzed for significant differences. In the statistical analysis, the repolarization and depolarization phase components in a cardiac cycle between healthy and COVID-19 groups were compared. Statistical analysis results for the parameters described in Table 1 are given in Table 2. Only, the parameters with the significant results were included to the table due to space considerations.

**Table 2** Calculated parameters and statistical results ($p < 0.05$)

| Parameters | Groups | Mean ± Std |
|---|---|---|
| QRS Interval | Healthy | ,08244489 ± ,008749325 |
| | COVID-19 | ,07640352 ± ,009865149 |
| RR Interval | Healthy | ,77713988 ± ,123476589 |
| | COVID-19 | ,73862431 ± ,136015762 |
| ST Interval | Healthy | ,25398596 ± ,020334934 |
| | COVID-19 | ,26051331 ± ,021274567 |
| QRS Amplitude | Healthy | ,67467538 ± ,221686010 |
| | COVID-19 | ,95626246 ± ,329996678 |
| T Amplitude | Healthy | ,13402635 ± ,058020148 |
| | COVID-19 | ,17376008 ± ,065838637 |
| ST Segment | Healthy | ,08552178 ± ,026174769 |
| | COVID-19 | ,09562169 ± ,026431562 |
| P Amplitude | Healthy | ,05607699 ± ,021190891 |
| | COVID-19 | ,07527458 ± ,032294691 |
| PR Interval | Healthy | ,14473479 ± ,014319553 |
| | COVID-19 | ,13424571 ± ,013382206 |
| QTC | Healthy | ,70238590 ± ,042035582 |
| | COVID-19 | ,72015280 ± ,051170380 |
| ECG Scalogram | Healthy | ,00369673 ± ,000235811 |
| | COVID-19 | ,00379381 ± ,000281916 |

According to the statistical analysis results, COVID-19 patients had significantly lower QRS and PR intervals; higher P and T amplitudes; ST segment; compared to healthy group.

A significant difference on RR interval was also observed between two groups. The QTc interval, which carries information about QT syndrome, is higher compared to healthy group and indicates long QT syndrome in COVID group. Evaluation of these results are given in the discussion section in a detailed manner.

## 3.1 Comparison with Related Studies and Major Contributions of this Study

In Tab. 3, a comparison of different methods is given.

Tab. 3 summarizes the experimental results of relevant studies using the same ECG dataset and showing the comparisons in between those. In these studies, it's clear that all authors applied CNN architectures using 12-lead ECG paper images for comparison of the normal and COVID-19 while some of them were added the other ECG papers containing MI and other diseases.

In this study, we extracted only lead-II ECG images from the paper and converted these extracted images into 1-D signals. Our purpose was to investigate ECG signal differences between COVID-19 and healthy in statistical manner. Purpose of vectoral conversion was to prevent the low quality of the paper images. In addition to that, another problem of the image dataset was very clear. Healthy ECG images were clearly distinguished from COVID-19 ECGs since COVID-19 ECGs are basically have a lot of abnormalities in paper. Our main contribution was to present abnormalities in ECG characteristics and what could be the underlying reasons of these abnormalities related to COVID-19. We published the results based on which part of the heart was most effected with COVID-19. Therefore, in our study we focused on lead-II ECGs which are the most common derivation for ECG interpretation. In discussion section, we interpreted all the differences and underlying reasons behind these differences using the relevant literature.

**Table 3** A comparison between image based studies

| Study | Method | Accuracy % | Sensitivity % | Precision % | Specificity % |
|-------|--------|-----------|--------------|-------------|---------------|
| [11] | Densenet201 | 99.1±0.44 | 99.1±0.44 | 99.11±0.43 | 96.9±0.8 |
| [35] | CNN with RC model | 99.0±1.05 | 99.6±1.26 | - | 98.4±2.06 |
| [13] | CNN | 98.57±1.14 | 99.23±0.59 | 97.73±1.91 | 98.0±1.29 |
| [36] | CNN | 98.81 | 98.81 | 98.81 | - |
| [12] | Efficient Net B3 | 81.80 | - | 80.8 | - |
| [37] | Efficient-ECGNet | 98.66 | - | 98.74 | - |
| [38] | SEResNet18 | 97.72 | 97.35 | - | 98.14 |
| [10] | MobileNet v2 | 98.33 | - | - | - |
| [14] | CNN | 98.11 | 98.60 | - | 96.40 |
| [9] | Hexaxial feature mapping with CNN | 96.20 | - | 94.33 | 94.00 |
| [39] | ECG-BiCoNet | 98.80 | 98.80 | 98.80 | 98.80 |

## 4 DISCUSSION

In this study, all the ECG graphs are converted into vector format with its exact time and amplitude values via proposed image to vector standardization methodology. Unlike machine learning studies using this dataset, characteristics of ECGs are revealed numerically from the data, not from the pattern. Therefore, evaluation metrics are composed of numerical values obtained from quantitative analysis of healthy and COVID-19 ECGs.

When the electrocardiographic findings presented in the study are examined, it is observed that the QTc is significantly longer on COVID-19 patients ($p < 0.05$). Fig. 7a and Fig. 7b shows the significant differences on QT interval parameters as a box plot containing outliers.

In clinical trials, physicians use QT interval assessments as a syndrome marker based on prolongation of the interval [22, 23]. During the current pandemic, the presence of hospitalized patients with prolonged QTc has been reported [24]. Prolonged Qt syndrome, characterized by arrhythmias, has a high tendency to heart attack. In addition, long QTc may indicate a risk factor for long QT syndrome, which is characterized by severe arrhythmias and carries a greater risk of comorbidities [26, 27]. Therefore, prolonged QTc in COVID-19 patients of this study can be interpreted as a risk factor for heart problems in their future lives.
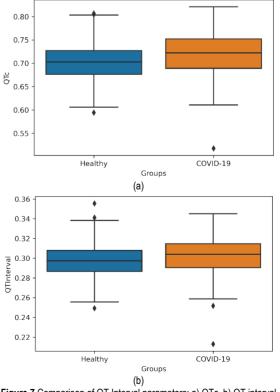


**Figure 7** Comparison of QT Interval parameters: a) QTc, b) QT interval

As it can be seen from Tab. 2, COVID-19 patients had significantly lower RR intervals, which indicate higher heart rate compared to healthy individuals ($p < 0.05$).

Statistical analysis also showed that COVID-19 patients had significantly longer ST segment compared to healthy group. Fig. 8 shows the ST segment differences as a box plot.



**Figure 8** ST Segment differences



(a)



(b)
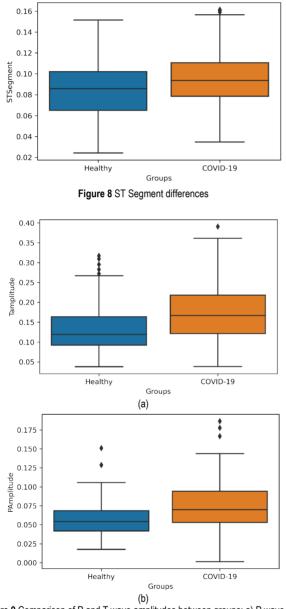
**Figure 9** Comparison of P and T wave amplitudes between groups: a) P wave. b) T wave

Multiple studies in the literature support the findings of this study. In a study, examining the ECG recordings of COVID-19 positive paediatric patients, ST segment elevation have been reported [28]. In another multicentre cohort study in which the ECG data obtained from COVID-19 patients during their hospitalization, prolongation of ST segment was observed in COVID-19 patients [29]. In a retrospective study carried out to investigate ST segment depletion-induced Myocardial infarction (MI). MI caused by

ST-segment elevation has been one of the most common conditions during the pandemic [30], and therefore increased ST segment can be an indicator for COVID-19 diagnosis using ECG analysis.

According to the findings, there are also notable differences on P and T waves between two groups. Fig. 9 shows the P wave and T wave amplitude differences between groups.

Similar to our results, ECG of most patients with MI showed nonspecific features; including T-wave abnormalities has also been presented in literature. T wave abnormalities are often a precursor of ST elevation MI (STEMI). T wave amplitude alteration in COVID-19 positive ECG analyses during clinical evaluations were observed in a study [31]. Thus, T-waves and P-waves alterations may indicate electrical stimulation and conduction problems in case of COVID-19.

Another remarkable parameter among the ECG parameters, the PR interval, had also significances between two groups. As it can be seen from table 2, healthy group had longer PR interval compared to COVID-19 patients ($p < 0.05$). Similar to our results, it was shown that PR interval was shortened in COVID-19 patients. In addition, PR interval considered for atrial fibrillation has also been shown by some researchers to be different in COVID-19 patients [32, 33].



(a)



(b)
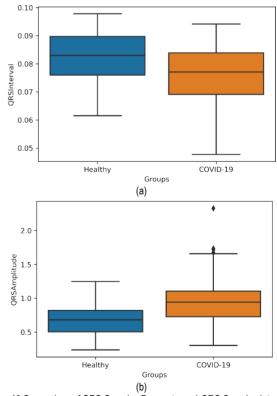
**Figure 10** Comparison of QRS Complex Parameters: a) QRS Complex Interval, b) QRS Complex Amplitude

Other remarkable findings were observed on QRS interval and QRS complex amplitude. As seen in Tab. 2, the QRS interval, which represents the time between the onset of the QRS complex and the onset of the previous P wave, was significantly decreased in COVID-19 patients in addition to

the decrease in PR interval ($p < 0.05$). Furthermore, the QRS complex amplitude was significantly greater in COVID-19 patients compared to healthy group. Fig. 10 shows the significance levels of QRS parameters between two groups.

In a hospital-based descriptive study, electrocardiographic changes in COVID-19 patients were presented and similar to our results, short QRS complex was seen in COVID-19 patients [34].

## 5 CONCLUSION

In the present study, ECG image recordings from 859 healthy individuals and 250 COVID-19 patients included in the open source dataset were analyzed with a comprehensive analysis, and different features of ECG were revealed by the further signal analysis. Our results showed that there are statistically significant effects on most of the ECG parameters in COVID-19 positive individuals compared to the healthy group. The remarkable point of the signal analysis was that achieving further analysis in a shorter time with a less noisy data compared to the original image dataset. Since the image data set contains twelve ECG leads per image, and recording of ECGs were applied with different papers and devices, a normalization was proposed to increase reliability. First, vectoral conversion to ECG images was applied using binarization and threshold, and each image was normalized using the pixel value of square indicator on the ECG paper. Therefore, only Lead-II images were extracted as a signal vector from the whole dataset. Then, the ECG signals were filtered and valuable characteristics were extracted from the noiseless signals. Finally, significant differences between groups were revealed using statistical analysis.

The proposed work presents a novel approach to analyze ECG image dataset obtained from COVID-19 and healthy individuals. Previous studies using this dataset focused on machine learning approaches to classify ECG papers as COVID-19 or healthy, using the properties of ECG image patterns. With the help of the approach proposed in this study, ECG signals instead of ECG images were evaluated to distinguish differences on characteristics of two groups. Even though it is important to distinguish COVID-19 ECGs from healthy ECGs, it is more important to determine ECG characteristics to understand the effects of COVID-19 on heart. The proposed methodology contributes on both classification and examination of ECGs. Our results are also supported by most of the studies in the literature investigating the effects of COVID-19 on ECG. It is thought that, our study can support the ECG image analysis since we have the properties of ECG paper. In future works, our algorithm can be adapted as a standardization method for the ECG image studies to extract characteristics of ECGs which is very helpful for physicians to interpret ECGs.

### Acknowledgements

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# Application of Probability-based Multi-objective Optimization in Portfolio Investment and Engineering Management Problems

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**Abstract:** Markowitz's approach could not deal with the overall optimization of both minimizing variance of return rate and maximizing return rate simultaneously due to its short of rational method for handling multi-objective optimization. In this article, a hybrid of the probability-based multi-objective optimization with the uniform design for experiments of mixtures is performed to solve the portfolio investment problem of concurrent optimization of both maximizing return rate and minimizing variance of return rate. The probability-based multi-objective optimization is employed to transfer the bi-objective problem of portfolio investment into a mono-objective one with total preferable probability as the goal for the overall optimization of the system in spirit of probability theory, the uniform design for experiments of mixtures is used to perform the subsequent discretization. Project management problem is rather a multi-objective to conduct naturally. The analysis shows the rationality of the hybrid solution.

**Keywords:** engineering management; multi-objective optimization; portfolio investment; probability theory; uniform design of mixtures

## 1 INTRODUCTION

In financial field [1-5], securities investors hope to obtain higher returns from securities investment and minimizing risks at the same time. Generally, it is a very common knowledge that a greater return of security is accompanied with a bigger risk for an investment. In order to reduce risk and pursue high efficiency with low risk, security investors could combine multiple securities according to rational investment ratios, that is, the so-called "portfolio of securities", it aims to obtain the maximum profit with less risk.

The portfolio investment theory of economist Markowitz holds that investors always hope to get as much profit ($E(R)$) as possible under certain risk conditions, or a reduction of risk ($X^\mathrm{T}CX$) as much as possible under certain rate of return, that is, to minimize the risk when the expected rate of return with $E(R) \geq c$ is met, or to get as much profit under the condition of the established risk $X^\mathrm{T}CX \leq b$. Furthermore, the expected return rate and variance of return rate are used to evaluate risky securities, and the latter is employed to indicate the risk in Markowitz's algorithm.

Obviously, Markowitz's method can only handle either the minimizing the variance of return rate with setting expected rate of return as a restraint condition, or maximizing the expected return rate and letting variance of return rate as a constraint condition. It is clear that Markowitz's approach could not deal with the overall optimization of both minimizing variance of return rate and maximizing return rate simultaneously due to its short of rational method for handling multi-objective optimization.

Besides, project management problem involves many objectives usually, therefore it is also a multi-objective optimization problem inevitablly. It needs to be implemented and completed with lower project cost, lower resource consumption, control project duration, and ensure project quality [5, 6]. From the point of view of system theory, the multi-objective optimization problem of engineering projects is generally composed of cost subsystem, resource control subsystem, time limit subsystem and quality subsystem, etc. These subsystems are relatively independent, and each completes its own specific functions and operational objectives. On the whole, the subsystems of each project interact and restrict each other, so the overall goal of the project should be fully considered in order to give full play to the overall function of the system. Make the project as a whole optimal, and realize the synergy among the time limit, cost, quality and resource investment, etc.

Recently, the probability-based multi-objective optimization was proposed [7], which is with a brand new concept of "preferable probability" and the assessments for the probability-based multi-objective optimization. As a rationally novel approach, which aims to conduct the overall optimization of the system in spirit of probability theory. The methodology could be used in many fields, including energy planning, programming problem, operation research, financial affairs, etc.

In this paper, a hybrid of the probability - based multi – objective optimization with the uniform design for experiments of mixtures is performed to solve the portfolio investment problem of concurrent optimization of both maximizing return rate and minimizing variance of return rate. Two steps are involved, preliminarily the probability-based multi-objective optimization is used to transfer the bi-objective problem of portfolio investment problem into a mono-objective one by means of preferable probability in spirit of probability theory, subsequently the uniform design for experiments of mixtures is used to perform the successive discretization.

## 2 SECURITIES PORTFOLIO PROBLEM
### 2.1 Fundamental Problem

There are two modes in Markowitz's algorithm for securities portfolio problem, which can be expressed by the following model (a) or (b),
Model (a),

$$\text{Min } f_2 = X^{\mathrm{T}}CX$$

$$\text{s.t. } f_1 = \sum_{i=1}^{n} x_i r_i \ge c \tag{1}$$

$$\sum_{i=1}^{n} x_i = 1, \ i = 1, 2, 3, \ldots, n$$

Model (b),

$$\text{Max } f_1 = \sum_{i=1}^{n} x_i r_i$$

$$\text{s.t. } f_2^2 = X^{\mathrm{T}}CX \le b \tag{2}$$

$$\sum_{i=1}^{n} x_i = 1, \ i = 1, 2, 3, \ldots, n$$

In Eqs. (1) and (2), the symbel $n$ represents the number of securities, and the expected retuan rate of each security is indicated by $r_1, r_2, \ldots, r_n$, respectively; the proportion of the $i^{\text{th}}$ security is $x_i$. $C$ represents the risk matrix of investment, and $X^{\mathrm{T}}CX$ represents the expected value of portfolio risk. Furthermore, $\sigma^2 = X^{\mathrm{T}}CX$ is used to reflect the variance of the return rate of securities portfolio and the risk of investment in principle. While $f_1 = E(R) = \sum_{i=1}^{n} x_i r_i$ is the expected value of the return rate of $n$ kinds of securities invested in a certain period of time; Factor $c$ represents the preset total return rate of portfolio investment; Factor $b$ describes the preset risk of portfolio investment. $\sigma^2$ indicates the deviation of various possible values of return rate from their expected values, that is, the uncertainty of return rate. The standard deviation of portfolio is the square root of variance $\sigma^2$.

In his portfolio investment theory Markowitz adopted either limiting the risk to a certain range to obtain as much profit as possible, or limiting the profit to a certain range to suffer as little risk as possible. This is fully similar to the $\varepsilon$-constraint solution in the of multi-objective optimization problem. Its disadvantage of this approach is that "one objective optimization" is lost in optimization instead of "multi-objective simultaneous optimization", thus the essential and true meaning of "simultaneous optimization of multiple objectives" is uncomplete.

According to Markowitz's practice, the retuan rate function $f_1$ and risk function $f_2$ are introduced, and their expressions are, respectively, as,

$$f_1 = E(R) = \sum_{i=1}^{n} x_i r_i$$

$$f_2 = \big[(x_1 \sigma_1)^2 + (x_2 \sigma_2)^2 + (x_3 \sigma_3)^2 + \ldots + (x_n \sigma_n)^2 +$$
$$+ \beta_{1,2}(x_1 \sigma_1)(x_2 \sigma_2) + \beta_{1,3}(x_1 \sigma_1)(x_3 \sigma_3) + \tag{3}$$
$$+ \beta_{1,4}(x_1 \sigma_1)(x_4 \sigma_4) + \ldots + \beta_{i,j}(x_i \sigma_i)(x_j \sigma_j) + \ldots +$$
$$+ \beta_{n-1,n}(x_{n-1} \sigma_{n-1})(x_n \sigma_n)\big]^{0.5}.$$

In Eq. (3), $\beta_{i,j}$ is the correlation coefficient between the $i^{\text{th}}$ security and the $j^{\text{th}}$ security.

Furthermore, according to the objective evaluation method of the probability - based multi - objective optimization methodology, $f_1$ belongs to the beneficial objective and $f_2$ belongs to the unbeneficial objective in the assessment.

Therefore, the answer to the "portfolio investment" problem is actually an optimization of bi-objective one. Therefore, the probability-based multi-objective optimization methodology can be used to evaluate it reasonably.

## 2.2 Hybrid of Probability-Based Multi-Objective Optimization Methodology with Uniform Design for Experiments of Mixtures to Solve the Portfolio Investment Problem

### 1) Fundamental procedure

In order to conduct hybrid of the probability - based multi – objective optimization with the uniform design for experiments of mixtures, two steps are involved, the preliminary step is to make conversion of the bi-objective problem of portfolio investment problem into a mono-objective one by means of probability-based multi-objective optimization in spirit of probability theory, the subsequent step is to use the uniform design for experiments of mixtures to perform discretization of successive optimization.

In the portfolio investment problem, the concurrent minimizing variance of return rate and maximizing return rate are two objectives inevitablly, the total preferable probability of this bi - objective problem is the decisive and unique objective function, which needs to be maximizing in a high-dimensional independent variable - space, therefore the complex data treatment might be involved, thus the uniform design for experiments with mixtures (UDEM) can be rationally combined to perform the simplifying treatment of the data processing.

The uniform design for experiments with mixtures (UDEM) was proposed by Fang et al [8], which is on basis of good lattice point (GLP). The method of UDEM could be employed to geneate a set of efficient sampling points for experimental design with the restraint of $x_1 + x_2 + x_3 + \ldots + x_n = 1$ for proportion $x_i$ with total number of $n$ [8], therefore it can be used as a rational sampling method for the portfolio investment problem here to perform the discretization for data processing with simplifying treatment.

In addition, Fang specially developed uniform design tables and their usage tables for the proper application [9].

According to Fang et al. [8, 9], the concrete steps of uniform design for experiments with mixtures (UDEM) are generally as follows:

### a) Choice of the uniform design table

Given the number of mixtures $n$, and the number of sampling points $p$, chose the corresponding uniform design table $U^*_p(p^t)$ or $U_p(p^t)$ and its utility table from the uniform design table provided in [8, 9], and the number of columns of the utility table is chosen as $n-1$. Label a mark of the original elements in the uniform design table $U^*_p(p^t)$ or $U_p(p^t)$ with $\{q_{ik}\}$.

### b) Establishment of a new element $c_{ki}$

For each $i$, establish its new element $c_{ki}$ according to following rule,

$$c_{ki} = \frac{2q_{ki} - 1}{2p} \qquad (4)$$

### c) Establishment of uniform sampling points for the mixtures, $x_{ki}$

$$x_{ki} = \left(1 - c_{ki}^{\frac{1}{n-i}}\right) \prod_{j=1}^{i-1} c_{kj}^{\frac{1}{n-j}}, \; i = 1, \ldots, n-1$$

$$x_{kn} = \prod_{j=1}^{n-1} c_{kj}^{\frac{1}{n-j}}, \; k = 1, \ldots, p \qquad (5)$$

Thus, $\{x_{ki}\}$ derives the corresponding uniform design table $UM_p(p^n)$ of the mixture under the conditions of preset $n$ and $p$.

### 2) Example of portfolio investment problem of three securities

Take the portfolio investment of three securities as the typical example. The specific optimization process is explained in details.

Let the expected return rate of security $A$ is $r_1 = 14\%$, and the standard deviation of return rate is $\sigma_1 = 6\%$; The expected return rate of $B$ securities $r_2 = 8\%$, and the standard deviation of return rate is $\sigma_2 = 3\%$; The expected return rate of $C$ securities is $r_3 = 20\%$, and the standard deviation of return rate is $\sigma_3 = 15\%$. Furthermore, it is assumed that the correlation coefficient between $A$ and $B$ securities is $\beta_{1.2} = 0.5$; The correlation coefficient between securities $A$ and $C$ is $\beta_{1.3} = -0.2$; The correlation coefficient between securities $B$ and $C$ is $\beta_{2.3} = -0.4$. Now we need to make a decision on this portfolio investment.

***Solution.***

In this section, the "portfolio investment" problem is analyzed on intentions of probability - based multi - objective optimization methodology. Now we need to handle the bi-objective simultaneous optimization problem of both minimizing variance of return rate and maximizing return rate.

Let $x_1$, $x_2$, and $x_3$ be the investment percentages of three securities, $A$, $B$, and $C$, respectively. Because of the constraint condition of $x_1 + x_2 + x_3 = 1$, there are in fact two independent variables, nominally $x_1$ and $x_2$.

However, the sampling points of this bi-objective optimization problem are scattered in 3 – dimensional space, therefore, so it has to include at least 19 sampling points with characteristic of "good lattice point" in the efficient zone for the discretization of data processing [7, 10, 11].

According to Fang et al [8, 9], this is a "uniform design for experiments with mixtures" problem due to the restraint condition of the three variables, we could take the uniform table $U^*_{19}(19^7)$ as the initial table to establish a uniform test design table $UM_{19}(19^3)$ with mixtures, which is shown in Tab. 1.

Thus the uniform test table $UM_{19}(19^3)$ with mixtures of Tab. 1 can be established on basis of uniform design table $U^*_{19}(19^7)$. Because the nubmber of variables $n$ equals to 3 here, and $p$ equals to 19 [7, 10, 11], from above rules, $x_{k1} = 1 - c_{k1}^{0.5}$, $x_{k2} = c_{k1}^{0.5} \cdot (1 - c_{k2})$, $x_{k3} = c_{k1}^{0.5} \cdot c_{k2}$ [8, 9].

Furthermore, the values of the return rate function $f_1$ and risk function $f_2$, the values of their partial preferable probability, the total preferable probability and ranking at the sampling points can be obtained, as are shown in Tab. 2.

Fig. 1 represents return rate vs risk at discrete sampling points. The results indicate that the 5th and 7th discrete sampling points exhibit the maximum total preferable probability, therefore they could be taken as the optimal solution of this portfolio problem.

As to the 5th sampling point, the corresponding investment ratio is $x_1' = 0.5133$, $x_2' = 0.3714$, $x_3' = 0.1153$, which results in the return rate of 12.46% and the risk of 3.13%.
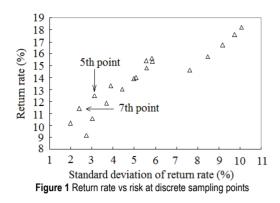
While for the 7th sampling point, its investment ratio is at $x_1'' = 0.4151$, $x_2'' = 0.5079$, $x_3'' = 0.0770$, and the corresponding return rate is 11.41% with the risk of 2.42%.

**Table 1** Uniform experimental table with mixtures of $UM_{19}(19^3)$ based on $U^*_{19}(19^7)$

| No. | $x_{10}$ | $x_{20}$ | $c_1$ | $c_2$ | $x_1$ | $x_2$ | $x_3$ |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 9 | 0.0263 | 0.4474 | 0.8378 | 0.0896 | 0.0726 |
| 2 | 2 | 18 | 0.0789 | 0.9211 | 0.7190 | 0.0222 | 0.2588 |
| 3 | 3 | 7 | 0.1316 | 0.3421 | 0.6373 | 0.2386 | 0.1241 |
| 4 | 4 | 16 | 0.1842 | 0.8158 | 0.5708 | 0.0791 | 0.3501 |
| **5** | **5** | **5** | **0.2368** | **0.2368** | **0.5133** | **0.3714** | **0.1153** |
| 6 | 6 | 14 | 0.2895 | 0.7105 | 0.4620 | 0.1557 | 0.3823 |
| **7** | **7** | **3** | **0.3421** | **0.1316** | **0.4151** | **0.5079** | **0.0770** |
| 8 | 8 | 12 | 0.3947 | 0.6053 | 0.3717 | 0.2480 | 0.3803 |
| 9 | 9 | 1 | 0.4474 | 0.0263 | 0.3311 | 0.6513 | 0.0176 |
| 10 | 10 | 10 | 0.5 | 0.5 | 0.2929 | 0.3536 | 0.3536 |
| 11 | 11 | 19 | 0.5526 | 0.9737 | 0.2566 | 0.0196 | 0.7238 |
| 12 | 12 | 8 | 0.6053 | 0.3947 | 0.2220 | 0.4709 | 0.3071 |
| 13 | 13 | 17 | 0.6579 | 0.8684 | 0.1889 | 0.1067 | 0.7044 |
| 14 | 14 | 6 | 0.7105 | 0.2895 | 0.1571 | 0.5989 | 0.2440 |
| 15 | 15 | 15 | 0.7636 | 0.7632 | 0.1264 | 0.2069 | 0.6667 |
| 16 | 16 | 4 | 0.8158 | 0.1842 | 0.0968 | 0.7368 | 0.1664 |
| 17 | 17 | 13 | 0.8684 | 0.6579 | 0.0681 | 0.3188 | 0.6131 |
| 18 | 18 | 2 | 0.9211 | 0.0789 | 0.0403 | 0.8839 | 0.0758 |
| 19 | 19 | 11 | 0.9737 | 0.5526 | 0.0132 | 0.4414 | 0.5453 |

**Table 2** Evaluation results of $f_1$, $f_2$, preferable probability and ranking at discrete sampling point

| No. | $f_1$ | $f_2$ | $P_{f1}$ | $P_{f2}$ | $P_t \times 10^3$ | Rank |
|---|---|---|---|---|---|---|
| 1 | 0.1390 | 0.0500 | 0.0526 | 0.0562 | 2.9553 | 8 |
| 2 | 0.1542 | 0.0557 | 0.0584 | 0.0516 | 3.0148 | 5 |
| 3 | 0.1331 | 0.0391 | 0.0504 | 0.0648 | 3.2670 | 3 |
| 4 | 0.1563 | 0.0584 | 0.0592 | 0.0494 | 2.9248 | 10 |
| **5** | **0.1246** | **0.0313** | **0.0472** | **0.0710** | **3.3518** | **1** |
| 6 | 0.1536 | 0.0585 | 0.0582 | 0.0494 | 2.8715 | 13 |
| **7** | **0.1141** | **0.0242** | **0.0432** | **0.0767** | **3.3151** | **2** |
| 8 | 0.1479 | 0.0559 | 0.0560 | 0.0515 | 2.8839 | 11 |
| 9 | 0.1020 | 0.0199 | 0.0386 | 0.0801 | 3.0952 | 4 |
| 10 | 0.14 | 0.0510 | 0.0530 | 0.0554 | 2.9357 | 9 |
| 11 | 0.1823 | 0.1007 | 0.0690 | 0.0158 | 1.0911 | 19 |
| 12 | 0.1302 | 0.0444 | 0.0493 | 0.0606 | 2.9873 | 7 |
| 13 | 0.1759 | 0.0974 | 0.0666 | 0.0184 | 1.2271 | 18 |
| 14 | 0.1187 | 0.0370 | 0.0450 | 0.0665 | 2.9897 | 6 |
| 15 | 0.1676 | 0.0919 | 0.0635 | 0.0228 | 1.4444 | 17 |
| 16 | 0.1058 | 0.0303 | 0.0401 | 0.0718 | 2.8775 | 12 |
| 17 | 0.1577 | 0.0847 | 0.0597 | 0.0285 | 1.7024 | 16 |
| 18 | 0.0915 | 0.0274 | 0.0347 | 0.0741 | 2.5677 | 14 |
| 19 | 0.1462 | 0.0761 | 0.0554 | 0.0354 | 1.9596 | 15 |

**Figure 1** Return rate vs risk at discrete sampling points

## 3 MULTI-OBJECTIVE OPTIMIZATION OF PROJECTS

In this section, the probability-based multi-objective optimization method is used to study the collaborative optimization of engineering projects rationally.

In the example of engineering project, the selection involves six new schemes and an original plan; the duration, resource consumption and total cost of each scheme are as the objectives to be optimized, see Tab. 3 [6]. Moreover, the weight factors of duration, resource consumption and total cost are 0.23, 0.07 and 0.70, respectively.

According to the meaning of the attributes, the duration, resource consumption and total cost are all unbeneficial indicators. Tab. 4 shows the evaluation results of this project.

The evaluation results show that scheme No. 4 is with the highest overall preferable probability, so it can be selected as the optimal scheme for this problem.

**Table 3** Six schemes and original plan of the project, and attribute values

| Scheme | Duration, A (day) | Resource consumption factor, $B$ | Total cost, $C$ (10K RMB) |
|---|---|---|---|
| 1 | 24 | 3.942 | 55.8 |
| 2 | 21 | 2.916 | 55.5 |
| 3 | 20 | 3.048 | 55.4 |
| 4 | 18 | 1.883 | 55.9 |
| 5 | 16 | 1.928 | 59.4 |
| 6 | 14 | 1.886 | 64.4 |
| Original | 26 | 4.876 | 57.0 |

**Table 4** Evaluation results of engineering projects

| Scheme | Partial preferable probability | | | Overall preferable probability | Rank |
|---|---|---|---|---|---|
| | $P_A$ | $P_B$ | $P_C$ | $P_t \times 10$ | |
| 1 | 0.1135 | 0.1050 | 0.1471 | 1.3532 | 6 |
| 2 | 0.1348 | 0.1432 | 0.1477 | 1.4434 | 4 |
| 3 | 0.1418 | 0.1383 | 0.1480 | 1.4585 | 3 |
| 4 | 0.1560 | 0.1817 | 0.1468 | 1.5113 | 1 |
| 5 | 0.1702 | 0.1800 | 0.1388 | 1.4813 | 2 |
| 6 | 0.1844 | 0.1816 | 0.1273 | 1.4211 | 5 |
| Original | 0.0993 | 0.0702 | 0.1443 | 1.2590 | 7 |

## 4 CONCLUSION

In this paper, the hybrid of the probability - based multi – objective optimization with the uniform design for experiments of mixtures is performed to solve the multi-objective optimization problems of portfolio investment and project management properly. The results show the rationality of the hybrid, which has bright future in applications in many fields.

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# Variability Management Mechanism for Domain Engineering and Case Study in SunRoof Control Domain

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**Abstract:** This study aims to suggest variability mechanisms for software product line development and to explain the results of case study. Software product line engineering is an extension of software engineering and many organizations constantly engage in reengineering and refactoring to adopt the software product line engineering. Software product line engineering has two engineering processes: domain engineering process and application engineering process. Feature Identification and feature model are key success factor to construct variability model. Feature model describes the variable parts to be extended or replaced and common part to be reuse by themselves. Feature model gives the directions to the following architecture design and component implementation. However, feature model is not the design strategy and variability mechanism for product line implementation. Therefore, these are the obstacles for organizations that are unfamiliar with feature model and variability mechanism to adopt software product line engineering. Several variability mechanisms for software intensive software are suggested but these are not applicable for embedded software since it has different development process and structure. In this paper, variability elements in architecture design and component design of embedded software are identified as state variable, state transition information, and algorithm. Variability management mechanisms are defined for these elements. To provide the detail strategy and to evaluate the suggested variability management methods, process and results of real case study are described.

**Keywords:** domain engineering; embedded software product line; feature model, sunroof product line; variability management

## 1 INTRODUCTION

The software product line has been a software development paradigm that arose from an effort to maximize the quality attributes of software such as reusability and maintainability. The result of combining this paradigm with the existing field of software engineering is Software Product Line Engineering (SPLE). Software reuse, which began to gain attention in the 1990s, aims at reducing the effort required to develop or maintain a new system similar to a legacy system, and eventually reducing software development costs [1]. It has since departed from reuse at the level of the library or source code, originating from the reuse of subroutines in the 1960s, and the scope of reuse has been expanded to include domain knowledge, development experience, and design decisions. In line with the conceptual extension and expansion of software reuse, software re-engineering technology has advanced to create better software by analysing and reconstructing a legacy system, and to reduce the maintenance cost of the software. The gradually expanded reuse technology has recently evolved into a software product line engineering technology that takes into account both business and technical interests. Since the "product family engineering (PFE)" approach and address the commonalities and variabilities of software products with a focus on architecture in the 1980s [5, 16, 20]. The programs of an SPL are distinguished in terms of features, which are end-user visible characteristics of programs [3]. Based on a selection of features, stakeholders can derive customer specific programs that satisfy functional requirements [14, 19].

Software product line engineering has two engineering processes: domain engineering process and application engineering process [9]. Domain engineering process produces the core assets that will be assembled based on feature selection. Application engineering processes generate the product instance from core assets based on product requirements. For helping the organization to adopt the software product line engineering, a reference model is a good guide to define the process and strategies. In this research, domain implementation method and case study results of sunroof software product line for variability management in domain engineering are presented.

## 2 BUSINESS DOMAIN FOR SOFTWARE PRODUCT LINE ENGINEERING

This chapter introduces the company that has applied SPL as well as the background of such an application of SPL technology, and briefly introduces the domain to which SPL technology is applied. The company OOO Holdings is participating in this case study. It is a company that produces various parts used in the automotive body domain, and its representative product includes sunroof controller software. The adoption of SPL technology has been carried out by the Electrical System Department of the Future Technology Research Center.

These days, automobiles are evolving into electronic devices. As a result, the nature of the industry is changing from a hardware-oriented industry to a software-oriented industry. Automobile assembly OEMs are demanding various strict standards for software quality improvement from electrical system component developers in keeping with this trend [7, 6]. In terms of process, certifications such as CMMI [4] or A-SPICE [21] are required, and in terms of safety, the functional safety grades proposed by ISO-26262 [8] are required depending on the importance of parts.

This company hoped to shorten the development period of products for various customers and efficiently reuse the products that were developed by improving the engineering skills of developers through appropriate development methods. Domestic automobile parts development firms have

only one or two developers, with a shortage of human resources. In order to overcome this, this company decided to adopt software product line engineering technology as a solution to increase the reusability and maintainability of software.

```
1. SR Controller [CA]
1.1. Ket Processing [CA]
1.1.1. Chattering [CA]
1.1.2. Key Combing [CA]
1.2. Operation Mode Management [CA]
(some more)
1.3. Control Service [CA]
1.3.1. Operating Power Control [CA]
1.3.2. Anti-Pinch [CA]
(some more)
1.3.6. Mode Management [CA]
        1.3.6.1. Wake Up Mode [CA]
        1.3.6.2. Sleep Mode [CA]
1.3.7. Motor Control [CA]
(some more)
1.4. Fail Safe [CA]
(some more)
1.4.5. Hall Sensor Diagnosis [CA]
        1.4.5.1. Hall Sensor Algorithm1 [CA][A]
        1.4.5.2. Hall Sensor Algorithm2 [CA][A]
(some more)
1.7. Parameter Configuration [CA]
1.8. Key Type [OE]
1.8.1. 3-Way Type [OE][A]
1.8.2. 3-Way 2nd Type [OE][A]
1.9. Blind Control [CA][O]
(some more)
1.14. EEPROM [OE]
```



**Figure 1** Some part of feature model

The sunroof is one of the components constituting the body of an automobile. Although it is an optional part, it is gradually being applied to an increasing number of vehicles. Recently, not only general sunroofs but also panoramic sunroofs have been developed and used. As a device for user convenience, it is also a product that requires emotional functions such as low noise as well as safety.

## 3 RESEARCH METHODOLOGY
### 3.1 Domain Modelling of Sunroof Control SPL

SPL domain analysis activities consist of term definition, feature modelling, legacy system analysis, and domain requirement specification. Term definition and feature modelling are generally carried out in parallel. Legacy system analysis is an additional activity as an extractive approach is taken in this case study.

Feature model is the most important model for managing the variabilities in domain. Product lines for information systems present variabilities both in non-functional and functional features [5]. This task aims to clearly identify the commonalities and variabilities of the products included in the product line. Feature models are arguably one of the most intuitive and successful notations for modelling the features of a variant-rich software system. A feature is a characteristic or end-user-visible behaviour of a software system [18]. Features are used in product-line engineering to specify and communicate commonalities and differences of the products between stakeholders, and to guide structure, reuse, and variation across all phases of the software life cycle [17, 22].

Fig. 1 shows the partial feature model and feature diagram of Sunroof Domain. Eighty features are identified. Three optional features and nine alternative feature groups (20 features) are identified as variable features. FORM methodology defined the semantic of feature model [10, 11], Feature model explains the variability information of domain with feature and feature attributes. Feature attributes define the feature category with CA (Capability), OE (Operational Environment, and IT(Implementation Techniques). CA means that feature belongs to capability category such as functional requirements. OE means that feature belongs to Operating Environment category such as operation systems and network systems. IT means that feature belongs to implementation techniques such as processes and rules Also, feature attributes define the feature variability with M, A, O. Variability is modelled with M (Mandatory), A (alternative) and O (optional). M means that feature should be included in product instance. O means that feature can be included selectively based on feature selection at product configuration time. A mean that one of feature set should be included in product instance. The domain requirement specification is usually performed at the end of the domain analysis activities.

### 3.2 Variability Mechanism for Sunroof Control SPL

Domain implementation aims to make modules recognized through architectural design into reusable modules as much as possible. Making it into a reusable module means turning the module into a verified library,

which can save 30 to 40% of the effort of testing the module when developing a product. In order to achieve this effect, it is necessary to find a way to quickly and easily reflect the modified contents in the module while avoiding the influence of other modules based on a thorough consideration of what variable information the module has to process when there is a change in the variable information. It is similar to a general software module design activity except for the task of finding variable information and applying it to the design. The domain implementation work is described for the activity of creating a document based on the source code [13].

### 3.3 Module Design for Processing State Variable Management Information

To separate control and operation, we need a special component for managing the control of state information. We have a "XYZ" module constituting the software is one of the modules that perform state management and plays a role in managing the operating state of the slide. This module has the variable attribute <<VOP>>. <<VOP>> stereotype is variability in implementation of function so that there are optional elements inside the module. The feature with the variable attribute <<VOP>> is as follows.

1.8.3. Slide Position Control [CA]

      1.8.3.1. Comport Position Control [CA][O]

**Figure 2** Feature model with optional feature
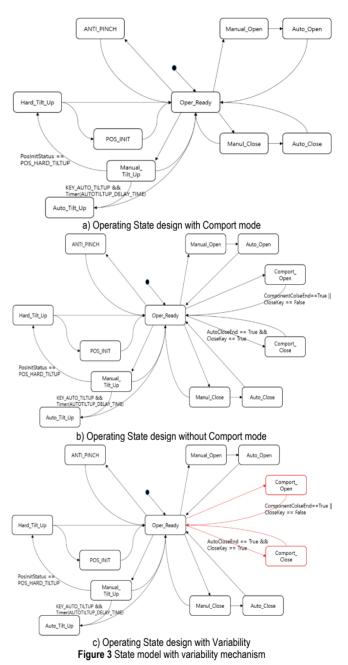
The control of the "Comport" position is optional depending on the slide controller. As a result, the action for managing the slide operation state for the operation command transmitted by the user input is affected. The results of modelling the state management behaviour with and without the Comport position control are as Fig. 3. At the request of the company, detailed items such as transition conditions are excluded.

The operation state behaviour model without the COM port mode is as shown in (b) of Fig. 3. There are a total of 10 states that comprise the state diagram. The modes are divided for each operation state in which the slide can be operated. The state returns to "Oper_Ready" when each operation is completed.

The operation state behaviour model with the COM port mode is as shown in (a) of Fig. 3. With the addition of the Comport mode, the "Comport_Open" and "Comport_Close" states have been added. The product line behaviour model created by combining the two operation state behaviour models is as follows.

The appearance of the product line driving state behaviour model is the same as the component mode driving state behaviour model as the behaviour model with the Comport mode includes the behaviour model without the COM port mode.
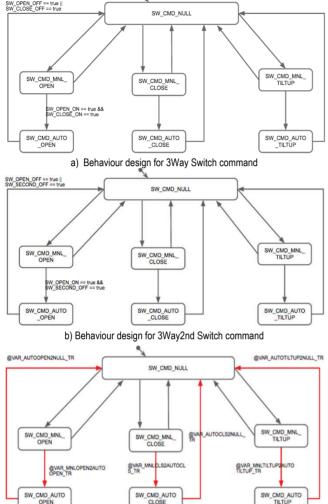
In the product line operational behaviour model, variable information is added to the "Comport_Open" and "Comport_Close" states. Variable information is indicated in the state by the stereotype as shown (c) of Fig. 3. The marked

information, the "Comport Position Control" feature that determines whether to select the two states is written along with the meaning that the two states are optional states. The product line behaviour model of the module created in this way is used to create a behaviour model instance for a product by selecting a feature to develop a product in the subsequent application stage. In this case study, two instances are created.



a) Operating State design with Comport mode

b) Operating State design without Comport mode

c) Operating State design with Variability
**Figure 3** State model with variability mechanism
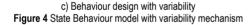
### 3.4 Module Design for Processing Variable State Transition Information

The case where the variable information becomes a state transition condition is similar to that of the variable state condition information discussed in the previous section. The difference is that the state itself is variable information in the

former case, whereas the transition condition under the same condition is managed as variable information in this case.



a) Behaviour design for 3Way Switch command



b) Behaviour design for 3Way2nd Switch command



c) Behaviour design with variability

**Figure 4** State Behaviour model with variability mechanism

When the "Switch Command Composer" module has the variable attribute <<VAP>>. In other words, it has alternative variable elements inside. Now it is time to check what the variable elements are. This module plays the role of combining specific switch commands according to the type of input switch.  As the domain model suggests, the slide product line supports two types of switches: "3 Way Switch" and "3 Way 2nd Switch." However, regardless of the switch type, the number of output commands is the same at eight (Manual Open, Manual Close, Manual Tilt Up, Auto Open, Auto Close, Auto Tilt Up, Switch Fault, None).

Based on this, the output command can be deemed as a state and the corresponding module can be designed using the state transition diagram. As a result of comparing the above two figures, the state remains the same as previously identified, but the conditions for transitioning the state are different. Unlike the behaviour model of the previous "XYZ" module, there is a variation point in the transition condition.

When a transition becomes a variation point, the method of adding as many transition lines as the number of variable

elements to the state diagram is used in general. However, when using this method, the state diagram may look messy. Therefore, a method in which only the transition condition is described separately may also be used. In this case study, the second method is used to design the control behaviour for generating the switch command of the product line module as shown in the Fig. 4.

### 3.5 Module Design for Processing Variable Algorithm Information

This section briefly explains how to perform detailed design when an algorithm variation point is identified in the design target module.

For the module implementing the algorithm, the detailed design is divided into two parts.
* Declaration of interface function
* Algorithm function

The declaration of the interface function is a technology for easily selecting a module implementing a specific algorithm for each product to be produced and reflecting it in the product architecture. This part allows the processing of the variable information of the module that has the algorithm itself as a variable element.

The algorithm function is almost dependent on the inside of the module and operates as a variable element itself. Therefore, this part needs to be designed in the same way as designing general software modules. The flow can be described in detail or the algorithm can be described using Pseudo Code or Flow Chart.

### 3.6 Module Design for Processing Variable Operational Condition Information

It is common to define a layer composed of modules in charge of logic operations under the principle of separating control and operation in the module architecture. Since these modules generally have an algorithm for operation, unlike the previous state management type, it is not possible to design the behaviour of a module based on a certain specification. If the logic that performs the module function is divided into several branching statements by the same condition and the actions performed in each branching statement are similar, it is possible to find a variation point in them.



1.x.x. Flashing Control[CA]

       1.x.x.1. Flashing Request Priority [CA][A]

       1.x.x.2. Flashing Behaviour [CA][A]

(Some more)
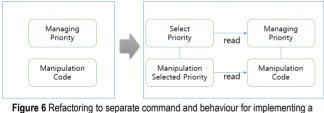
**Figure 5** Feature model with alternative feature

The "ABC" module constituting the software is responsible for performing a specific operation according to the state of the module performing the logic operation. This module has the variable attribute <<VAP>>. This means that

there are alternative elements inside the module. The feature with the variable attribute <<VAP>> is as Fig. 5.

The above feature information shows that the priority of flashing requests and the type of command for error handling vary depending on the product. Because of checking how the previously developed system reflects the priority change factor in the system, the method of directly modifying the operation logic that generates the conditional statement and the instruction corresponding to the condition of the module has been used. That is, two variable factors have been identified.

- Command priorities
- Behaviour attributes for operation processing (number of times, waiting time, etc.)

If the source code is directly modified whenever there is a change in the two variable elements identified, the efficiency of development can be reduced through repeated modification of the module and tests for each product development. In this case, the most effective way to remove the variable information from the source code is to separate the priority information and the command information created according to the combination from the source code, allowing modification of such information from outside the source code. This method allows only the logic that reads and processes priority data, as well as the logic that determines the command to be generated in response to the key input based on the priority, to be implemented in the corresponding module. The "ABC" module designed by reflecting this concept is as Fig. 6.



**Figure 6** Refactoring to separate command and behaviour for implementing a command

The "ABC" module has two sub-modules. The first "Flashing Priority Elector" selects the request with the highest priority among the errors to be inspected. Information about priorities is not included in the module. The second "Command Maker" module generates commands to fulfil the selected request. Command information that must also be created is managed separately from the module. Such a module design separates variable elements from the source code to allow the module to accommodate and process various combinations.

## 4 RESULTS AND DISCUSSION

Product line module implementation serves two purposes. First, it aims to create concrete implementation models based on the conceptual modules acquired from architecture design. Second, it aims to determine the technique for implementing the variable information reflected in the design. This section describes the implementation rules based on the C language used for automotive electrical system software development.

### 4.1 Definition of Implementation Rules for Logical Model

An object-oriented language such as Java provides various methods to implement the module defined in the architecture as an independent component at the language level. However, as for the C language, there is a limit to implementing the logical module defined in the architecture as an actual independent module at the language level. This is because calling it an actual module makes it impossible to forcibly block the access restrictions of the developed module. As a result, developers make arbitrary use, and architecture and consistency are gradually lost as development progresses. In order to prevent such a problem in advance, it is necessary to define the rules for developing modules in the C language.

Things to consider when writing the rules are as follows:

- What is the physical implementation unit of the module? Is it a folder? Is it a file? Is it a function?
- How should the layer of design be implemented in the architecture?
- How should the interface defined in the architecture design be implemented?

As there are more team members involved in software development, it becomes increasingly difficult for architectural design to be consistently implemented into codes in the absence of such rules. If some developers implement the module as a file while other developers implement the module as a function included in the file, module management becomes impossible from then on. In this case study, the following criteria are applied based on the module architecture for implementation.

**Table 1** Implementation strategy for architecture

| Architecture Element | Implementation Unit |
| --- | --- |
| Layer | folder/Package |
| Module | Module file (.c) |
| Module Interface | Header file (.h) for each module |
| Internal Module in | Function |

The implementation based on the above criteria leads to the development of the following code structure. There should be as many C files as the number of modules defined in the module architecture in the package.

### 4.2 Determination of the Mechanism of Variable Element Implementation Inside of Module

How to implement the variable elements inside the module described in the product line module design should be determined? The most easily used variable information processing mechanism in the C language is to utilize the macros and the pre-processor provided by the C compiler. A macro is the easiest way for organizations or developers to deal with variable elements for the first time. However, with an increase in the number of features, the source code

becomes messy, reducing readability. Accordingly, a more advanced technique should be applied thereafter.

The mechanism applied to implement the variable information applied in this case study is as follows.

In this case study, three implementation mechanisms were mainly used: macro, declaration of data, and external HMI program.

**Table 2** Implementation mechanism for variability type

| Variability Type | Variable unit | Implementation Mechanism |
|---|---|---|
| Control State | Behaviour Model | Macro Macro definition for feature |
| Transition Condition | Behaviour Model | Macro Macro definition for feature |
| Operational Condition | Priority in Key combination Command based on key combination | Text script Data Definition |
| Parameter | Parameter value | External HMI Program development |
| Algorithm | Implementation logic | Function Macro |

An example of processing variable information using the macro pre-processor provided by the C language can be found in the Switch Command Composer module. The detailed design of the module shows that all variable elements are included in the module. Each variable element has a structure in which one variable element is selected according to feature selection. When implementing a module with this structure, macros are used in general.
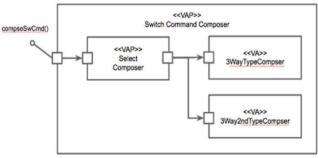


**Figure 7** Variability management in module inside

The source code implementing the above design is as follows. In the _selectComposer() function, the function to be called is determined based on the feature selection.

When information related to operating conditions is completely removed from the source code, variable information can be changed using a simple text-based script. The written text script can be used in various ways depending on the development environment. In this case study, the method of generating the corresponding data based on the script file is selected due to the limitation in the performance of the hardware. The sample code below is generated based on a text script that specifies the priority of commands. There are 11 predetermined commands, and the priority of each command and the corresponding behaviour attributes are specified and initialized as variables using the data structure.

In this case study, the variability of the parameter value is handled by developing an HMI program that sets the

parameters using the LIN network before operating the product. The Fig. 9 shows the developed HMI program.

```
/*********************
*     File name   : SwitchCommandComposer.c
*     Purpose     : Demonstration of a simple program.
*
*********************/

#ifndef      __SWITCHCOMMANDCOMPOSER_C__
#define      __SWITCHCOMMANDCOMPOSER_C__

#include "SwitchCommandComposer.h"

void compoSwCmd(void) {
    _selectComposer();
}

void _selecComposer(){
#ifdef FEATURE_3WAY_TYPE
    _3WayTypeComposer();
#elif FEATURE_3WAY2ND_TYPE
    _3Way2ndTypeComposer();
#endif
}
```

```
void _3WayTypeComposer(void){

switch (enuSwCmd)      {
    case SW_CMD_NULL :
    if(COND_SW_OPEN_ON)
        enuSwCmd = SW_CMD_MNL_OPEN;
    else if(COND_SW_CLOSE_ON)
        enuSwCmd = SW_CMD_MNL_CLOSE;
    else if(COND_SW_TILTUP_ON)
        enuSwCmd = SW_CMD_MNL_TILTUP;
    else
        enuSwCmd = SW_CMD_NULL;
    break;
    (...)
    default :     break;
    }
}
void _3Way2ndTypeComposer(void) {
    switch (enuSwCmd) {
        case SW_CMD_NULL :
    if(COND_SW_OPEN_ON)          {
        enuSwCmd = SW_CMD_MNL_OPEN;
    else if(COND_SW_CLOSE_ON)
        enuSwCmd = SW_CMD_MNL_CLOSE;
    else if(COND_SW_TILTUP_ON)  enuSwCmd = SW_CMD_MNL_TILTUP;
    else
        enuSwCmd = SW_CMD_NULL;
    break;
    (...)
    default :           break;
    }            // end of switch(enuSwCmd)
}
```

**Figure 8** Example of variability implementation (determination of function call based on feature selection)

## 4.3 Creation of Design Documents using Source Code Comments

A case of application to simplifying detailed design using comments when implementing source code is presented. For electrical system software developers, this may be a strategy that can be used in situations where it is not possible to spend a lot of time documenting the design content.

As of now, tools that automatically generate documentation based on source code comments include JavaDoc and Doxygen. Since JavaDoc is dependent on the Java language, Doxygen is used when development is based on the C language. As Doxygen provides various comment

formats and commands, it has the advantage of automatically obtaining various types of documents. Doxygen, however, cannot contain all the details of the design, and it should be used for the purpose of assisting the simplification of the design.

```
/*********************/
/*     Macro */
/*********************/
#define PRIORITY_MAX_NO 11

#define COMMAND1      0x00
#define COMMAND2      0x01
#define COMMAND3      0x02
#define COMMAND4      0x04
#define COMMAND5      0x08
#define COMMAND6      0x10
#define COMMAND7      0x20
#define COMMAND8      0x40
#define COMMAND9      0x80
#define COMMAND10     0x100
#define COMMAND11     0x200

#ifdef VARIANT_TABLE


/******************************************/
/*     Priority Logic variant Table */
/******************************************/

typedef struct {
unsigned char Priority;
unsigned char Mode;
unsigned char Work_Count;
unsigned char On_Time;
unsigned char Off_Time;
unsigned char failcheck;
unsigned char Stop_Control;
} fault_Handling_Table

const fault_Handling_Table priority_TBL[PRIORITY_MAX_NO] = {
/* Priority, Mode, Work_Count, On_Time, Off_Time, Fail_check,
Stop_Control */
{ 0, 0, 0, 0, 0, 0, 0},
…
};
#endif
```

**Figure 9** Example of variability implementation (determination of function call based on feature selection)

An example of writing comments on source code using the comment command of Doxygen is shown Fig. 10. Comments can be added to the beginning of files, functions, and variables. Below is an example that was written at the beginning of the file.

The command supported by Doxygen starts with @ to write a brief introduction, date of creation, version, rights, etc. Additional information can be included by using the @note and @par commands. In this case study, additional information such as @par Feature:Fault Priority is added to indicate that the module implements a specific feature.

In the comments applied to the function, the @note command can be used to specify whether the function is an internal module function or an interface function, in addition to the basic description of the function. Although these comments are not enforceable, they can be used to make a promise between the developers that the module will be used

through the interface by providing such information to the developer. The following function is the interface function provided by the ABC module. In order for another module to interact with this module, this function must be called. When this function is called, the function that internally determines the priorities and the internal function that executes the selected command are called in turn.

```
/**
*******************
* @brief  ABC Module.
* @details      xxx Software
*      Product Line Project.
* @author      ooo
* @version 1.0.0
* @file   abc.c
* @copyright   Copyright by ooo.
* @warning Target is unknown.
*      Complier is unknown
* @note
* @par
* Project: xxx Software Product Line Project.
* @par
* Target: Unknown.
* @par
* Complier: Unknown.
* @par
* Features: Fault Priority
*********************/
```

**Figure 10** Example of Variability management of document based on feature section

## 4.4 Discussions

To evaluate suggested design method, two products are selected among the products defined in the product line to introduce the virtual process of production activity and the implications.

The task of selecting a feature for product development from the feature model is performed. The criterion for selecting a feature is the customer's requirements. The requirements of the customer need to be analysed to determine which features satisfy the requirements. In reality, product requirement analysis and feature selection are performed almost simultaneously. Examples of possible product configurations based on the variable elements examined in the product line module development are as Tab. 3.

**Table 3** Association between feature and product instance

| Feature | Product A | Product B |
|---|---|---|
| Comport Position Control | O | X |
| Switch Type | 3 Way Switch | 3 Way 2nd Switch |
| Fault Priority | Priority Script 1 | Priority Script 2 |
| Parameter | Product A Parameter value | Product B Parameter value |
| Slide Position Calculation Method | XX Device based Algorithm | YY Device based Algorithm |

The product architecture instance development process receives the product feature list, product requirements, and product line architecture created in the previous tasks as inputs, and proceeds in the following order:

- Creating product architecture instances using the product feature list
- Modifying the product architecture considering new product requirements
- Only the results of the first task are presented in this study.

When creating a product architecture based on product features and product line architecture, it is necessary to ensure that selectable modules are present in the product line architecture. In other words, it is necessary to check whether a module with a variable attribute <<VO>> is included in the design. As for such a module with a variable attribute, the module itself can be excluded from the product architecture according to the feature selection. After removing the unselected module, all the variable attribute information in the product line architecture is removed.

The Fig. 11 shows the difference between the product module architecture derived from product line module architecture. There was no module with a variable attribute <<VO>> in the architecture of the slide control software. This means that the product architecture is consistent with the product line architecture.
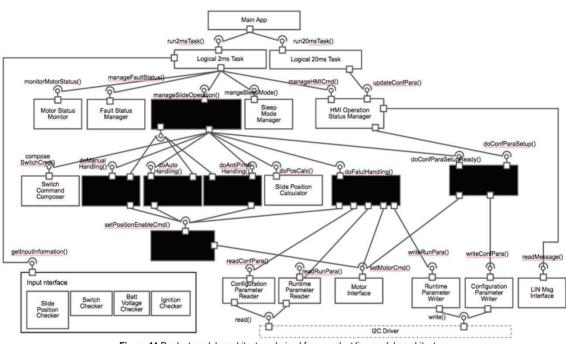


Figure 11 Product module architecture derived from product line module architecture

## 5 CONCLUSIONS

In this paper, domain implementation methods based variability management techniques are suggested to make the component to be more reusable based on feature selection at product instantiation phase. In SPL, a product based on selected features can be generated or composed using the components developed in domain implementation [12-16].

Software product line engineering is not a treasure trove over the rainbows. This technology is a development paradigm that has emerged to improve the reusability and maintainability of software and can be embodied in various forms. The implementation may be a software platform, or it may be software developed in a component-based method. Software product line engineering has been considered as powerful methodology for platform development and reusable architecture construction. However, construction of software product line requires high qualified engineers and large investment in time and cost. As other software development methodology, guides for adopting the software product line engineering and techniques for variability management are the critical. Many software product line have been constructed in software intensive domain, therefore, there are many guidelines and variability management techniques in software intensive domain. However, very few case studies are available for embedded software domain so that small-sized companies and novice engineers at software product line engineering are not easy to manage the variability. In this paper, design methods for variability management in embedded software were suggested and a case study of automotive sunroof control software product line is described as domain implementation guides. State, state transition, algorithm are the main variable parts in embedded software domain. Data structure and interface are also variable parts but these are already defined in other domains. Suggested mechanisms contribute to help the embedded engineers to identify the variable parts. Also, these helps to decide the implementation strategies and patterns of software modules to be more extensible including variable parts.

### Acknowledgments

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# Influence Characteristics of Electronic Payment Platform Service on User Behavior: Focusing on Chinese Users

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**Abstract:** In recent years, mobile payment has gained widespread popularity and has become the main payment method for many consumers in China. With the increase in user scale and usage frequency, the scale of mobile payment transactions will continue to grow in the future. This study aimed at investigating the impact of electronic payment platform service characteristics on customer usage intentions in a user-centered study in China. This study made use of SPSS 22.0 handles basic statistics, while the statistical tool Smart PLS 3.0 handles hypothesis testing. A survey of 70 people who used electronic payment platforms was conducted. Results of the study revealed that between electronic payment platform service characteristics, convenience, security, reliability, and reactivity. The impact on customer usage intention and usage behavior is as follows: characteristics, convenience, security, reliability, and reactivity of electronic payment platform services. The results of the survey showed that users' attitudes towards usage and user behavior had a positive impact.

**Keywords:** electronic payment; mobile payment; platform service; user attitude; user behavior

## 1 INTRODUCTION

Credit card terminals were originally developed because of this quick adoption, hardware manufacturers like Hypercom and Verifone have emerged. The function of payment networks and payment processors was changed by the introduction of credit card terminals, turning them from businesses that processed paper vouchers into suppliers of electronic communication services. Payment terminals served as the foundation of this era's payment network [1].

Companies needed new kinds of online payment terminals as the Internet first took off in the 1990s to suit their needs for online business. The result is a large number of new online payment companies were born one after another. These businesses decide not to compete with major payment processors because of the significant hurdles to entry into the payment processing industry. Instead, they concentrated on creating technology for consumers and businesses. These businesses make up what is referred to as payment gateways. Payment gateways can be reconfigured and connected to commercially available payment processors to process merchant payment information and customer payment instructions [5].

According to a Chinese network information study, the complete layout of payment firms in the field of the rise in individuals utilizing mobile internet payment has also been fueled by mobile payment. The number of smartphone payment users has grown steadily since 2021. The 49th "Statistical Report on Internet Development in China" from the China Internet Network Information Center claims that. China had 904 million mobile payment customers as of December 2021 [2, 16]. There will be 42.49 million more people than in June 2021.

The inclusive development of mobile payment narrows the geographical distribution gap. The fusion of digital technology and inclusive finance is getting deeper as new information technologies like artificial intelligence, big data, and 5G emerge so quickly. Mobile payments enhance the accessibility and convenience of inclusive financial services as a key tool bearer of digital inclusive finance. Mobile payment has progressively gotten into the e-commerce space and has grown to be a significant means of payment there because of China Telecom's ongoing mobile network upgrades, infrastructure expansion efforts, and Chinese e-commerce technologies are being developed and made more widely known. The size of the mobile payments market in China will increase in the next year. Chinese consumers' consumption concepts and behaviors are evolving. By 2026, it is anticipated that mobile payment transactions would total 1,290.42 trillion [13].

Third-party platforms such as Alipay and WeChat Pay will be the first to accept payment institutions such as Cloud Quick Pass in 2021, and promote deeper interconnection between online and offline scenarios, services, and payment. In offline situations, Alipay, WeChat Pay, and UnionPay QuickPass have mutually recognized payment codes in many locations across the nation. It is anticipated that all cities will have this capability by 2022. The function of self-service payment and activation of Cloud QuickPass was officially launched, and WeChat Pay has interconnected and collaborated with 12 banking institutions. Many common payment channels, such as WeChat Pay, Alipay, UnionPay QuickPass, Apple Pay, And Mi Pay, And Huawei Pay, Samsung Pay, and others, are supported by online platforms such as Meituan and Pinduoduo. With the continuous integration of Internet technology into our life and the rapid development of e-commerce, the market demand for mobile payment methods is becoming more and more muscular. Understanding the influencing elements of consumers will help the industry for third-party mobile payments gain substantially from adopting these services. This research fills the gap in current theoretical research by designing a questionnaire to study the influence characteristics of electronic payment platform services. This provides a sufficient theoretical basis and decision-making reference for the mobile payment industry to solve the problem of

consumers' user behavior and has great practical significance.

This paper takes the mobile payment methods of Chinese consumers as the starting point, designs a questionnaire to measure, analyzes the results of the questionnaire, examines the overall situation of consumers' willingness to use mobile payment, and studies the factors that affect user attitude toward and user behavior third-party mobile payment. Following a thorough examination, the researchers chose four variables for analysis: convenience, security, reliability, and reactivity. To investigate the influence of electronic payment platform service characteristics on customer use intention, focusing on Chinese consumers. It remains to be seen whether the method of payment and settlement on the electronic payment platform can indeed be low-cost, fast, convenient, safe, and reliable. The online payment and settlement tools developed by many hidden dangers, such as credit card payment and settlement, are independent and difficult to use together. These self-contained concealed cards have made an effort to work with the website alliance's newly formed online settlement and payment provider. The credit card can only be used for settlement inside the same network; inter-network settlement is not technically possible. This greatly improves the development of online payment and settlement businesses. It also brings much inconvenience to users. Therefore, this study will explore the relationship between electronic payment platforms and user attitudes to analyze the characteristics of electronic payment platforms to provide better guidance for the development of electronic payment platforms.

## 2 THEORETICAL BACKGROUND
## 2.1 Characteristics of Payment Platform Service

The definition of payment service quality refers to the definition of service quality. It is a distinction between quality levels.

**Convenience**: makes it easy to learn and use the service instead of removing the inconvenience of the means or methods that have been used in the past. According to a previous study, convenience was discovered to significantly influence the intention to accept electronic payment services [3, 17, 18]. Offline consumption is increasing when the efficiency and convenience of ordering products or services online are judged to require a direct experience of online consumption. Blut [4] conducted a meta-analysis of e-service quality studies published between 2000 and 2014 and discovered four determinants of e-service quality. There are web design, functionality (utility), customer service (convenience), and security and confidentiality. Finally, there is a view that the perceived convenience of online shopping is related to the prominence of shopping attitudes of live e-merchants. Shopping patterns also differ, and based on the classification of these consumer groups, it is argued that online shopping platforms need to classify and functionalize convenience. It was recorded and used as a dependent variable. Consumer attitudes, shopping engagement processes, and mobile shopping exploring the position of consumers' mobile shopping behavior, which acknowledges that it is, but proves that it is not as important

as computer shopping.

**Security**: is related to safely operating the service without leaking personal and financial information provided in the process of using the electronic payment service. E-banking services were empirically examined using the seven criteria of accuracy, security, transaction speed, user-friendliness, and convenience [5]. Even though some of these determinants are dependent on other variables. The majority of these determinants were statistically significant, suggesting that they have a stepwise or inter-relational structure. It increases consumer trust and improves consumer attitudes while trusting the payment platform.

**Reliability**: Customers often make comparisons between the service they received and the assistance they required. Sadly, there are times when the perceived and desired levels of service differ resulting in a service quality gap. The five aspects of this gap, according to Parasuraman [6], are stated as follows in the rater model stands for Responsiveness, Sustainability, Security, tangibles, service and empathy, and dependability, which are all important factors to consider (convenience). Five values of service quality, such as economic feasibility, safety, convenience, reliability, and reaction time among the factors, economic feasibility, safety, reliability, and response time are positive influences on customer satisfaction. It was found that economic feasibility, reaction time, and reliability had a positive impact on the client's intention to reuse. Lee [7] conducted a study using the TAM model to examine the variables influencing the desire to use a mobile easy payment service powered by Fintech. He used six factors such as convenience, reliability, innovativeness, self-efficacy, suitability, and visibility as factors that influence intention to use through the effect on perceived usefulness.

**Reactivity**: Responsiveness in the electronic payment service refers to the access-loading speed and transaction processing speed recognized by users in the process of accessing the system. According to a previous study, responsiveness has been discovered to have a favorable impact on the intention to utilize electronic payment [6, 7].

## 2.2 User Attitude

Attitude is a psychological concept formed by thoughts, beliefs, and emotions toward a specific object [8]. Zajonc and Markus [9] have a behavioral dimension attitude. Attitude is defined as a summary of hypothetical constructs expressed as overall moods or evaluative judgments about people, things, or problems, and consists of the emotional and cognitive dimensions except for this because it obscures the relationship with the actual behavior. Fishbein and Ajzen [10] outlined the principle of deliberate action and argued that an attitude toward a specific action is more appropriate than a general attitude to predict a specific action. The degree to which a person views a certain activity favorably or negatively is referred to as their attitude toward behavior. The theory of rational behavior developed into the theory of planned behavior, and competitive models that revise and supplement these theories appeared, and the attitude toward behavior received the attention of many researchers.

Although behavioral theory and planned behavioral theory were applied to give importance to attitudes toward using behavior, the attitude toward coupon usage alone cannot fully explain consumer behavior toward coupon use [11]. Additionally, since time, behavior, and context are not described, employing merely the attitude toward the item does not always anticipate any specific behavior logically associated with the object. Therefore, unless the criterion content is measured with comparable generality or multiple behavioral criteria, a relationship between attitude toward an object and a single criterion behavior cannot be expected [12].

The behavioral intention assumption of According to the technological acceptance paradigm, behavioral intention simultaneously influences attitudes toward using and perceiving perceived utility, perceived ease of use, and external factors, usefulness. External variables influence perceived usability.

## 2.3 User Behavior

Consumers' purchase intention is based on predictions about future behavior or individual beliefs and attitudes. It refers to the probability of being transferred to the actual purchase behavior. 'Intention' refers to the extent to which consumers are also defined as expressing the will to take a specific future action [13]. Meanwhile, the possibility that a buyer will have a purchase intention actually engage in the purchasing activity that they expect or plan to do in the future, and their beliefs and attitudes. In the study of purchase intention, it was argued that it is an effective method to ask the behavioral intention in order to predict the behavior of an individual who reported that the intention to perform or not to perform Behavior is a direct predictor of behavior [14]. The term "purchasing intention" describes the consumer's propensity to buy a good or service, and it also refers to the decision to buy a certain item. Cheah [15] conducted an empirical analysis of short films using the theory of planned behavior, it was discovered that factors influencing consumers' behavior purchase intentions are consumer behavior attitudes, subjective rules, and control over perceived behavior, especially consumers' attitudes toward mobile video. A series of strengths of online payment platforms also promote consumer attitudes and willingness to consume [19]. The fact that people are subject to positive consumer attitudes promotes consumer attitudes, which in turn promotes consumer willingness and creates consumer trends, i.e. consumer willingness is influenced by the opinions of acquaintances and friends, which means that it becomes an important criterion for the formation of subjective rules.

## 3 RESEARCH MODEL AND RESEARCH HYPOTHESIS

From the viewpoint that the customer's attitude toward use and behavior will be greatly influenced by the service qualities of the electronic payment platform, the service characteristics, convenience, security, reliability, and responsiveness of the electronic payment platform is chosen as a variable. Examining the outcomes of the relationship is

the goal of this study between service characteristics. Convenience, security, reliability, and reactivity of electronic payment platforms effect on user attitude using use behaviors through empirical research. The research model of this study is displayed Fig. 1.
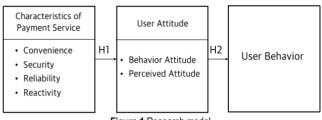


**Figure 1** Research model

## 3.1 Research Hypothesis

This research is based on previous research entitled "Influence characteristics of electronic payment platform service on customer use intention: focusing on Chinese users". This study builds on previous studies. Data analysis is very helpful for analyzing the influence of electronic payment platform characteristics on customers' willingness to use. By analyzing a large amount of data information such as the characteristics, convenience, security, reliability, and responsiveness of the electronic payment platform, the customer's platform service characteristics are investigated. There are effects on User views are influenced by perceived utility and usability toward the use and user behavior. Using, a Chinese user-centered study on the following presumptions is used in order to determine how service attributes of electronic payment platforms affect client usage intentions.

Hypothesis 1: Characteristics of electronic payment platform service have has favorable effects on user attitude.

Hypothesis 1_1_1: Convenience has favorable effects on behavior attitude.

Hypothesis 1_2_1: Security has favorable effects on behavior attitude.

Hypothesis 1_3_1: Reliability has favorable effects on behavior attitude.

Hypothesis 1_4_1: Reactivity has favorable effects on behavior attitude.

Hypothesis 1_1_2: Convenience has favorable effects on perceived attitude.

Hypothesis 1_2_2: Security has favorable effects on perceived attitude.

Hypothesis 1_3_2: Reliability has favorable effects on perceived attitude.

Hypothesis 1_4_2: Reactivity has favorable effects on perceived attitude.

It was asserted that a system's ability to influence attitudes and user behavior depends on how easily and effectively users believe it to be toward the system. It was said that attitude had a significantly positive (+) impact on user behavior. The following hypotheses were developed in light of these earlier investigations.

Hypothesis 2: User attitude has favorable effects on user behavior.

Hypothesis 2_1: Behavior attitude has favorable effects on user behavior.

Hypothesis 2_2: Perceived attitude has favorable effects on user behavior.

## 3.2 Variable Operational Definition

Following previous research analysis and integration, the structure model is used to analyze the customer usage intention and usage behavior. This study used a questionnaire with 8 concepts and 27 questions covering convenience, security, and reliability, which took 10 days to complete.

Convenience refers to whether paying through an electronic payment platform is more convenient and easier. This paper proposes three questions to investigate convenience.

Security suggests whether the customer's use of the electronic payment platform is authentic and safe, and whether it can better protect personal privacy. This paper

designs three research questions on security issues.

Reliability means that customers trust electronic payment platforms and thus become more popular with the general public. This paper proposes three research questions to investigate the reliability problem.

Reactivity refers to the system's ability to promptly and accurately utilize the electronic payment platform, while meeting market demands. This paper proposes three research questions to investigate the reactivity problem.

The user attitude is influenced by the customer's attitude and the service characteristics of the electronic payment platform. This paper designs three questions to study the reactivity problem.

The user behavior service characteristics of the electronic payment platform have an impact on the customer's user behavior. This paper designs three questions to study the reactivity problem.

**Table 1** Operational definition

| Variables | | Details | Prior study |
|---|---|---|---|
| Characteristics of payment platform service | Convenience | - Paying through payment software is easier and more convenient<br>- Learning to pay with payment apps is easy<br>- Paying with a payment app is more convenient than paying with cash by carrying your phone with you | [4] |
| | Security | - The security measures of the settlement software platform (for example, binding cell phones, setting strong security passwords, and SMS phone authentication) have security<br>- The payment software can protect your privacy (e.g., real name authentication for large transfers from WeChat to Alipay)<br>- The information provided to you by the payment software (basic information about the merchant) is really reliable | [5] |
| | Reliability | - Payment software platforms are reliable<br>- Electronic payment software platform feels trust<br>- The electronic payment software platform is now more popular with the public | [6, 7] |
| | Reactivity | - Payment software platform encounters problems can be contacted to solve the platform<br>- Payment platform with the continuous economic and social development to make relevant updates (for example, WeChat Alipay related small programs, the green code function during the epidemic, etc.)<br>- The current network payment platform software meets the relevant market demand | [4] |
| Behavior attitude | | - Always willing to use payment software<br>- Recommend people around you to use payment software for payment<br>- Use payment software because people around you rate it highly | [8-12] |
| Perceived attitude | | - The high penetration rate of electronic payment software increases the usage rate of payment software<br>- The interface of the electronic payment software is simple and easy to use<br>- With the development of social technology, electronic payment software will be more convenient to use. | |
| User behavior | | - Real life has been the habit of using payment software<br>- Good prospect of electronic payment software<br>- The feeling of using electronic payment software and the expectation of using it match | [13-15] |

**Table 2** Demographic Characteristics (*n* = 70)

| ITEM | | Frequency | Ratio (%) |
|---|---|---|---|
| Sex | Male | 39 | 55.71 |
| | Female | 31 | 44.29 |
| Age | Under 20 years old | 2 | 2.9 |
| | 20-29 years old | 22 | 31.43 |
| | 30-39 years old | 27 | 38.57 |
| | Over 40 | 19 | 27.14 |
| Education | High school and below | 2 | 2.86 |
| | College degree | 25 | 35.71 |
| | University graduation | 39 | 55.71 |
| | Master degree or above | 4 | 5.71 |
| Job | Student | 21 | 30 |
| | Company employee | 14 | 20 |
| | Government employee | 16 | 22.86 |
| | Business service | 19 | 27.14 |

## 3.3 Demographic Characteristics

This study was empirically analyzed through a questionnaire survey. In partnership with a Chinese survey service provider, the questionnaire survey was carried out online. Mobile payment-using Chinese consumers were polled for the study (Tab. 2).

The survey was started from April 1 to April 25, 2022. Eighty-five questionnaires in all were returned. The overall number of legitimate questionnaires received was 70, however, 15 of them were invalid owing to human or system errors. According to the data analysis of the findings, this study is mostly focused on Chinese customers of electronic payment platforms who are experienced and aged 20 to 39 and possessing a bachelor's degree In terms of employment, 21 students account for 30 % of the workforce, 19 corporate

employees account for 20 %, 16 government employees account for 22.86 %, and 19 business service workers account for 27.14 %.

**Table 3** Reliability and internal consistency

| Variables | | Factor loading | AVE | Composite reliability | Cronbach's alpha |
|---|---|---|---|---|---|
| Convenience | A1 | 0.900 | 0.805 | 0.925 | 0.879 |
| | A2 | 0.902 | | | |
| | A3 | 0.890 | | | |
| Security | B1 | 0.890 | 0.750 | 0.900 | 0.833 |
| | B2 | 0.842 | | | |
| | B3 | 0.865 | | | |
| Reliability | C1 | 0.807 | 0.714 | 0.882 | 0.801 |
| | C2 | 0.847 | | | |
| | C3 | 0.880 | | | |
| Reactivity | D1 | 0.713 | 0.675 | 0.860 | 0.767 |
| | D2 | 0.873 | | | |
| | D3 | 0.868 | | | |
| Behavior attitude | E1 | 0.907 | 0.741 | 0.896 | 0.824 |
| | E2 | 0.802 | | | |
| | E3 | 0.871 | | | |
| Perceived attitude | F1 | 0.933 | 0.870 | 0.952 | 0.925 |
| | F2 | 0.936 | | | |
| | F3 | 0.929 | | | |
| User behavior | G1 | 0.910 | 0.844 | 0.942 | 0.908 |
| | G2 | 0.946 | | | |
| | G3 | 0.900 | | | |

**Table 4** Correlation and discriminant validity

| Variable | AVE | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Convenience | 0.805 | 0.897* | | | | | | |
| Security | 0.750 | 0.614 | 0.866* | | | | | |
| Reliability | 0.714 | 0.668 | 0.840 | 0.845* | | | | |
| Reactivity | 0.675 | 0.595 | 0.702 | 0.709 | 0.821* | | | |
| Behavior attitude | 0.741 | 0.681 | 0.840 | 0.832 | 0.752 | 0.861* | | |
| Perceived attitude | 0.870 | 0.691 | 0.763 | 0.775 | 0.707 | 0.842 | 0.933* | |
| User behavior | 0.844 | 0.692 | 0.763 | 0.767 | 0.642 | 0.815 | 0.827 | 0.919* |

\* The analysis's output, the AVE value of all variables, represents each variable's correlation. All variables made considered to have discriminant validity due to their being higher than the square.

## 4 EVALUATIVE ANALYSIS
### 4.1 Method of Data Analysis

This paper uses Smart PLS 4.0 to analyze structural equations and SPSS 22.0 for basic statistics (partial least squares). Basically, Cronbach's Alpha should be 0.7 or greater to indicate reliability. Concentration validity and discriminant validity are two categories of validity. Component Reliability (CR) and variance extraction index value (AVE) of each factor. In broad sense, the factor loading value should be 0.6 or higher, the component reliability value should be 0.7 or higher, and the variance extraction index value should be 0.5 or higher. When the square root of the variance extraction index value is compared to the correlation coefficient, the variance extraction index value is greater than the values of the vertical and horizontal correlation coefficients. In this study, after the evaluation of the measuring model was complete, the research model's reliability and validity were investigated.

### 4.2 Analysis of Structural Model

PLS was chosen as the data analysis technique in this study taking into account the characteristics of the variables including theoretical soundness, sample size, and questionnaire self-development. If the $R^2$ value is 0.26 or higher, and the degree of fitness is high, if the degree of fitness is expressed as a medium between 0.26 and 0.13, and less than 0.13, the degree of fitness can be expressed as low. Behavior attitude (0.798) and perceived attitude (0.704) of the component value made evaluated as high, and user behavior (0.732) made be evaluated also as high. The research outcome model is displayed in Fig. 2.

Hypothesis H1-1-1, convenience has a favorable (+) effect on behavior attitude. Due to the statistics being meaningful at a 95 % level of significance, this theory was selected. ($\beta = 0.143$, *T-value* = 2.112, *Path coefficient* = 0.05). The more convenient the features of an electronic payment platform service, the better the behavior attitude.

Hypothesis H1-2-1, security has having a favorable (+) effect on behavior attitude. This theory was chosen because the data were relevant at a 95 % level of significance. ($\beta = 0.377$, *T-value* = 2.480, *Path coefficient* = 0.05). A better conduct attitude is one of the hallmarks of electronic payment platform service.

Hypothesis H1-3-1, one of the responsibilities of the characteristics of electronic payment platform service, reliability has having a favorable (+) effect on behavior attitude. Due to the statistics being meaningful at a 95 % level of significance, this theory was selected. ($\beta = 0.271$, *T-value*

= 2.541, *Path coefficient* < 0.05). Reliability of the characteristics of electronic payment platform service the better behavior attitude.

Hypothesis H1-4-1, reactivity has having a favorable (+) effect on behavior attitude. Due to the statistics being

meaningful at a 95 % level of significance, this theory was selected. (*β* = 0.210, *T-value* = 2.435, *Path coefficient* < 0.05), like a consequence, the hypothesis is accepted. Reactivity of the characteristics of electronic payment platform service the better behavior attitude.
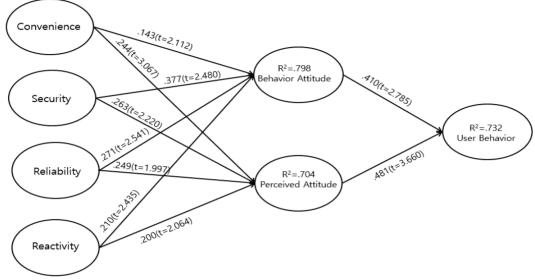


**Figure 2** Results of research model

**Table 5** Hypothesis test result summary

|  | Cause variable | Result variable | Path coefficient | T-statistics | Result |
|---|---|---|---|---|---|
| H1-1-1 | Convenience | Behavior Attitude | 0.035 | 2.112 | Accept |
| H1-2-1 | Security | Behavior Attitude | 0.013 | 2.480 | Accept |
| H1-3-1 | Reliability | Behavior Attitude | 0.011 | 2.541 | Accept |
| H1-4-1 | Reactivity | Behavior Attitude | 0.015 | 2.435 | Accept |
| H1-1-2 | Convenience | Perceived Attitude | 0.002 | 3.067 | Accept |
| H1-2-2 | Security | Perceived Attitude | 0.027 | 2.220 | Accept |
| H1-3-2 | Reliability | Perceived Attitude | 0.045 | 1.997 | Accept |
| H1-4-2 | Reactivity | Perceived Attitude | 0.039 | 2.064 | Accept |
| H2-1 | Behavior Attitude | User Behavior | 0.005 | 2.785 | Accept |
| H2-2 | Perceived Attitude | User Behavior | 0.000 | 3.660 | Accept |

Hypothesis H1-1-2, convenience has having a favorable (+) effect on perceived attitude. Due to the statistics being meaningful at a 95 % level of significance, this theory was selected. (*β* = 0.244, *T-value* = 3.067, *Path coefficient* < 0.05), like a consequence, the hypothesis is accepted. The convenience of the characteristics of electronic payment platform service the better perceived attitude.

Hypothesis H1-2-2, security has having a favorable (+) effect on perceived attitude. Due to the statistics being meaningful at a 95 % level of significance, this theory was selected. (*β* = 0.263, *T-value* = 2.220, *Path coefficient* < 0.05), like a consequence, the hypothesis is accepted. The security of the characteristics of electronic payment platform service the better perceived attitude.

Hypothesis H1-3-2, reliability has having a favorable (+) effect on perceived attitude. Due to the statistics being meaningful at a 95 % level of significance, this theory was selected. (*β* = 0.249, *T-value* = 1.997, *Path coefficient* < 0.05), like a consequence, the hypothesis is accepted. The reliability of the characteristics of electronic payment platform service the better perceived attitude.

Hypothesis H1-4-2, reactivity has having a favorable (+)

effect on perceived attitude. Due to the statistics being meaningful at a 95 % level of significance, this theory was selected. (*β* = 0.200, *T-value* = 2.064, *Path coefficient* < 0.05), like a consequence, the hypothesis is accepted. The reactivity of the characteristics of electronic payment platform service the better perceived attitude.

Hypothesis H2-1, user attitude has to have a favorable (+) effect on user behavior. Due to the statistics being meaningful at a 95 % level of significance, this theory was selected. (*β* = 0.410, *T-value* = 2.785, *Path coefficient* < 0.05), so hypothesis H2-1 is adopted. Hypothesis H2-2, user attitude has to have a favorable (+) effect on user behavior. Due to the statistics being meaningful at a 95% level of significance, this theory was selected. (*β* = 0.481, *T-value* = 3.660, *Path coefficient* < 0.05), so hypothesis H2-2 is adopted.

## 5 DISCUSSIONS

For the research goal outlined in the introduction, the following findings are derived according to the research findings. It has been established that the service characteristics of the electronic payment platform

significantly affect consumer willingness to use it. In previous studies of information systems, they have been studied in terms of the characteristics of the service's level of quality. However, the most recent studies on the service characteristics of electronic payment platforms show that, in terms of the characteristics of electronic payment platforms, it is also possible to study customers' attitudes and behavioral intentions to use them, in addition to customer satisfaction and repurchase intentions. This is the result of using the electronic payment platform's service attributes. The service qualities of the electronic payment platform are intended to affect the customer's attitude about using it, should be used usage intention.

The following is an analysis and explanation of this research. The first theory is chosen. utilizing the characteristics of electronic payment platform service convenience, security, reliability, and reactivity characteristics of electronic payment platform services have an impact on customer satisfaction that is positive (+). This demonstrates that the qualities of the characteristics of electronic payment platform services have a big impact on how users feel about using the platform. The better the features of the electronic payment platform services, the better the users feel about using the platform, the better the users behave, and the more effective and useful the electronic platform is. Therefore, the online platform should pay attention to the characteristics of electronic payment platform services, to increase the motivation for the future development of electronic payment.

Secondly, from the point of view of the diversity of users of the electronic payment platform, it is necessary to bring more comprehensive service features to the users of the platform, rather than blindly pursuing the increase in the platform and the improvement of the customer's attitude towards using it. In this study, the payment system's high- or low-level payment service characteristics, and the actual differences perceived by the consumer before making the payment, based on the expectations of the payment service characteristics, constitute the service characteristics. So, to reduce the perceived differences in the user before the consumer performs the service the payment platform should first improve the characteristics of the service of the electronic ah payment platform. Even if the platform users are very diverse in age and education, the electronic payment platform increases the convenience of the platform for the customer more convenient to use the platform; improves the security of the bottle set, is easier for customers to increase the frequency of use, and increase goodwill; increase the trust of people from all walks of life to the platform, thus increasing the number of people who try to use the electronic payment platform; improve the responsiveness of the platform, so that more customers' related use of the platform is solved; after these features of the e-payment platform are improved, customers' attitudes toward using it will be further enhanced, thus influencing actual consumer behavior.

# 6 CONCLUSION

This experiment examines the relationship between the characteristics and attitudes toward electronic payment platforms and the actual usage behavior of Chinese consumers at the center of the study. An attempt was made to grasp the relationship between the characteristics of electronic payment platforms and user attitudes toward use and actual use behavior, and to conduct an empirical study of the examination of the previous study and Chinese consumers who consume using electronic payment platforms for online shopping for consumption objects. The factors that constitute the characteristic features of the electronic payment platform are convenience, security, reliability, and reactivity aspects. The electronic payment platform, faces diverse consumer groups, the actual shopping and consumption behavior of consumers is influenced by the customer's attitude toward using it, and the customer's attitude towards using it is influenced by the characteristics of the electronic payment platform. The current electronic payment platform and its characteristics of the increasing demand have long been recognized. Although the characteristics of the currently used electronic payment platforms are constantly changing in response to consumer needs, the basic characteristics of almost most electronic payment platforms do not change much. This study focuses on those e-payment platforms that are now holding a majority share of the market in China. To the extent that the vast majority of electronic ah payment platforms have features on them, four features were selected. It was demonstrated whether there is a relationship between these characteristics and the customer's attitude towards using them, and a comparative analysis of the data was carried out. The influence of the features of the electronic payment platform on the customer's attitude to use and the effect of actual consumer behavior was analyzed. Among them, the features of the electronic payment platform are highly correlated with convenience, security, reliability, and reactivity. The results of the analysis show that the characteristics of the electronic payment platform are positively correlated with the customer's attitude. The data analysis revealed that the user attitude is positively (+) impacted by the electronic payment platform's convenience, security, dependability, and responsiveness.

This study still has much problems. The sample survey's sample size is insufficient, the selection criteria that influence the electronic payment platform are few and insufficiently thorough, and the impact relationship between each sample is too one-sided. There are various other elements besides the ones mentioned in this article that influence company outcomes.

The selected samples are only apply to the consumption characteristics of electronic payment platforms with Chinese consumers as the research center. For those electronic payment platforms in other countries and third-party electronic payment platforms, their correlation with the survey sample data is not representative of the whole situation. Therefore, it is recommended that new work be completed and continue to develop.

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# Effect of AI: The Future Landscape of National Cybersecurity Strategies

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**Abstract:** Artificial intelligence (AI) is considered a vital factor that will fundamentally alter the cybersecurity environment. AI technology is progressing much faster than expected, and AI-based security services are being introduced into the global security market on a daily basis. However, how AI can contribute to the cybersecurity field and what changes it will bring remain unknown. Nonetheless, cybersecurity is not merely a technical issue but also a process for dealing with regulations, policies, and security risks; therefore, the introduction of AI technology introduction can make a fundamental difference in cybersecurity policy as a whole. This study primarily aims to better understand the concept and characteristics of AI from the cybersecurity perspective and identify its future implications on cybersecurity environment at the national policy level. This study predicts what modifications will be made to national cybersecurity strategies (NCSS) when machine learning (ML) is introduced and implemented. It also provides a basic policy recommendation that offers potential responses to these changes. The study first describes the emergence of AI in the cybersecurity field and explains AI-ML technical services and AI security policy elements. Second, through NCSS material analysis, this study categorizes NCSS into 11 categories and selects the critical functions of each dimension. Finally, it predicts the changes that will occur when AI is introduced within the selected NCSS category. It also introduces the priorities and considerations required for these changes.

**Keywords:** artificial intelligence (AI); cyberattack; cybersecurity; machine learning (ML); national cyber security strategies (NCSS)

## 1 INTRODUCTION

Artificial intelligence (AI) has emerged as one of the most critical technologies in every aspect of the information age. In cybersecurity, technology development for solving security problems on the basis of AI is rapidly progressing. Compared with conventional cybersecurity solutions, AI-enabled security systems are more flexible, adaptable, and powerful [1]. Although AI technology remains incomplete, and the application of AI technology in cybersecurity remains in its infancy, experts believe that AI security systems will help to improve cybersecurity performance and defense, and ultimately, significantly impact the cybersecurity environment.

Meanwhile, AI utilization in cybersecurity also affects the aspect of the attack. Previous studies have predicted the future AI cyberattacks as follows. First, even if the influence of AI is stronger in cybersecurity, the fundamental goal of cyberattacks will not change. In addition to stealing data and shutting down systems, AI-powered cyberattacks also manipulate data to influence human behavior. Second, AI-powered cyberattacks will not be used in all areas. AI cyberattacks require more time, resources, and capital than traditional cyberattacks. Therefore, AI-powered cyberattacks will be employed in a much more sophisticated way in large-scale cyberattack targeting, government agencies, and companies rather than individuals. Third, experts have different opinions about when exactly AI-armed cyberattacks will transpire, but they predict that they will occur in the near future [2].

Thus, how can countries respond to these cybersecurity changes? On the basis of the National Cyber Security Strategy (NCSS), this study attempts to envision how AI will affect national cybersecurity and what areas the country should improve. However, AI cybersecurity research has paid limited attention to national behavior and national strategies. Thus, when considering the characteristics of AI cyberattacks, national behavior must also respond to these changes. The reason for this is that the government's national cybersecurity strategy is critical to addressing cybersecurity issues, even though private companies that own and operate the majority of information technology (IT) are critical to improving the country's cybersecurity system [3].

Over the last decade, NCSS has been widely used worldwide as a national guideline for addressing cybersecurity issues at the national level. On the basis of the NCSS, we determined that the development of countermeasures in an evolving AI cybersecurity environment is a good starting point for a national review of AI security policy.

This study extensively reviews existing AI and NCSS-related materials. The study is organized as follows. First, it introduces the emergence of AI in the cybersecurity field and explains related technical services and policies. Second, the outline of NCSS is explained, and its categories and elements are selected on the basis of the existing materials. Finally, we predict the changes that will occur when AI is introduced within the selected NCSS category. We also suggest priorities and considerations required for these changes.

## 2 RELATED WORKS

In the field of cybersecurity, research on changes and countermeasures resulting from the introduction of AI technology has been conducted since 2010. Existing studies can be broadly classified into two categories. First, studies on AI technology application in cybersecurity. Ref. [4] analyzed the errors of AI and suggested how to effectively apply it to cybersecurity. Ref. [5] investigated how to respond to cyberattacks using AI on the basis of a literature review and proposed ways to construct a safe AI system. Ref. [6] presented a future research direction by analyzing "AI-based cybersecurity", which is expected to play an important role in intelligent cybersecurity services and management. Ref. [7] presented an AI-based cybersecurity model on the basis of papers published from 2016 to 2020. Ref. [8] explained

the current state of AI use in cyber security and presented case studies and application programs.

Second, studies that describe countermeasures and recommendations on the basis of changes in the implementation of AI technology in the cybersecurity from a specific perspective. Ref. [9] analyzed how to effectively utilize AI technology, which is expected to have the greatest impact in cybersecurity, with a focus on web application security. Ref. [1] presented from an organizational perspective on a mature cyber environment combined with AI technology. Ref. [10] described the role of AI in cybersecurity and provided recommendations on how organizations can leverage AI in cybersecurity. Ref. [11] analyzed how AI can affect cyber defense and attacks from the 5G technology perspective and suggested countermeasures. Ref. [12] identified major problems in cybersecurity regarding AI use from a criminological viewpoint. Ref. [13] evaluated current challenges related to AI in cybersecurity in the US and proposed solutions.

Research on policy changes and responses at the national level due to the introduction of AI technology in the cybersecurity environment remains scant. Thus, the study's primary goal is to identify changes in national cybersecurity policies as a result of the introduction of AI technology and to provide considerations for responding to them. Particularly, this study aims to outline NCSS, a key national guideline for solving cybersecurity problems at the national level. Over the past decade, many countries have adopted NCSS tailored to their characteristics, and roughly 80 countries have announced NCSS since 2006 [14]. In addition, this study focuses on machine learning (ML), which is currently receiving the most attention and activation in cybersecurity research in AI technology. The research questions of this study are as follows.

- Research Question 1. How does the introduction of AI technology in cybersecurity environments change the core functions of NCSS?
- Research Question 2. What are the recommendations or considerations that NCSS can make to address the key challenges associated with these changes?

This study aims to answer research questions through an extensive review of AI national strategy reports published by countries worldwide, NCSS guidelines, and data released by various international organizations and research institutes. Moreover, we analyze the key changes and provide recommendations for NCSS core features adopted in the study.

## 3 AI IN CYBERSECURITY
### 3.1 Brief History of AI in Cybersecurity

Attempts have been made to predict and detect various cyberattacks using AI technology. The security industry has utilized AI for more than a decade to withstand changes in attackers and to create a system that analyzes, shares, and defends attack information [15]. However, malicious cyberattacks were not as diverse a decade ago as they are today. Thus, attempts to introduce AI technology into

cybersecurity have only received limited attention. In addition, the method of pattern matching allowed the intrusion detection and attack analysis system to fully defend against these attacks. In contrast to the situation 10 years ago, however, the recent cyber threats caused by cybersecurity issues are substantial in terms of quantity and scope [16].

These attacks are likely to increase even further. Recent cyberattacks have been more successful than in the past as they have become more intelligent, organized, and diverse as a result of the constant emergence of new Information and Communications Technology (ICT) industries. To effectively respond to these cyberattack changes, various solutions and response systems have become increasingly necessary, technically and administratively. People have also inquired about how cyberattacks respond; is it possible to anticipate daily evolving cyberattacks? Or, is it possible to detect and respond in advance to unforeseeable Black swans (which, once they occur, cause severe system damage)? Recent attention has been drawn to the need for the introduction of AI technology, which is anticipated to provide answers to these questions [15].

Specifically, ML is one of the most prevalent ways to describe AI applications in cybersecurity and one of the fundamental elements of the next frontier of cybersecurity defense [17]. Using ML technology, research and applications are being conducted in various cybersecurity fields, including security control, threat detection, and prevention. It also provides an immediate, powerful, and proactive response to cyber threats in real time [18]. These security services make cybersecurity more straightforward, proactive, and effective [17].

Such secure ML models can be classified into three general types. First, there is supervised learning. This algorithm is a method of giving and learning problems and answers simultaneously. This algorithm is mainly used for problem solving, such as recognition, classification, diagnosis, regression, and decision trees. In the cybersecurity field, the method is used for network traffic analysis, spam filtering, and malware detection. Second, unsupervised learning is a way of learning only by giving problems. The method is mainly used for clustering, density estimation, and dimensional reduction, and it is best suited for identifying features. In cybersecurity, the algorithm is used for malware identification, user behavior analytics, and network anomaly detection. Third, reinforcement learning is a method for learning through the evaluation of outcomes. Through this method, ML agents can learn to behave through game-like environmental experiences [19].

### 3.2 Description of AI in Cybersecurity

The discussions on AI use in cybersecurity can be divided into technical and policy issues. Particularly, discussions on AI technology use are a key part of cybersecurity. Based on the existing discussions, the current and future applications of AI in cybersecurity technology are as follows.

- **Intrusion and threat detection.** The technology quickly detects, analyzes, and defends against cyberattacks or

malicious activity in real time; it is useful for threats, such as data leakage.

- **Security monitoring.** This technology identifies information about network traffic, internal and external behavior, data access, and many other functions and activities. It focuses on handling log files and error messages from various products.
- **Vulnerability scan and removal.** The technology removes vulnerabilities by identifying and prioritizing weaknesses in the system to counter attacks, such as target zero-day attacks and IoT devices.
- **Data classification.** The technology examines newly introduced data and categorizes sensitivity levels. The system is then protected according to the characteristics of the data, such as privacy and data protection regulations.
- **Spam filtering and social engineering detection.** The technology uses predefined parameters and various statistical models to detect and block spam and classify malicious activities.
- **Security automation.** This technology helps automate repetitive tasks, eliminating the need for repeated, low-value decisions, and it is effectively used in areas, such as threat intelligence.
- **User behavior analytics.** The technology identifies user behavior and accurately detects and blocks new forms of cyberattacks in real time. It also detects accounts through suspicious user behavior analysis and protects the system.
- **Network traffic profiling and network anomaly detection.** The technology analyzes network traffic to calculate risk rating scores. The network risk score provides an estimated risk level and various data-based incompatibilities to rapidly identify anomalies and high-risk situations.
- **Endpoint security.** This technique is trained by unique algorithms. The algorithm is taught to discover new malicious files on the basis of the characteristics of previously discovered malicious files, and it can be used to censor traffic and automatically identify threats.

Meanwhile, global discussions and expectations regarding the application of AI technologies, including cybersecurity, have prompted a review of AI policy. AI cybersecurity policy and AI security policy are discussed. These policies provide some high-level principles and recommendations for technology use.

Ref. [20] predicted that AI development will directly impact nuclear weapons, aircraft, cyber, and biotechnology, which can be an innovative future technology for national security. Particularly, they explained that AI and ML can revolutionize cybersecurity and cyber warfare. Ref. [21] described the attributes of AI, which are expected to affect the security environment and the changes that can occur. The report provides high-level recommendations, such as close collaborations and identification of best practices, necessary for policymakers and stakeholders to respond to changing threat environments through analysis in the near future. Ref. [22] defined AI security as "the robustness and resilience of AI systems, as well as the social, political, and economic systems with which AI interacts". On the basis of this definition, she introduced the AI security map to explore complex AI security environments. Finally, she provided policymakers with recommendations, such as facilitating early global coordination and holding the technology industry accountable.

## 4 PARADIGMS FOR NATIONAL CYBERSECURITY STRATEGY
### 4.1 History of NCSS

In the late 1990s and early 2000s, many countries began to announce national security strategies (NSS) in response to the need to present a consistent approach to the various security issues that emerged from the Cold War [23]. These NSSs included non-traditional security domains, such as energy, climate change, terrorism, cyber, human rights, and the environment. At that time, the cybersecurity domain had been regarded as one of the new non-traditional security domains that policymakers should consider.

Until the 1990s, the idea that cybersecurity would affect national security was not considered possible [24]. This need for cybersecurity has become evident since the early 2000s, alongside a meteoric rise in the number of Internet users and a clear tendency for government agencies, private companies, the military, and economic activities to shift their operations online [25]. As data and information are considered the most valuable assets and values in society and the scope of cybersecurity areas to be protected gradually expands in the private and public sectors, cyberattacks are described as the most likely new threat to the country in the national security strategy [26]. Particularly as a result of this shift in perception, official recognition and responses regarding the dangers of cyberattacks that occurred worldwide in 2006. Moreover, cyberattacks on Estonia in 2007, cyberattacks during the Russo-Georgian War in 2009, and a cyberattack on Iran's nuclear program using the Stuxnet worm, prompted many countries to recognize that: first, a cyberattack that threatens national security is possible; second, the countries' critical infrastructure is extremely vulnerable to cyber security; and third, comprehensive policy responses should be discussed at the national level, as these attacks can be under the control of a foreign power [23].

Since the mid-2000s, a series of cyberspace incidents have elevated cybersecurity to a higher priority than physical security at NSS. In addition, countries have recognized the need for a cybersecurity strategy distinct from national security strategies in order to implement a comprehensive strategic approach. Since 2006, in response to cyber threats, a growing number of nations have begun to publish the NCSS; today, this includes approximately 80 countries. Essentially, NCSS describes a country's priorities, principles, and strategies for addressing cybersecurity issues at the national level.

The NCSS worldwide has similar goals and shares common topics and interests in many areas. However, slight differences exist in cybersecurity approaches depending on the country's cyber threat environment, social and political

situation, geopolitical security tendencies, and cyber awareness level [27]. For example, no official definition of cybersecurity exists, and only a few countries define it. Additionally, countries have diverse perspectives regarding the extent to which cybersecurity should be addressed. Meanwhile, over the past decade, NCSS has constantly evolved to address new cybersecurity challenges with the rapid expansion of ICT. The scope of the NCSS has expanded as the cybersecurity field has become more inclusive and expansive over the past decade.

## 4.2 Categories and Elements of NCSS

Many countries have announced NCSS in the last decade. Furthermore, research institutes, international organizations, and companies have issued guidance on the NCSS elements. The cumulative NCSS and recommendations over the last decade have laid a solid foundation for the nation to build a comprehensive NCSS and, eventually, an implicit international agreement on what should be included in the NCSS. This study identifies the major categories and elements of NCSS on the basis of the most recent NCSS published by 15 countries and the NCSS guidelines of international organizations, research institutes, and companies.

- **Critical infrastructure protection.** Countries strive to protect vital infrastructure and provide pertinent services in a secure manner. Countries make efforts to identify and mitigate the risks associated with their primary CIs and CIIs; strengthen network security, develop the next-generation security infrastructure, determine the roles and responsibilities of government branches, and share information [28].
- **Foster a cybersecurity culture.** To foster a cybersecurity culture, countries should raise citizens' awareness of the dangers of cyber threats and the importance of cybersecurity. In addition, the demand for the security of citizens' basic rights, such as privacy and cybersecurity, must be balanced [29].
- **Counter cybercrimes.** Cybercrime activities include various malicious activities that affect citizens and society. Blocking cybercrime is key to protecting society from online attacks. Cyber-crime response mainly comprises the enactment of cyber-crime laws, expansion of cooperation among related government agencies, and expansion of international cooperation [29].
- **Cyber diplomacy.** Understanding and effectively responding to the ever-evolving cyber threat environment is a crucial aspect of international cooperation. Through various international cooperation and exchange measures, such as trust-building support, cybersecurity capacity building, international standards development, and participation in international organizations, the countries can create a common knowledge base and cybersecurity synergies, such as combating transnational crime [30].
- **Public-private partnerships.** Public-private partnerships are the cornerstone of effectively protecting critical infrastructure and managing security risks in the short and long terms [30]. Countries consider public-private common goals, information sharing, and incentives to effectively build partnerships with the private sector.
- **Foster R&D.** NCSS focuses on R&D and technical innovation to enhance its competitiveness by transforming into cutting-edge products and fostering the growth of highly qualified professionals and researchers [30]. These R&Ds not only include the development of new tools for defense and recovery from cyberattacks, but also scientific research in computer science, electrical engineering, mathematics, and cryptography, as well as social science research in psychology and economics.
- **Training and educational programs.** Educating and training cybersecurity personnel is a significant factor in ensuring the long-term sustainability of national cybersecurity capabilities. NCSS covers cybersecurity education and training for professionals and citizens in the public and private sectors. In this regard, countries use many forms, such as developing advanced curricula and adding cybersecurity-related education to curricula, e.g., mathematics and science, to improve workforce expertise [31].
- **Cybersecurity emergency readiness and cybersecurity exercises.** The Computer Emergency Response Team (CERT) plays a crucial role in preventing, detecting, mitigating, and responding to cybersecurity incidents on a national scale. The national CERT provides proactive and reactive functions as well as preventive and educational services, despite variations in operation methods, organizational forms, the scope of roles, requirements, and available resources for each country [30]. Nationally, the Computer Emergency Response Team (CERT) plays a pivotal role in preventing, detecting, mitigating, and responding to cybersecurity incidents. The national CERT provides proactive and reactive functions as well as preventive and educational services, despite differences in operation methods, organizational forms, the scope of roles, requirements, and available resources for each country [29].
- **Cyber contingency.** A cyber contingency plan is a primary element of NCSS and is a procedure for rapid response and recovery in case of a sudden cyber emergency, which can lead to a national disaster. The cyber contingency plan is primarily contained within the national contingency plan. Countries should define cyber crisis responses in stages to respond to emergencies and clearly delineate the roles and responsibilities of all parties involved [29-30].
- **Effective governance.** Many countries adopt specific government agencies, such as the National Cybersecurity Center, to coordinate their cybersecurity initiatives. For effective governance, the government seeks to promote effective cooperation between the public and private sectors and to establish and encourage formal or informal information-sharing exchanges [32].

- **Cyber military and counter-intelligence.** NCSS includes military affairs related to cybersecurity. Some countries separately issued cyber defense strategies from the Department of Defense. Many countries focus on cyber military activities, such as protecting their networks, cyber defense, tactical cyber war, strategic cyber war, and cyber deterrence [23].

## 5 FUTURE LANDSCAPE OF NCSS

On the basis of the NCSS categories identified in the study, this study details future changes in the cybersecurity environment as a result of the AI use. It lists critical considerations for governments.

- **Critical infrastructure protection.** Major critical infrastructures, such as transportation, health care, and energy, are becoming increasingly dependent on AI-ML. Conventional cyberattacks employing machine learning focused on automating attacks. Future cyberattacks that use ML are anticipated to generate new attack vectors utilizing programs, such as genetic algorithms and enhanced learning, as well as systematically infiltrating various systems, such as the cloud, IoT, and industrial IoT/SCADA, resulting in greater damage [2].

  The country should develop successful backstops by actively introducing AI solutions to protect critical infrastructure from AI cyberattacks by malicious actors [33]. To this end, major infrastructure cybersecurity teams should reliably introduce and deploy AI security systems using various methods, such as systems and network testing, traffic analysis, and identification of normal network behavior. In addition, they should host spam filters to block malicious links that may contain malware, conduct routine system checks, and update security monitoring. These systems should be highly robust and enhance the resilience of systems against unanticipated cyberattacks.

  Meanwhile, these AI solutions necessitate dedicated personnel for system management. The government requires personnel to train the AI, monitor the threat identification results of the AI security system, and ascertain whether the identified threats are in fact threats. Therefore, the government should consider how to recruit new AI-skilled staff and how to retrain existing security staff [34].

- **Foster Cybersecurity Culture.** Several security systems are already using monitoring systems to identify suspicious behavior and criminal activities. The integration of AI-ML functions in the monitoring system has enabled the processing of information, images, and audio on a larger scale. In addition, AI monitoring systems are likely to detect unauthorized humans and devices in significant quantities, by combining physical security to complement endpoint telemetry, logs, and network data with security cameras and device webcams [35].

  These changes will make it easier for countries to monitor their citizens and will reduce the associated costs [22]. Several future AI security monitoring systems designed for everyday life may not integrate value systems that consider human rights. AI technology will significantly impact basic human rights [22], including privacy, surveillance, and control, which are likely to be of the most significant issues of contention. Therefore, striking a balance between people's fundamental rights and cybersecurity will be more important than ever. Citizens will be increasingly interested in when, where, and how AI systems are used by government agencies, and the kinds of biases in AI data [36-37].

  The NCSS must consider ways to disclose how AI security systems and data are collected, stored, protected, shared, and managed to strengthen the government's credibility and ensure that national interests are intact. Furthermore, standards that encourage the ethical use of AI to balance basic human rights and security must be developed. Decision makers of NCSS should explicitly consider how to develop such a standard by establishing a council, committee, or task force. Finally, the government should strive to enhance security awareness through AI ethics education on the dangers of AI misuse and accidents targeting various actors.

- **Public-Private Partnership.** The AI security environment is a structure that cannot achieve desired results through governments or businesses alone. The success of the AI security strategy depends on the cooperation and active participation of the private and public sectors. Rather than attempting to solve AI-related problems independently, decision makers and the national security community should discuss how to collaborate with AI companies. To achieve satisfactory technical outcomes in various aspects, such as safety, security, sustainability, and long-term planning of AI security system development, continuous government investment and incentives that can be provided to companies must be considered [22]. Furthermore, while maintaining active partnerships with the private sector, cybersecurity policymakers must also establish internal guidelines on how much the country can rely on the private sector to develop AI security capabilities, or what capabilities the government should develop internally.

- **Training and Educational Program.** At the workforce level, AI use in cybersecurity has the following advantages. First, the workload of the security team is reduced. Cyber security analysts spend considerable time reviewing security logs and incident records. When AI takes care of a time-consuming and straightforward tasks, the cybersecurity analyst can spend more time and effort analyzing accidents identified by AI-based cybersecurity systems. Second, human errors and oversights can be reduced. AI-based technologies and robotic process automation technologies will ultimately strengthen the cybersecurity team's capacity to cope with low-level security threats, such as ransomware, malware, and crypto mining, among others. Finally, models can be tailored to the specific needs of the operator. Machine learning performs better on specific tasks than on a broad range of tasks [2].

When companies or nations struggle to find qualified cybersecurity professionals, AI can be a viable alternative. AI security systems cannot, however, replace every aspect of cybersecurity. Particularly, machine learning, which focuses primarily on security, is most effective when it assists "human" analysts. Utilizing AI, cybersecurity professionals should concentrate on new forms of precision threats. Therefore, AI-powered cybersecurity training should be included in the education of future cybersecurity experts.

The NCSS must consider such training and education in the future; for example, how to improve the accuracy and efficiency of security systems using ML as well as measures to compensate for weaknesses in AI systems, among others. AI security education includes re-education and retraining of existing experts, as well as newly introduced experts.

- **Effective Governance.** Effective governance is crucial for AI cybersecurity success. NCSS has not mandated a single governance structure to clarify the nation's cybersecurity strategy to date. To effectively respond to the AI cybersecurity environment, the NCSS of the future should establish a transparent, ethical, all-encompassing, and unified AI cybersecurity governance [33]. There is a need for a standardized method of collecting and organizing the government's information on its citizens.

Governance of cybersecurity that is centralized requires the assignment of roles and responsibilities across all organizations. Moreover, such governance should include defining the role of cyber analysts, monitoring the output of algorithms, detecting abnormal behavior, identifying the risk tolerance range of the output of algorithms, establishing alternative plans in the event that algorithms fail, and defining performance metrics that objectively measure AI success.

- **Cyber Military and Counter-Intelligence.** The military will utilize AI for multiple purposes, including defense and offense. It will aid in accelerating cyber operations. Specifically, the military can use AI systems to collect vast quantities of data from enemy forces and take advantage of the increasingly asymmetrized strategy of modern warfare. The arms race of an Autonomous System is a crucial concern, as it ranges from simple upgrades and more effective weapons to the development of fully autonomous weapons and killer robots.

AI systems and automated weapons will continue to remain an issue in the near future because no consensus exists on the available configurations for their use in the military. In addition, the military is considering adopting autonomy in the command chain using an AI security system based on data within an acceptable. The problem is that AI-automated security systems are likely to significantly impact deterrence and escalation dynamics. In the case of deterrence, people sometimes give up their arguments for better decisions in the decision-making process, but that is not possible in automation systems using AI [22]. Future NCSS must develop AI principles to guide the ethical and responsible use of AI in the military, and establishing clear international standards

should be a major priority. In addition to the introduction of AI systems, it should consider how relevant personnel, such as AI security experts, can be recruited, educated, and trained to adapt to the military's unique culture.

- **Data Management: Categories to Add.** AI effectively collects, organizes, and analyzes vast amounts of data, enabling organizations to derive more value from the data. Data are the core of AI implementations and cybersecurity. AI security systems build models on the basis of data and determine the construction of proactive protection functions, the timing of alarm issuance, the determination of countermeasures to potential threats, and the response to abnormal actions. For AI technology to be effective in a cybersecurity environment, AI algorithms must be driven by the correct data system. Security data can lead to effective results only if it can provide detailed information about events that have occurred within AI security systems, such as machines, applications, protocols, and network sensors. Therefore, the NCSS of the future should consider proper access and the management of AI security data. The NCSS data strategy should be organically linked to the main content of national security and the national data strategy.

Meanwhile, the goal of future cyberattacks involves manipulating data and algorithms, as well as simply attacking major infrastructure. Data manipulation and algorithmic interference not only have a decisive impact on decision makers but can also cause unintended conflicts and disputes, such as political friction between countries and escalations into war. Governments must provide a coherent, transparent, and standardized governance framework for sharing different data sets among government agencies, researchers, and the private sector, in conjunction with national data strategies. This framework should be aligned with the governance framework proposed by International Organization for Standardization (ISO) and Organisation for Economic Cooperation and Development (OECD).

## 6 CONCLUSION

The cybersecurity environment is vast and intricate, and we cannot accurately predict all the changes that will occur because this requires a great deal of trial and error, time for the introduction of new technologies, and stable social and institutional shifts. This study introduces, at an elementary level, the changes in the cybersecurity environment that will be applied to AI in the near future and the policy priorities accordingly. On the basis of the research analysis, this study predicts the future landscape that the NCSS will encounter due to the effects of AI.

The predictions are as follows: First, even though the NCSS's scope and function have been expanding over the past decade, the implementation of AI will result in further expansion. This is a natural consequence of the cyber domain permeating the social community gradually. Cybersecurity and artificial intelligence are closely intertwined, and cybersecurity is not only a security domain but also a broad domain that encompasses critical infrastructure sectors and other social domains. For a nation to successfully build an AI security environment, national policies must be incorporated

into goals and plans. The NCSS will play a crucial role in presenting the country's common goals and direction to other high-level national strategies, such as national security and defense strategies, AI strategies, information system strategies, national digital safety strategies, and big data strategies.

Second, the NCSS must establish a cybersecurity environment in which humans and systems can work together. AI-based cybersecurity solutions require close partnerships between people and systems, and in the near future, the coexistence of humans and AI security systems will become critical in the agenda for the cyberspace domain. Many people in the AI marketing industry assume that AI-based cybersecurity technology can easily replace humans. The ability to collect and process vast amounts of information is important, and AI will affect the diagnosis, decision making, and evaluation of the national security strategy establishment. However, even though AI positively improves many areas of the cybersecurity environment, AI-based security systems cannot yet fully and automatically adapt to environmental changes. In the near future, while AI technology is still not completely developed, a national-level discussion on the interdependence of AI systems and human factors is warranted, and highly trained security teams will continue to play a key role in the final decision-making stage in detecting, identifying, and protecting various cybersecurity threats.

This study is significant in that it explains the policy implications of adopting the evolving cybersecurity environment and provides insights into the evolution of the cybersecurity landscape. This study is an excellent starting point for comprehending the ebb and flow of NCSS within the AI cybersecurity environment. Given that the development and implementation of AI technology remain in their infancy, precisely analyzing changes in the nation's AI cybersecurity strategy and proposing countermeasures are challenging.

Future research must aim to understand national and global trends by specifically comparing and analyzing changes in national strategies in the AI cybersecurity environment on the basis of the NCSS and national AI strategies described by current countries.

## Acknowledgments

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# Design of Efficient Phishing Detection Model using Machine Learning

Bong-Hyun Kim

**Abstract:** Recently, there have been cases of phishing attempts to steal personal information through fake sites disguised as major sites. Although phishing attacks continue and increase, countermeasures remain in the form of defense after identifying the attack. Therefore, in this paper, we designed a phishing detection model using machine learning that provides knowledge and prediction by learning patterns from data input to a computer. For this, an analysis model was built using sklearn logistic regression, and the phishing probability was visualized using a heatmap. In addition, a graph was used to visually indicate the result, and a function for attribute information of a phishing website was provided.

**Keywords:** ensemble method; heatmap; machine learning; phishing detection; random forest; sklearn

## 1 INTRODUCTION

Many victims occur every year as a result of deceiving others over the phone or the Internet, or stealing identity or financial information through phishing, pharming, and smishing. Until recently, there have been cases of phishing attempts to steal personal information through fake sites disguised as major sites. Although phishing attacks continue and increase, countermeasures remain in the form of defense after identifying the attack [1]. A phishing site refers to a malicious web site that requests personal and financial information from users through a web page similar to the real thing and causes various attacks, particularly financial damage. The attacker composes and sends an attack email or message to the user, convincing the user to connect to a spoofed server [2]. If the page displayed by the spoofed server is mistaken for the real server and personal information is entered, the information is delivered to the attacker who manages the spoofed server. Actual phishing attack methods and routes vary by phone call and text message.

In computing, phishing is the act of using e-mail or messenger to deceive by pretending to be a message from a trusted person or company. This deception is a form of social engineering that attempts to fraudulently obtain confidential information such as passwords and credit card information. As reports of phishing incidents increase, methods to prevent phishing are needed. These methods include law, user training, and technical tools. Recently, in addition to phishing using a computer, phishing using a phone is also called voice phishing. There are many different types of phishing.

To prevent and minimize this damage, we are working to eradicate phishing scams worldwide. Korea stipulates punishment for fraud under the "Criminal Act", punishment for telecommunication financial fraud under the "Special Act on Prevention of Damages from Telecommunication Financial Fraud and Refund of Damages", and penalties for falsification and false display of phone numbers under the Telecommunications Business Act. Since 2012, a comprehensive government-wide response system has been prepared and operated [3, 5].

The US federal government has the "Identity Fraud and Impersonation Prevention Act" and the "Identity Fraud Enforcement Punishment Act" to protect personal information. In addition, states such as California, Florida, and Illinois have state-level phishing fraud prevention laws. Currently, the "Fraud and Scam Prevention Act" to protect the elderly who are susceptible to fraud has passed the US House of Representatives and is before the Senate [4].

Similar to Korea's legal system, Japan is governed by the Act on the Prevention of Illegal Use of Mobile Voice Communication Services and Identification of Contractors by Mobile Voice Communication Operators, and the Payment of Damages Recovery Contributions with Funds from Criminal Use Accounts, etc. In addition, phishing fraud prevention policies are being strengthened for the elderly, such as making alert calls to the elderly or subsidizing the purchase cost of a preventive phone equipped with an automatic recording function. In Europe, central banks and payment system operating organizations are publicizing the risk of phishing scams by disclosing information that analyzes payment method fraud data. As the criminal methods and means of phishing scams become more sophisticated and complex, a comprehensive and continuous response is required in the future. In particular, it is necessary to strengthen individual preventive measures for the elderly, who are vulnerable to phishing scams such as the United States and Japan. In addition, telecommunication companies, platform companies, and banks should actively respond to new phishing scams due to technological advancements and changes in communication usage methods [6].

Deep learning achieves higher levels of recognition accuracy than ever before. This accuracy can meet user expectations in consumer electronics and is critical in safety-critical applications such as driverless vehicles. Recently, advances in deep learning have advanced to the level of outperforming humans in some tasks, such as classifying objects in images through deep learning. In this paper, fraud detection and sales prediction were performed using deep learning. To this end, the performance of each model that can be used for data analysis was investigated and a machine learning model suitable for the situation was adopted.

Therefore, in this paper, we designed a phishing detection model using machine learning that provides knowledge and prediction by learning patterns from data input to a computer. For this, an analysis model was built using sklearn logistic regression, and the phishing probability was visualized using a heatmap. In addition, a graph was used

to visually indicate the result, and a function for attribute information of a phishing website was provided.

## 2 RELATED WORKS
### 2.1 Phishing

Phishing is an attack method that has been in use since the mid-1990s. It started with a group of young people designing AOL's chat room feature to impersonate an AOL administrator. AOL's 'New Member Chat Room' is designed to provide users with site access assistance. The hackers created valid AOL admin screens like 'BillingAccounting' and alerted users to an account problem. Phishing was created to understand illegal and similar attacks. However, it is currently mainly used in connection with fraudulent activities using e-mail. Also, these illegal phishing scams continue to this day [7, 8].

First, an attack using social engineering is a way to convince users to do something they wouldn't normally do. It is to install a malicious program on a computer using an external device and cause a security problem. Next, an attack using a general e-mail is a method of attacking using a generally frequently used e-mail address [9, 10].

A phishing attack is a set of actions taken by hackers to take advantage of users. Email phishing scams are often easy to spot because of grammatical or misspelling errors in emails, but attackers have become more sophisticated and have evolved to use human emotions, including fear, anger, and curiosity, to entice victims. There are different types of phishing attacks [11, 12]. These include classic email attacks, social media attacks, and attacks with multiple names such as smishing and vishing. Tab. 1 shows definitions of common harmful attack types.

**Table 1** Harmful attack type

| Type | Concept |
| --- | --- |
| Phishing | usually done by e-mail |
| Spear phishing | segmented e-mail |
| Whaling | highly targeted emails typically aimed at executives |
| Internal phishing | Phishing attacks that originate within an organization |
| Vishing | attack with phone calls |
| Smishing | done by text message |
| Social media phishing | attacks using Facebook or other social media posts |
| Parming | DNS cache corruption |

There are several characteristics of phishing. Using email to pretend to be a trusted email address. Most of the phishing emails impersonate the sender. For example, if a scammer deceives into being Citibank, in this case, it is sent randomly by disguising as a normal e-mail address such as "info@citi.com". You will be asked to enter your credit card number or password. This is the ultimate goal of phishing scammers. Never enter such information. Not detected by antivirus software. This is because, in the case of a phishing scam, the URL can be hidden as an HTML mail without any attachments in the form of a simple mail without any features. HTML mail that attacks attachments or vulnerabilities is distinct from phishing. You don't need any

special skills other than the skills to create a website. A phishing scam is a way to create websites and send emails. Anyone can make it because the technology is the only technology to create a website. Making it look like a large company site isn't too difficult, as you can pull the HTML source and photos from the actual website.

In the case of existing phishing detection technologies, blacklist-based detection is easy to implement and has a low false positive rate, but there is a limitation in that unknown phishing sites cannot be detected, such as problems that antivirus solutions face. In particular, in the case of Korea, it is difficult to detect phishing sites using blacklists because there is an insufficient system for collecting and sharing blacklists of phishing sites in Korea compared to overseas. In addition, the URL structure analysis technique has a limitation that the detection rate can be greatly reduced even if the attacker changes the URL pattern even slightly.

Various existing phishing-related detection algorithms and studies have been conducted. Phishing detection for mobile browsers, phishing detection using minimum classification error method, and phishing site blocking method using domain characteristics were studied. To detect phishing sites, blacklist-based, HTTP referrer detection, and heuristic-based methods have been studied to detect phishing sites. However, a phishing detection study was conducted using the data analysis and prediction technology in a situation where research was insufficient.

### 2.2 Machine Learning
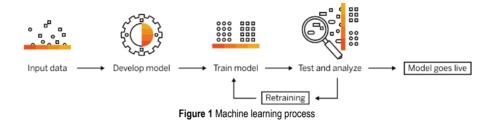
Machine learning is one of many subsets of the currently trending technology, artificial intelligence. Instead of explicitly programming computers to learn and improve, the focus is on training computers to learn from data and improve through experience. Machine learning applications improve through application and become more accurate as the data available increases [13].

Machine learning helps businesses by driving growth, unlocking new revenue streams, and solving tough problems. Data is a key driving force behind business decisions, but in the past, businesses have used data from a variety of sources, such as customer feedback, employees, and finance. Machine learning research automates and optimizes this process. Companies can get results faster with software that analyzes very large amounts of data at high speed.

Machine learning and its components deep learning and neural networks are all a detailed subset of AI. AI processes data to make decisions and make predictions. AI not only processes data with machine learning algorithms, but also makes it intelligent as it learns the data without additional programming. Artificial intelligence is a superset that encompasses all machine learning-related subsets. The first subset is machine learning, which has deep learning within it and neural networks within deep learning.

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programming. Artificial intelligence is a superset that encompasses all machine learning-related subsets. The first subset is machine learning, which has deep learning within it and neural networks within deep learning [14, 15, 20, 21].

Machine learning consists of several types of machine learning models that apply different algorithmic techniques [22]. Depending on the nature of the data and the desired outcome, one of four learning models can be applied: supervised, unsupervised, semi-supervised, or reinforcement. You can apply one or more algorithmic techniques within each model, depending on the data set being used and the desired results. Machine learning algorithms are primarily designed to classify things, discover patterns, predict outcomes, and make informed decisions [16, 17]. Algorithms can be used one by one, or multiple algorithms can be combined for maximum accuracy when complex and more unpredictable data is involved [18, 19]. Fig. 1 shows the process of how a machine learning process works.



**Figure 1** Machine learning process

In this paper, we analyzed the efficiency of phishing detection using deep learning framework and ensemble technique. That is, machine learning classification and regression machine learning models were compared, and through this, which model performed better was evaluated. In conclusion, this paper is a phishing detection study using machine learning that provides knowledge and predictions by learning patterns from data input to a computer. An analytical model is built using logistic regression of sklearn as a research method. A heatmap is used to visualize and indicate the phishing probability. Then, the results are visualized and displayed using graphs.

## 3 DATA COLLECTION AND TRANSFORMATION

In this paper, using the supply chain data set used by DataCo Global, the region, payment method, and customer where sales fraud was detected were derived. Unlike previous studies, we implemented a methodology to compare machine learning classification and regression machine learning models. In particular, deep learning frameworks Tensorflow and keras were used, and ensemble techniques XGBoost and LightGBM were used. Through this methodology, we analyzed which model performed better and predicted fraud detection and sales.

For data collection and transformation, import pandas, a library that can handle table types often used in data analysis. It also imports numpy, a library that makes mathematical operations easy. Import the matplot library to draw graphs. Finally, we import the seaborn library to visualize the data. Loading data uses the pandas read_csv method to load csv data. The datasets were provided by Kaggle and used.

To improve data utilization, the data were transformed and applied to the study. Converts float64 and int64 data to float32 and int32, respectively, to save memory usage. The final data has 10,000 rows and 50 columns including labels. Fig. 2 shows the final data set after data conversion.

```python
float_cols = data.select_dtypes('float64').columns
for c in float_cols:
    data[c] = data[c].astype('float32')

int_cols = data.select_dtypes('int64').columns
for c in int_cols:
    data[c] = data[c].astype('int32')

data.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 10000 entries, 0 to 9999
Data columns (total 50 columns):
 #   Column             Non-Null Count  Dtype
---  ------             --------------  -----
 0   id                 10000 non-null  int32
 1   NumDots            10000 non-null  int32
 2   SubdomainLevel     10000 non-null  int32
 3   PathLevel          10000 non-null  int32
 4   UrlLength          10000 non-null  int32
 5   NumDash            10000 non-null  int32
 6   NumDashInHostname  10000 non-null  int32
 7   AtSymbol           10000 non-null  int32
 8   TildeSymbol        10000 non-null  int32
 9   NumUnderscore      10000 non-null  int32
 10  NumPercent         10000 non-null  int32
 11  NumQueryComponents 10000 non-null  int32
 12  NumAmpersand       10000 non-null  int32
 13  NumHash            10000 non-null  int32
 14  NumNumericChars    10000 non-null  int32
 15  NoHttps            10000 non-null  int32
```

**Figure 2** Part of the final data set after data transformation

## 4 ANALYSIS AND PREDICTION
### 4.1 Data Analysis

In this paper, we designed a phishing detection model using machine learning that provides knowledge and prediction by learning patterns from data input to a computer. For this, an analysis model was built using sklearn logistic regression, and the phishing probability was visualized using a heatmap. In addition, a graph was used to visually indicate the result, and a function for attribute information of a phishing website was provided.

To analyze the data using the final data set, correlations were calculated. For correlation, def.corr() was applied. By analyzing the Spearman correlation, a function with a linear correlation was derived in terms of predicting the phishing classification of a website. Also, the derived results were visualized with a heatmap. Fig. 3 visualizes the results of correlation analysis with corr_heatmap(data, 0, 10).

**Figure 3** Result of analysis with 'corr_heatmap(data,0,10)' setting
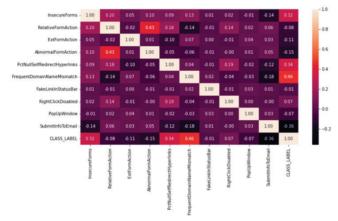


**Figure 4** Correlation analysis result according to 'corr_heatmap(data,30,40)' setting

As can be seen from the results, looking at the first 10 columns, we can see that there are no features that have a strong correlation with the label. On the other hand, NumDash has a negative effect on labels, so it can be seen that the lower the number of Dash, the more likely it is a phishing site. In the same way, even under the corr_heatmap (data, 10, 20) and corr_heatmap (data, 20, 30) setting conditions, a strong correlation function was not derived for the label. However, in the analysis set with corr_heatmap(data, 30, 40), it was found that the correlation function of intensity was derived from the label. Fig. 4 is a visualization of the correlation analysis results according to the corr_heatmap (data, 30, 40) setting.
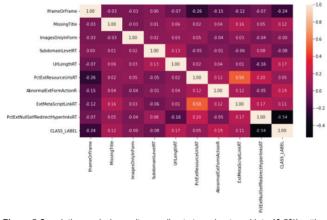


**Figure 5** Correlation analysis result according to 'corr_heatmap(data,40,50)' setting

The higher the value of 'InsecureForms', the more likely it is to be a phishing site. 'PctNullSelfRedirectHyperlinks' shows the same positive correlation as 'InsecureForms'. 'SubmitInfoToEmail' is a site that asks users to expose detailed information in their emails, indicating a higher chance of phishing.

In addition, in the result of setting corr_heatmap(data, 40, 50), the phishing probability increases when a 'null self-redirect' hyperlink occurs because it negatively affects the label in the left column 'PctExtNullSelfRedirectHyperlinksRT'. Fig. 5 is a visualization of the correlation analysis results according to the corr_heatmap(data, 40, 50) setting.



**Figure 6** Interdependency measurement results using Mutual Information
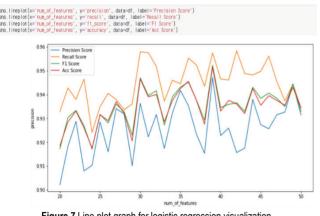
In addition, to analyze the information dependence between each other, Mutual Information was applied. Mutual information refers to a method of measuring how interdependent random variables. Find linear and non-linear correlations between labels. Fig. 6 shows the results of measuring interdependence using Mutual Information.

### 4.2 Data Prediction

In this paper, a phishing detection technique using machine learning that provides knowledge and prediction by learning patterns from data input to a computer by itself was studied. To this end, an analysis model was built using logistic regression of sklearn, and a random forest method was finally applied for data prediction.

First, a line plot graph was used to visualize logistic regression analysis. To do this, import the module that provides evaluation metric calculations from the sklean.metrics package. In addition, a line chart was used to visualize and group data trends. As evaluation indicators, the number of features was visualized as a graph with accuracy, precision, recall, f1_score, and performance evaluation indicators were output. Fig. 7 visualizes logistic regression analysis using a line plot.

Next, a visualization of the performance was performed using a random forest to improve the logistic regression baseline. Random forest is an ensemble method for learning

multiple decision trees. Random forests are being solved for various problems such as detection, classification, and regression. In the final random forest model, 32, the number of features of the model that performed best in all evaluation metrics, were applied. In addition, a final random forest model was trained based on the optimal n features, and used sort values, a method for sorting labels based on values.



**Figure 7** Line plot graph for logistic regression visualization
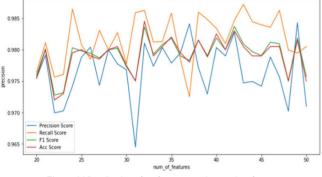


**Figure 8** Visualization of performance using random forest

As a final prediction result, accuracy = 0.947162, precision = 0.957468, recall = 0.952287, and f1_score = 0.9515 were derived. Fig. 8 shows the final output of performance visualization using random forest.

## 5 CONCLUSIONS

Recently, there have been cases of phishing attempts to steal personal information through fake sites disguised as major sites. Although phishing attacks continue and increase, countermeasures remain in the form of defense after identifying the attack. Typically, an attacker composes and sends an attack email or message that induces the user to connect to a spoofed server. If the page displayed by the spoofed server is mistaken for the real server and personal information is entered, the information is delivered to the attacker who manages the spoofed server. Actual phishing attack methods and routes vary by phone call and text message.

Accordingly, a method for effectively preventing phishing is to predict and prevent in advance. To this end, a typical technique used is to design and build a predictive

model using machine learning. Machine learning is an effective analysis method suitable for a rapidly changing big data environment with a lot of data related to the problem to be solved.

The phishing detection project using machine learning techniques performed regression analysis using sklearn, a machine learning library. Therefore, in this paper, we constructed a phishing detection model using machine learning that provides knowledge and prediction by learning patterns from data input to a computer. Finally, in the prediction model results, the accuracy was 0.947162, the precision was 0.957468, the recall was 0.952287, and the f1_score was 0.9515, respectively.

Through this study, it can contribute to information protection by efficiently detecting phishing, a type of social engineering. In addition, it does not waste a lot of manpower and time by using machine learning as a security solution to prevent phishing attacks. Sites suspected of being phishing can be detected through the judgment stage and significant damage can be prevented.

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# AI-based Electric Fire Detection State Judgment Data Set Construction

Hee-Chul Kim

**Abstract:** In this paper, we create a virtuous cycle ecosystem of AI data for judging electric fire status. Data collection reflects feedback on inspection results such as collection of electric fire status judgment data through cloud sourcing and purification, processing, inspection and data disclosure of the collected data. It is necessary to determine the cause of the damage through fire forensics in order to confirm the property damage caused by the fire. The damage investigation so far is based on the experience of the investigator, and it is difficult to conduct a sufficient investigation and analysis of multiple fires. Accordingly, by building a data set for AI learning for the cause analysis of electric fires, The AI composition that can overcome the subjective and unprofessionalism of the forensic of electric fires is made. Therefore, we study the reliability and system development feasibility of digital conversion of fire detection report and data for AI learning.

**Keywords:** 1st dragon mark; 2nd dragon mark; cause of fire; electric fire; electrical fire causes; fire detection; melt marks

## 1 INTRODUCTION

The digital conversion of the fire status survey report and its use as data for AI learning (fire occurrence, dispatch date, fire location, cause, ignition-related equipment, damage situation, weather situation, etc.). It reminded us of the importance of fire forensics to check fire property damage [1]. In case of electrical accidents such as electric overload, trekking, compression damage, insulation breakdown, and short circuit, the metal is melted by arc or Joule heat and then re-solidified molten traces occur [2].

There are two types of melt marks: the primary short-circuit marks generated by a short circuit after the wire coating is lost, and the secondary short-circuit marks generated by the short circuit after the wire coating is lost due to the heat of a fire. And after melting by the heat of fire, the molten trace solidified again is called a fissure trace [3, 4]. It is absolutely necessary to establish an electric fire-related data set to identify the ignition point and cause of such a fire site.

In response to the need to apply AI for fire detection, fire forensics analyzes the cause of an accident, and can be used as basic data in various ministries such as the police, insurance, firefighting, and safety and disaster centers. In the case of CCTV, which can reveal the cause of the fire, it is damaged in case of fire or is not installed inside the house, so it has a low possibility of use [5]. To overcome this limitation of manpower, fire detection using AI is needed. The areas of interest for each subject of fire detection are different, providing fire detection data from various perspectives and remotely performing fire detection, overcoming the limitations of fire detection personnel and effectively managing disaster situations [6].

To promote the policy of expanding the application of intelligent information technology in in response to the 4th industrial revolution, the basic plan for national digital transformation through intelligence is established and the scale of the national informatization field for ICBM (IoT, Cloud, Bigdata, Mobile) related technologies is continuously expanding. Accordingly, data set construction requires a large amount of manpower and time for large-large-scale data collection. In addition, in order to expand the application of cutting-edge technology for the identification of the cause of fire, the vision for building AI/big data, future radiance, and governance and the realization of a disaster safety digital platform were made. In addition, the digital conversion of the fire investigation report and its use as data for AI learning (fire occurrence, dispatch date and time, fire location, cause, ignition-related equipment, damage situation, weather situation, etc.)

Fire-related property damage continues to increase from 2011 to 2020, and the amount of damage is close to 600 billion won as of 2020. In order to classify victims only by identifying the cause of damage through fire forensics, it is necessary to identify the cause in other fields, such as the police and insurance, in addition to firefighting. The fire investigation so far is a method based on the experience of investigators, and it is difficult to sufficiently investigate and analyze many fires.

Therefore, in this paper, the construction of the state judgment data set for the AI-based electric fire detection is designed in Chapter 2 the construction of data for AI learning and the refinement work In Chapter 3, we analyzed the state of scars and traces for data acquisition, and in Chapter 4, we developed an AI data utilization model.

## 2 RELATED WORKS
### 2.1 Building Data for AI Training
#### 2.1.1 Electric Fire Status Judgment Data
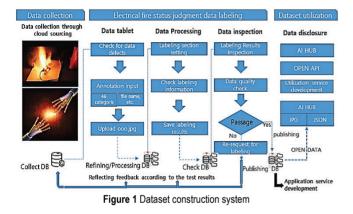
From 2011 to 2020, the occurrence of electric fires accounted for 20%. The limitation of the fire-related data management system is that only statistical data disclosed by the National Fire Agency through the National Fire Information System are provided, so there is a limit to the use of artificial intelligence [6]. In the case of fire detection, it plays an important role not only in firefighting-related fields, but also in insurance, police, and fire recovery [7]. In particular, a high-level objective/reliable analysis report is required when the payment of damage recovery costs is determined according to fire detection.

## 2.1.2 Building Data for Artificial Intelligence Learning
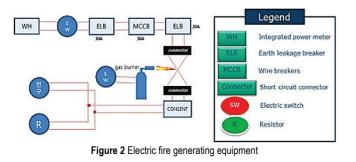
In the data construction environment for artificial intelligence learning, a data set construction system is used as shown in Fig. 1 for data collection, electrical fire status determination data labeling, and data set utilization [8]. By accumulating the experimental data of the 1st dragon mark, the 2nd dragon mark, and the fissure, it builds a data set to provide a solution by building a system that can determine the cause of a short circuit through Ai-based situation recognition/judgment. Build an electric fire cause analysis system using AI as a data set for AI learning. The cause of fires occurring in these various environments is excluded from errors that occur depending on the individual ability of the monitor, and the results of the inspection are presented with high objectivity. It is for the development of a fire detection service that enables smooth progress of administrative services such as insurance related to recovery after an accident by quickly analyzing the cause of the accident.



**Figure 1** Dataset construction system

A data set is built by classifying electrical related short circuits that occur in the event of a fire in the fire situation data into fire causes (primary dragon marks) and non-fire causes (secondary dragon marks, heat marks). Digital conversion work is carried out by securing the wire deformation form of 5 types of wires can be mainly identified at the fire site as raw data.

## 2.2  Raw Data Collection Method

Raw data is collected through electric fire generating equipment as shown in Fig. 2.



**Figure 2** Electric fire generating equipment

The short circuit of the first melting mark is tested at room temperature and at a high temperature ranging from about 2,000 to 6,000 °C at the moment of short circuit. This causes a phenomenon in which the surface of the metal is melted in an instant, and the short-circuited part is scattered or the power is cut off. Here, the experiments are collected using the generation equipment under safe and standardized experimental conditions [9].

## 2.3  Raw Data Purification

It utilizes cloud based data storage that can collect and store large-scale data. A distributed development environment software development tool that enables collaboration in a distributed environment is used.

A computer system capable of processing multimedia using stable high-speed Internet/infranet capable of sending and receiving large amounts of data is required [10, 11].

To strengthen data transmission efficiency, cloud sourcing is applied and a system that can be transmitted quickly on the web is built. After reading the image stored in the server to the PC, it creates JSON and saves only JSON to improve work efficiency. In this data purification process, clear data purification standards are established according to the purpose of data construction, data types, and domain characteristics. In the refining step, after setting the objects required for data labeling, the data is refined according to the standards required for data for artificial intelligence learning [20]. Data purification uses tools (software) and applies methods such as exclusion or transformation according to set rules, and methods of visually checking and inspecting data by the operator [12, 13, 19].

The quality measurement standards that occur in the process of inspecting the purification and labeling results are somewhat emotional and subjective for each individual. A clear result that an individual inspector can be sure of is marked ○, and even a slightly unclear result is marked with △, and the final quality evaluation is requested by an expert. The evaluation results of experts are immediately fed back to individual inspectors, so that inspectors can share the evaluation criteria of experts and maintain consistent quality measurement standards in the future [14].

## 3    DATA ACQUISITION
## 3.1  Generation of Raw Data by Primary Dragon Marks

The primary short-circuit marks are melt marks that occurred before the fire or that the insulation material was damaged due to a fire and then short-circuited. When an electric short occurs, a large current of 2,000 A to 3,000 A is generated and high-temperature heat is generated. Although a fire can be caused by a spark generated by a short circuit, the current flows back and damages electrical equipment and equipment. Install an earth leakage breaker and a circuit breaker after the primary power switch to install safety equipment so that the breaker operates immediately when a large current occurs.

For the primary short circuit scar generation method, apply commercial power (220 V, 60 Hz) as shown in Fig. 3.

In a situation where loads (light bulbs and electrical facilities) are connected, an electrical short circuit (SHORT CIRCUT) is generated by artificially shorting the + and - lines between the electrical short connectors. At this time, the generated molten wire is used as raw data [15].
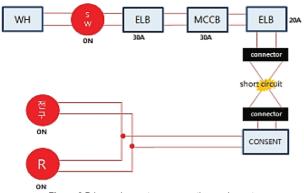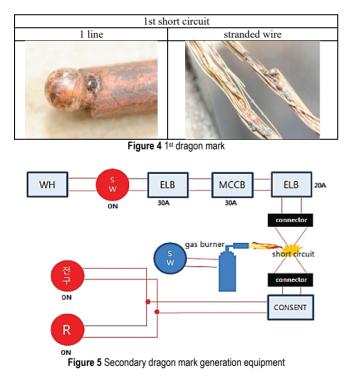


**Figure 3** Primary dragon trace generation equipment

### 3.1.1 Data Acquisition by Primary Short Circuit

Fig. 4 is the raw data generated by collecting the primary short circuit traces that lead to fire when the wiring sheath is short-circuited due to insulation deterioration or physical external force.

| 1st short circuit | |
| --- | --- |
| 1 line | stranded wire |
|  |  |

**Figure 4** 1st dragon mark



**Figure 5** Secondary dragon mark generation equipment

### 3.2  Generation of Raw Data by Secondary Dragon Marks

Fig. 5 shows the situation in which commercial power (220 V, 60 Hz) is applied and the load (light bulb and electrical equipment) is connected as the second method of melting traces. The gas burner is operated between the electrical short connectors to artificially melt the + and –

wires with a flame to generate an electrical short circuit (SHORT CIRCUIT), and then use the molten wire as raw data [16].

### 3.2.1 Data Acquisition by Secondary Dragon Marks

Fig. 6 shows the selection of secondary traces that are short-circuited due to burning of the wire sheath due to the heat of the fire.

| 2nd dragon mark | |
| --- | --- |
| 1 line | stranded wire |
|  |  |
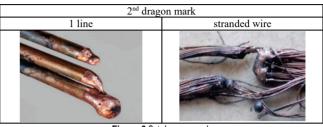
**Figure 6** 2nd dragon mark

### 3.3  Generate Fifteen Raw Data

The heatstain generation method is a method to check the cause of the fire when the commercial power (220 V, 60 Hz) and the load (light bulb and electrical equipment) are cut off. The gas burner is operated between the electrical short-circuit connectors regardless of the fire as traces of metal such as wires being melted by the heat of fire. After artificially melting the + and – wires with flames, the molten wires are used as raw data [17, 18]. Fig. 7 shows the selection of the heat traces from the molten wire due to the heat of fire in a state in which electricity is not energized.

| forty | |
| --- | --- |
| 1 line | stranded wire |
|  |  |
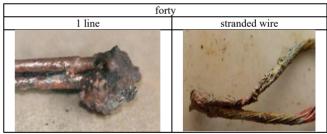
**Figure 7** Forty

### 3.4  Utilize Data for Artificial Intelligence Learning
### 3.4.1 Use of Electric Fire State Judgment Data Set

It is a service cooperation that utilizes data such as external companies, institutions, and individuals built to support the construction of platforms and portal sites. It supports technology by discovering services in AI technology based on electric fire status judgment data and utilizing user community. Here, for the feedback and update of the electric fire state judgment dataset published through the AI hub, the required service item extraction and interface are provided through the modular implementation of the Open API. UI/UX implementation according to usability through individual provision it implements UI/UX according to usability through the extraction of necessary service items and individual provision of interfaces through modular

implementation of Open API. Fig. 8 shows the linkage with various DBs through modularization of domestic and overseas DBMS linkage adapters.
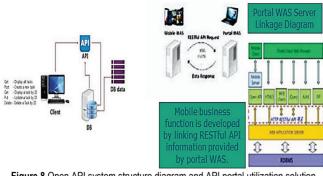


**Figure 8** Open API system structure diagram and API portal utilization solution WAS connection processing diagram
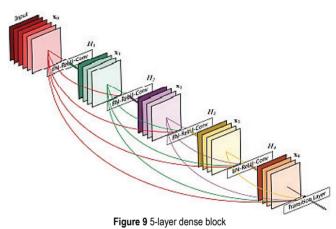
### 3.4.2 Spread of Data for AI Learning

In building a data value chain ecosystem, a value chain ecosystem is established by discovering new values through public-private data connection and openness for the combination/analysis of various heterogeneous data. Data-related technology development and decision-making tool R&D support, data and artificial intelligence infrastructure reinforcement, AI manpower expansion, and cooperative ecosystem are established. Create a data business and establish a data-centered virtuous cycle system by strengthening data access/analysis/utilization by preparing legal data distribution methods. In order to support the infrastructure to utilize data from all industrial fields linked to the AI cluster, data from the national/social/industrial fields are integrated and managed by the AI cluster. Data utilization infrastructure support measures such as space and computing resources for public-private data linkage are also needed. In addition, it is necessary to support the improvement of data utilization capabilities by securing know-how for data utilization and profit creation through active cooperation with overseas advanced companies, and accumulating experience in conducting business. To secure IoT sensor data, which is a prerequisite for securing source data, organizations related to the Internet of Things (IoT) industry and corporate cooperatives are formed. In order to increase the utilization of AI Hub, it is necessary to prepare a plan to provide data provider rewards through simplification of the sign-up process, introduction of My Data, and alliances between various companies such as credit card companies. Companies share AI learning datasets by industry group in consideration of the purpose of using data for AI learning. As a shared hub that can spread datasets, a cloud-based learning data sharing center for each industry group is installed to increase the utilization of AI Hub. In order to strengthen data connectivity for AI learning between companies, starting with the standardization of API standard protocols for platform linkage in a global-oriented open ecosystem, a data set linkage system for artificial intelligence learning is configured. Establish an integrated platform and platform operating organization for data set interworking so

that real-time sharing, update, and feedback of data sets for artificial intelligence learning can occur.

## 4 DEVELOPMENT OF AI DATA UTILIZATION MODEL
### 4.1 Electric Fire Status Judgment Data

Data utilization model development for AI learning is a representative dataset CIFAR-10 of SOTA (State of the art) Image classification part. This is a search for model candidates that are open as open source among models with high performance and are customizable and used universally. DenseNet re-uses features by connecting the feature maps of all layers, significantly lowers computational complexity by reducing the number of parameters, and applies SOTA performance to a small number of parameters.



**Figure 9** 5-layer dense block

In Fig. 9, DenseNet consists of 3 Dense Blocks and 2 transition layers. Unlike ResNet, which combines previous information, it is a structure that preserves information by concatenating multiple networks. As a learning method, DenseNet connects all layers to ensure that the flow of information is maximized. Therefore, the input image is passed through the convolution layer to extract features, and then the feature information is connected without merging and transmitted to the next layer.
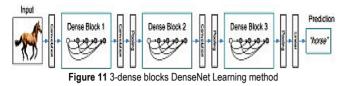


**Figure 10** DenseNet architectures for ImageNet

The Pooling Layer in Fig. 10 is used for downsampling between dense blocks, and when the output comes out to the last dense block through the transition layer that changes the

1×1 conv layer to 2×2 avgPooling, it passes through the classification layer and outputs the result.

As a learning method, DenseNet connects all layers to ensure that the flow of information is maximized. Therefore, the input image is passed through the convolution layer to extract features, and then the feature information is connected without merging and delivered to the next layer.



**Figure 11** 3-dense blocks DenseNet Learning method

In Fig. 11, through the connection, each layer can directly access the loss function and the gradient from the input signal, making it easier to learn features.

### 4.2 Selection of Learning Model Quality Indicators

In the learning method, the graph in Fig. 12 below shows FLOPS (FLoating point Operation Per Second) when width, depth, and resolution are increased, respectively. Width, depth, and resolution all quickly saturate up to 80 % Accuracy, and performance improvement after that is imited. To combine width, depth, and resolution, the depth is set to $\alpha$, width $\beta$, and resolution $\gamma$, and $\alpha$, $\beta$, and $\gamma$ that satisfy $\alpha \times \beta^2 \times \gamma^2 \approx 2$ when $\varphi = 1$ are searched through grid search. Find out. (The values of $B_o$ are $\alpha = 1.2$, $\beta = 1.1$, $\gamma = 1.15$) Here, if $\alpha$, $\beta$, and $\gamma$ are found through grid search, $\varphi(0, 0.5, 1, 2, 3, 4, 5, 6)$ is used to make the final result. To create a factor to multiply the existing width, depth, and resolution and use it.



**Figure 12** ImageNet Top-1 Accuracy of FLOPS according to w, d, r
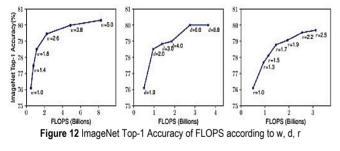
**Table 1** Class model indicator

|  |  | Predicted Condition | |
| --- | --- | --- | --- |
|  |  | Positive (PP) | Negative (PN) |
| Actual Condition | Positive (P) | True Positive (TP) | False Negative (FN) |
|  | Negative (N) | False Positive (FP) | True Negative (TN) |

The accuracy of a machine learning classification algorithm is a measure of how often the algorithm correctly classifies data points. Accuracy is the number of correctly predicted data points among all data points. Building a fire detection and electric fire judgment data set can contribute to job creation by using cloud sourcing for AI learning data collection, processing, and verification. In the future, accuracy will be used together with other quality indicators

such as precision and recall using various ratios of true/false, positive/negative, as in Tab. 1.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \qquad (1)$$

## 5 CONCLUSION

In this study, when the insulation of the wire is destroyed, a closed circuit of the power supply is formed without the load connected, which is called a short circuit. In the event of a short circuit, there is no load, so the resistance becomes zero, so according to Ohm's law, the current becomes infinite, which becomes very dangerous.

As a result of these studies, it is possible to efficiently respond to disaster situations by monitoring the fire scene in real time through on-site photos of electrical fires caused by electrical causes. In addition, accuracy can be achieved by identifying the exact cause of the fire. In addition, objective supervision that excludes the subjectivity of fire detectors can maximize the reliability and accuracy of inspection results. Technology using the electrical fire judgment data set is used in the actual field, which can reduce the cost of fire scene inspection, such as rapid cause identification and manpower problem resolution. In addition, it can contribute to the development of other disaster safety design systems, which is expected to greatly increase market competitiveness.

In the future research, the developed platform will combine electrical fire judgment data and various datasets in fire detection, and link it with big data AI algorithms to realize technology such as situation recognition and judgment technology as a state-of-the-art system. By advancing smart identification technology, avatars are used to collect professional data related to electrical fires, expanding the scope of application in other similar facility monitoring system fields, greatly contributing to the life safety of the people.

### Acknowledgements

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# Mechanical Alloying Synthesis of AB$_3$ Zirconium Substituted Intermetallic

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**Abstract:** Several ternary RareEarth-Magnesium-Nickel intermetallics (RE-Mg-Ni) emerged in last decade for their specific hydrogen storage capability. Nickel is now considered among strategic metals with recurrent rising price, Magnesium although its good gravimetric facility suffers from frequent oxidation or irreversible poisoning. Zirconium alloys are recognized for their improved anti-corrosion properties with enhanced wear resistance for high temperature machinability in industrial applications or energy research purposes. We proposed in this paper double substitution possibility replacing Magnesium and reducing Nickel charge. We developed new generation of quaternary Zirconium-AB$_3$ intermetallic LaZr$_2$Ni$_5$Al$_4$ using mechanical alloying method. Two binary raw materials are involved in this alloying reaction, the first is LaNi$_5$ and the second is ZrAl$_2$ (Laves phase C14) and both precursors are achieved quasi-quantitively using high frequency induction melting. The final target AB$_3$ compound crystallizes in Trigonal system with space group R-3m (166) and following experimental conditions (Fritsch P7, $\Omega$ = 450 rpm) an acceptable synthesis yield (>80%) is obtained starting from 20 hours mechanical alloying. Rietveld refinement is performed to have real matrix parameters and AB$_3$ powder surface is analyzed using Scanning Electron Microscopy.

**Keywords:** intermetallic compounds; mechanical alloying; metals and alloys; Rietveld refinement; Zirconium

## 1 INTRODUCTION

Zirconium is known to have a very good resistance to corrosion and generally Zr-substitutions are elaborated on matrix-confined metallic structures regarding the wide range of physical properties that it can afford to the final material [1-3]. Several Zirconium based minerals are biocompatible (body implants) and furthermore Zircaloys can be used for high temperature applications (energy conversion) or ceramic materials due to their hard refractory properties (High Density Composites) giving excellent stability when exposed to aggressive chemicals [4-6].

In some cases, micro-indentation tests give or reach values up to 238 HV on Vickers hardness scale [7]. Energy storage reactions on Mg-RareEarth intermetallics can be easily found extensively in literature [8-10] but it is focused presently on synthesis methodology to develop novel quaternary AB$_3$ substituted intermetallic.

It was also demonstrated that various Zirconium hydrides formulae (ZrH, ZrH$_{1.6}$, ZrH$_2$, ZrH$_4$) can be formed following hydrogen reduction on Zirconium; and having good electrical conductivity or superconductivity characteristics [11]. Varying hydrogen amount makes ZrH$_x$ getting improved mechanical properties (regarding Zr-metallic element alone) and decreasing any crystal dislocations inside zirconium structure. So, the presence of hydrogen can serve as a controlling agent regarding the mechano-chemical properties of the end-up material [12].

Exploring new manufacturing techniques to enhance the microstructure and/or performance of Zirconium alloys (reducing the grain size for example to improve mechanical properties) constitute big challenge for their developments. Also, studying their behavior under extreme conditions is necessary to understand these new materials with improved stability and reliability.

We report in the present paper about a detailed synthesis and refinement processing of a new Zirconium based AB$_3$ compound LaZr$_2$Ni$_5$Al$_4$ using mechanical alloying method. This procedure involves the prefabrication of two binary precursors LaNi$_5$ and ZrAl$_2$ which are directly acquired using a high frequency induction melting.

## 2 MATERIALS AND METHODS

Elementary Lanthanum (La, ingot in oil, Merck Germany) and Nickel (Ni, Rod, Goodfellow USA) are used directly as purchased in atomic proportion 1:5 to carry out the binary precursor LaNi$_5$. For the Laves phase C14 precursor ZrAl$_2$, Zirconium (Zr, Rod, Goodfellow USA) and Aluminum (Al, Slag, Merck Germany) are also directly used from the provider in atomic proportion 1:2. All experiments with high frequency induction melting (Generator 25 kW) are done in inert atmosphere using secondary vacuum pump ($10^{-4} – 10^{-5}$ mbars).

LaZr$_2$Ni$_5$Al$_4$ intermetallic alloy was elaborated within a mechanical alloying configuration of Fritsch P7: $\Omega$ = 450 rpm, ball to powder ratio 36:1, jar volume 45 cm$^3$, and 5 stainless steel balls $\varnothing$ = 12 mm with mass $m$ = 7.16 g. X-ray diffraction patterns are analyzed using a Bruker Diffractometer working with Copper Cu K$_{alpha}$ irradiation. Qualitative and quantitative analysis are accomplished respectively using following software HighScore and FullProf (for Rietveld). Scanning Electron Microscopy was done by an instrument type FEI Quanta 200.

## 3 RESULTS AND DISCUSSION
### 3.1 Characterization of Binary Precursor ZrAl$_2$

Electron Probe Micro-Analysis (EPMA) was carried out at first on several different regions and an example of EPMA micrography of ZrAl$_2$ sample is shown in Figure 1: we observe an overall primary gray zones and other minor black spots. The results of this microprobe analysis are given in Figs. 2 and 3 where it is obviously demonstrated that the gray areas correspond to ZrAl$_{2.04(10)}$ compound and minor black points to ZrAl$_{3.2(1)}$.

ZrAl$_2$ sample was also correctly refined using Rietveld method (ICSD reference data #150527) [13] as given in the

following Fig. 4 and Tab. 1 estimating almost a quasi-quantitative yield for this synthesis.
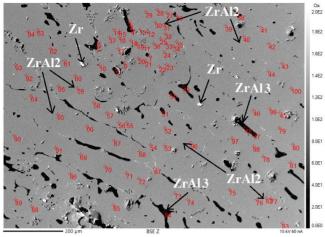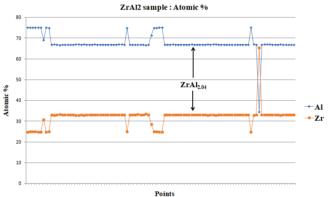


**Figure 1** EPMA micrography of ZrAl₂ sample



**Figure 2** Atomic proportions obtained from EPMA analysis of ZrAl₂
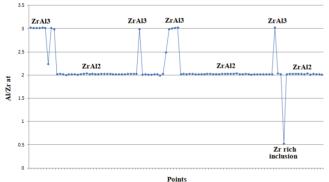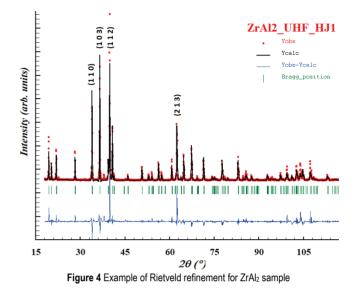


**Figure 3** Atomic ratios obtained from EPMA analysis of ZrAl₂

**Table 1** Matrix parameters of refined sample ZrAl₂

| Phase | Space group | Lattice parameters (Å) | $V$ (Å³) | Weight fraction (%) | $R_f$ | $R_{Bragg}$ | $\chi^2$ |
|-------|-------------|------------------------|----------|---------------------|-------|-------------|----------|
| ZrAl₂ | P6₃/mmc | $a$ = 5.27934 (8) $c$ = 8.7428 (2) | 211.03 | 100 | 8.18 | 14.20 | 6.94 |

We have acceptable profile matching as verified from the values of conventional agreement factors ($R_f$, $R_{Bragg}$, $\chi^2$), this

ZrAl₂ sample crystallizes in the space group P6₃/mmc (SG 194) with the following matrix parameters: $a = b$ = 5.27934 (8) and $c$ = 8.7428 (2).



**Figure 4** Example of Rietveld refinement for ZrAl₂ sample

## 3.2 Characterization of Binary Precursor LaNi₅

Many synthesis reaction pathways are existing in literature to easily achieve this intermetallic compound LaNi₅ [14]. We illustrate in the following Fig. 5 an insight on a micro-analysis mapping. Different focus points are selected, and the atomic proportion plot (Fig. 6) demonstrates that we obtain a precise nominal composition corresponding to LaNi₄.₉₇₍₅₎, obviously the atomic ratio calculation also given in Fig. 7 confirm that this sample appears to have practically uniform distribution of the desired phase.
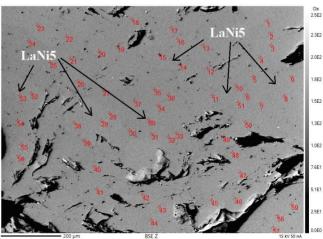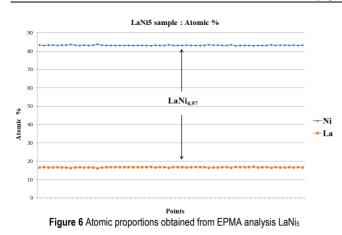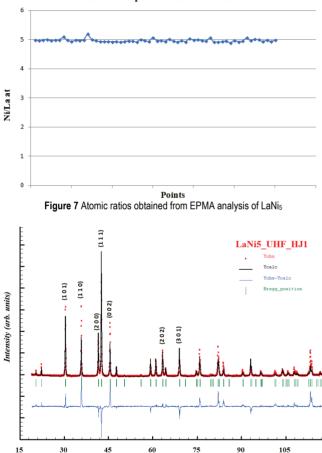


**Figure 5** EPMA micrography of LaNi₅ sample

We have further undertaken the structural refinement to get the real matrix parameters using the same previous procedure with Rietveld method. This sample was refined according to the reference data (atomic positions and site occupations) from literature and patterns information from ICSD #155913 file assessment [15].

**Figure 6** Atomic proportions obtained from EPMA analysis LaNi₅



**Figure 7** Atomic ratios obtained from EPMA analysis of LaNi₅



**Figure 8** Example of Rietveld refinement for LaNi₅ sample

**Table 2** Matrix parameters of refined sample LaNi₅

| Phase | Space group | Lattice parameters (Å) | $V$ (Å³) | Weight fraction (%) | $R_f$ | $R_{Bragg}$ | $\chi^2$ |
|---|---|---|---|---|---|---|---|
| LaNi₅ | P6/mmm | $a = 5.0134$ (1) $c = 3.9831$ (1) | 86.70 | 100 | 19.20 | 30.30 | 9.47 |

An example of structural refinement is simulated in the following Fig. 8 with (hkl) planes indexation. A very good

convergence is also mentioned regarding factors values in Tab. 2.

This Rietveld refinement confirm the homogenous phase stated and supporting previous atomic ratios evaluation by the microprobe analysis.
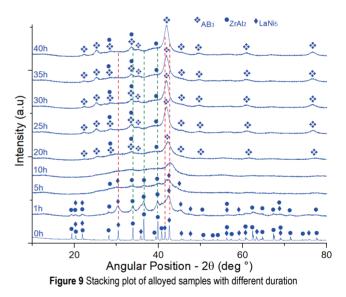
LaNi₅ is obtained within a quasi-total yield and the corresponding sample crystallizes in the space group P6/mmm (SG 191) with the following matrix cell parameters: $a = b = 5.0134$ (1) and $c = 3.9831$ (1).

### 3.3 Elaboration of AB₃ Alloy LaZr₂Ni₅Al₄

We have carried out in this section the intermetallic mechanical alloying reaction between the two precursors LaNi₅ and ZrAl₂ in molecular ratio 1:2 according to the following scheme:

$$\text{LaNi}_5 + 2\,\text{ZrAl}_2 \xrightarrow[\Omega = 450\text{ rpm, } \Delta t = 1\text{h to 40h}]{\text{Mechanical Alloying (Fritsch P7)}} \text{LaZr}_2\text{Ni}_5\text{Al}_4$$

The superposition of obtained diffractograms for all powder samples with different milling duration are represented in the stacking Fig. 9.



**Figure 9** Stacking plot of alloyed samples with different duration

Powder evolution seems to be affected by clear amorphization starting from 1h processing where several initial diffraction peaks become overlapped within broadening signals, this observation is strongly accentuated up to 10h. Afterwards, different collected diffractions data are obviously displayed that certainly imply a new emerged intermetallic which will be further corroborated as major AB₃ compound following Rietveld refinement.

The minimum activation energy to achieve this new compound ($2\theta = 41.93°$) is accumulated in 20 h milling time (at disk rotation speed $\Omega = 450$ rpm, injected shock power 6.2 W/g) which corresponds to an overall kinetic energy of 124 Wh/g.

At first step and before AB₃ structural simulation, we tried to verify and testing the Rietveld processing on prior samples (duration 1 h and 5 h).

It is shown on consecutive Figs. 10 and 11 successful demonstration of Rietveld refinement applied on these alloyed samples where $AB_3$ target product is not yet appeared, allowed Bragg reflections are found to be attributed for initial $AB_5$ and $AB_2$ precursors (LaNi$_5$ and ZrAl$_2$).



**Figure 10** Rietveld refinement of alloyed powder mixture for 1 h
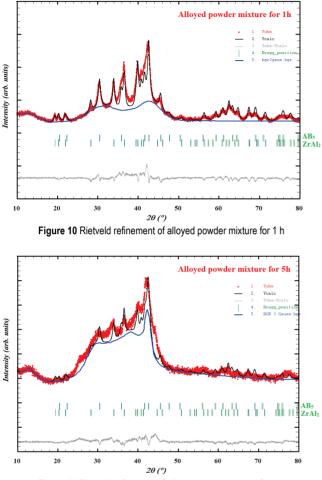


**Figure 11** Rietveld refinement of alloyed powder mixture for 5 h

**Table 3** Nearest-neighbor distribution of distances (partially crystalline intermetallics)

| Amorphous contribution in alloyed sample for 1 h duration | | | |
|---|---|---|---|
| Position $2\theta$ | Distance (Å) | FWHM | Attribution |
| 34.32 | 2.61 | 8.95 | $AB_2$ |
| 41.43 | 2.18 | 3.32 | $AB_5$ |
| Amorphous contribution in alloyed sample for 5 h duration | | | |
| Position $2\theta$ | Distance (Å) | FWHM | Attribution |
| 29.74 | 3.01 | 5.45 | N/A (intermediate) |
| 36.48 | 2.46 | 8.37 | $AB_2$ |
| 42.31 | 2.13 | 2.18 | $AB_5$ |

We have found and perceive that computed amorphization contribution seems to be necessary and introduced in the program inputs to have subsequent appropriate convergence. In the first case of Fig. 10, the refinement was made possible unless two suitable amorphous related phases have been performed and deconvoluted using ABF Fit MacSoftware. The fitting can also evaluate as given in Tab. 3 the nearest-neighbor distribution of distances

corresponding to each amorphous contribution induced by mechanical alloying experiment.

It was further noted in second case of Fig. 11 that extra fitting contribution ($2\theta = 29.74°$) was raised from ABF Fit simulation (Tab. 3) and might almost concern a transitional or intermediary state before reaching the desired crystalline compound. A very similar profiling shape was also observed at 10 h milling time, however refinement was limited regarding the very high broadening signals. According to Figure 9 and beginning from 20 h duration, the new compound appearing (at $2\theta = 41.93°$) seems to be stable even for long powder milling (up to 40h). Refinement was subsequently carried out (example Fig. 12) applying adequate crystal data (Tab. 4) conforming reference $AB_3$ material LaMg$_2$Ni$_9$ [16].

**Table 4** Atomic positions and occupation factors in LaZr$_2$Ni$_5$Al$_4$

| LaZr$_2$Ni$_5$Al$_4$ Cristal System: Trigonal / Space Group: R$\bar{3}$m (n° 166) | | | | | |
|---|---|---|---|---|---|
| | Wyckoff positions | $x$ | $y$ | $z$ | Occ. |
| La | 3a | 0 | 0 | 0 | 1 |
| Zr | 6c | 0 | 0 | 0.146(6) | 1 |
| Ni1 | 3b | 0 | 0 | 1/2 | 0.555 |
| Al1 | 3b | 0 | 0 | 1/2 | 0.444 |
| Ni2 | 6c | 0 | 0 | 0.333(1) | 0.555 |
| Al2 | 6c | 0 | 0 | 0.333(1) | 0.444 |
| Ni3 | 18h | 0.5015(6) | 0.4985(6) | 0.0857(5) | 0.555 |
| Al3 | 18h | 0.5015(6) | 0.4985(6) | 0.0857(5) | 0.444 |
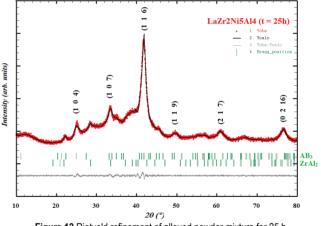


**Figure 12** Rietveld refinement of alloyed powder mixture for 25 h

This new synthesized phase was refined in Rhombohedral R$\bar{3}$m space group, and successful Rietveld simulation was obtained in Fig. 12 showing the $AB_3$ inter-reticular planes index.

Alloying metallurgy demonstrates here that a double metal-substitution would be possible without altering the crystallographic system of reference structure LaMg$_2$Ni$_9$.

An overview of all convergent X-ray patterns refinements was summarized in this following tabulated datasheet (Tab. 5). It is therefore confirmed that major $AB_3$ phase (yield > 80%) formed for 20h operation (stay minor ZrAl$_2$) and without significant modification after 25 h.

Qualitative observations in X-ray stacking plot of Fig. 9 are corroborated regarding the quantitative results obtained from Rietveld refinements in Tab. 5. Very small amount of initial $AB_2$ precursor ZrAl$_2$ remain in powder, it is also

provided interestingly that we can reach almost 90 % of this intermetallic alloy with extended duration (40 h). But certainly, in scope of a potential industrial scale-up or commercialization outcome, the optimum and better energy/time ratio would be the samples corresponding to interval time between 20 - 25 h.

**Table 5** Quantified phases found after mechanical alloying of different mixtures

| Milling time | Phase | Space group | Lattice parameters (Å) | $V$ (Å³) | Weight fraction (%) | $R_f$ | $\chi^2$ |
|---|---|---|---|---|---|---|---|
| 0 h | ZrAl₂ | P 63/m m c | $a$ = 5.27933(1) $c$ = 8.74284(1) | 211.03 | 42 | 26.4 | 12.8 |
| | LaNi₅ | P 6/m m m | $a$ = 5.01338(1) $c$ = 3.98306(1) | 86.70 | 58 | 18.6 | |
| 1 h | ZrAl₂ | P 63/m m c | $a$ = 5.27933(1) $c$ = 8.74284(1) | 211.03 | 42 | 15.1 | 9.1 |
| | LaNi₅ | P 6/m m m | $a$ = 5.01338(1) $c$ = 3.98306(1) | 86.70 | 58 | 14.8 | |
| 5 h | ZrAl₂ | P 63/m m c | $a$ = 5.27933(1) $c$ = 8.74284(1) | 211.03 | 42 | 29.8 | 6.8 |
| | LaNi₅ | P 6/m m m | $a$ = 5.01338(1) $c$ = 3.98306(1) | 86.70 | 58 | 30.6 | |
| 20 h | AB₃ | R-3m | $a$ = 5.14787(1) $c$ = 23.77881(1) | 545.73 | 80 | 10.9 | 15.2 |
| | ZrAl₂ | P 63/m m c | $a$ = 5.32196(1) $c$ = 8.50014(1) | 201.14 | 20 | 14.4 | |
| 25 h | AB₃ | R-3m | $a$ = 5.14313(1) $c$ = 23.86803(1) | 546.77 | 83 | 3.7 | 9.7 |
| | ZrAl₂ | P 63/m m c | $a$ = 5.35148(1) $c$ = 8.50242(1) | 210.87 | 17 | 5.5 | |
| 30 h | AB₃ | R-3m | $a$ = 5.14207(1) $c$ = 23.87111(1) | 546.61 | 85 | 1.7 | 4.3 |
| | ZrAl₂ | P 63/m m c | $a$ = 5.35182(1) $c$ = 8.49647(1) | 210.75 | 15 | 3.4 | |
| 35 h | AB₃ | R-3m | $a$ = 5.13574(1) $c$ = 23.88005(1) | 545.47 | 88 | 6.4 | 11.4 |
| | ZrAl₂ | P 63/m m c | $a$ = 5.33861(1) $c$ = 8.47411(1) | 209.16 | 12 | 8.4 | |
| 40 h | AB₃ | R-3m | $a$ = 5.13565(1) $c$ = 23.88844(1) | 545.64 | 89 | 2.6 | 11.2 |
| | ZrAl₂ | P 63/m m c | $a$ = 5.32945(1) $c$ = 8.47399(1) | 208.44 | 11 | 8.3 | |
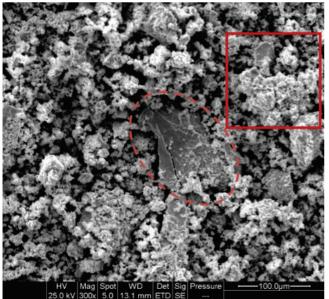


**Figure 13** SEM morphology in secondary electron mode of sample AB₃ – 25 h

Intermetallic compound LaZr₂Ni₅Al₄ (25 h) crystallizes in the space group R-3m (SG 166) with the following matrix parameters: $a = b$ = 5.14313(1) and $c$ = 23.86803(1). High precision given on crystal lattice indicate the appropriate

convergence as well (see Tab. 5: $R_f$ and $\chi^2$) for the refinement simulations carried out in this section.

**Table 6** Average atomic values obtained following Energy Dispersive Analysis of quaternary compound LaZr₂Ni₅Al₄

| LaZr₂Ni₅Al₄-25h | Theoretical Atomic Percentages | Atomic Percentages found by EDX |
|---|---|---|
| %La | 8.3 | 10.1 |
| %Zr | 16.7 | 15.9 |
| %Ni | 41.7 | 39.9 |
| %Al | 33.3 | 34.1 |

A sample of obtained mechanical alloyed powder at 25h was then analyzed using Scanning Electron Microscope SEM as given in next Fig. 13. In most concentrated focus SEM scan, surface morphology exhibited an overall homogeneous spherical-shape agglomerates (< 10 microns) and rare exceptions of localized bigger particles are observed corresponding to residual ZrAl₂ phase. It is also noted that Energy Dispersive Analysis (EDX) demonstrate according to Tab. 6 good convergence toward the nominal composition of intermetallic alloy developed LaZr₂Ni₅Al₄.

The average error found allover several spots (< 3 %) is considered very acceptable for this type of EDX analysis [17, 18]. Basically, the article is carried out to fulfill a detailed report on the technical assessment to achieve a new AB₃

intermetallic compound using a substitution transition element like Zirconium regarding its anti-corrosion advantages and extended high thermal operations as well energy conversion or storage. Melting point of Zirconium is about 1852 °C which constitute a big temperature gap (regarding low melting point for Aluminum and high oxidation sensitivity of Lanthanum) to overcome a quaternary intermetallic synthesis using high temperature melting furnace. The mechano-milling metallurgy processing presented in this case will be an efficient solution to elaborate withing an eco-compatible pathway the desired product.

## 4 CONCLUSIONS

In this study, we presented a novel mechanically alloyed Zr-AB$_3$ quaternary intermetallic. Metallurgy procedure involved two binary raw materials LaNi$_5$ and C14 Laves phase ZrAl$_2$, both of which are easily and completely produced by high frequency induction melting. X-ray diffraction data obtained for initial two compounds was validated by Rietveld refinement showing practically quasi-quantitative pattern in agreement with EPMA observations. Following mechano-milling procedure of binary precursors (Fritsch P7, $\Omega = 450$ rpm), more than 80 % of AB$_3$ crystalline phase LaZr$_2$Ni$_5$Al$_4$ was achieved after 20 hours duration which corresponds to equivalent activation energy of 124 Wh/g. Surface morphology demonstrated homogenous spherical particles less than 10 microns and Energy Dispersive analysis confirmed the nominal composition of the desired intermetallic material. Further perspective will consist in determining the exacts energy storage properties: solid-gas gravimetric hydrogen capacity, other thermodynamic parameters could be elucidated from isotherms of sorption behavior at different temperatures to retrieve the enthalpy and equilibrium pressure. Another more important substitutions will be exchanging totally rare earth metals using more sustainable elements keeping high level of expectation about favorable energy rendering.

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# The Optimal Strategy for Combining the EFQM and SWOT Methods in Power Plants

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**Abstract:** The current research has selected the best course of action and assessed the performance in power production plants using a combined method of the Organizational Excellence Model and SWOT methodologies. The primary goal of this study is to evaluate the organization's current performance status, identify its issues, and propose appropriate implementation strategies to address negative circumstances. Components of the Organizational Excellence Model include leadership, policy and strategy, human resources (people), partnerships and resources, procedures, customer outcomes, human resource results, community results, and key performance results. Descriptive surveys constitute the current research methodology. The managers and specialists of the power plants within the firm under study comprise the statistical population of this research. The Organizational Excellence Model questionnaire was an integral part of the research instrument. SPSS software was utilized to analyze the collected data. The results analysis revealed that only the element of key performance results was rated as average, whereas other components, such as processes, customer results (clients), human resources results, and community results, all scored above average. Leadership, policy and strategy, partnerships, and resources also scored above average, along with the components of human resources (employees), processes, and customer results.

**Keywords:** EFQM; leadership; power plants; strategy; SWOT

## 1 INTRODUCTION

Energy has a significant impact on a society's ability to prosper economically, promote social welfare, enhance quality of life, and maintain security. Global studies have consistently demonstrated a clear correlation between a nation's level of development and its energy consumption, underscoring the importance of emerging nations gaining access to new energy sources to advance and bolster their economies. Given that electrical energy is a critical and fundamental component of industrial, economic, and social development and prosperity, it is reasonable to assert that a measure of a nation's evaluation and development lies in its capacity to produce and distribute electrical energy. Electricity is generated through various power facilities and technological advancements. A power plant comprises a set of commercial buildings where electrical energy is generated by harnessing various energy sources, including gravitational potential energy, chemical energy, renewable energy, fossil fuel energy, etc., and converting them into electrical energy using generators (these rotating machines convert mechanical energy into electrical energy) [1].

The organization seeks to identify its internal strengths and weaknesses, as well as external opportunities and threats, using the SWOT analysis approach. It's worth noting that there are several techniques available to assess an environment's strengths, weaknesses, opportunities, and threats. Therefore, it appears that combining this approach with another method is the most prudent approach for comprehensively understanding these components. Focusing on the company's current achievements can be beneficial in selecting a complementary approach. One of the most widely used performance measurement frameworks is the Organizational Excellence Model, often referred to as EFQM. Combining the EFQM approach with the SWOT method appears to address the shortcomings of both models effectively. This combination allows for a systematic examination of both the external and internal environments (identifying strengths and weaknesses, opportunities and

threats) and provides an accurate assessment of the organization and its stakeholders.

On the other hand, the SWOT technique addresses a fundamental shortcoming of the EFQM method, which lacks an appropriate and straightforward mechanism for translating enablers into strategies and executive orders. A targeted process should be followed when describing and transforming the selected criteria into a plan. Various methods exist for evaluating performance, each of which analyzes a specific aspect or stage of performance. As a result, their independent use may have limitations. Power plant performance indicators play a significant role in the analyzed firm, making it crucial to identify any weaknesses now in order to make improvements in the future. Consequently, the researcher in this study employed EFQM and SWOT approaches to analyze performance and identify the best plans for the researched organization.

## 2 THEORETICAL FOUNDATIONS AND A REVIEW OF BACKGROUND LITERATURE

### 2.1 Organizational Performance

An indicator of an organization's success is its ability to accomplish its objectives effectively. Evaluating organizational performance can be based on how efficiently the company achieves its goals. According to Kanter and Binkerhoff (1981), organizational performance is the disparity between an organization's actual results and its planned objectives or inputs [2]. In essence, an organization's performance measures how effectively it has met its goals, generated profit, and safeguarded its most valuable assets, including its employees, clients, and financial resources. Performance also directly influences an organization's efficiency [4].

### 2.2 Performance Evaluation

Performance evaluation involves the application of a set of performance indicators that encompass various aspects of
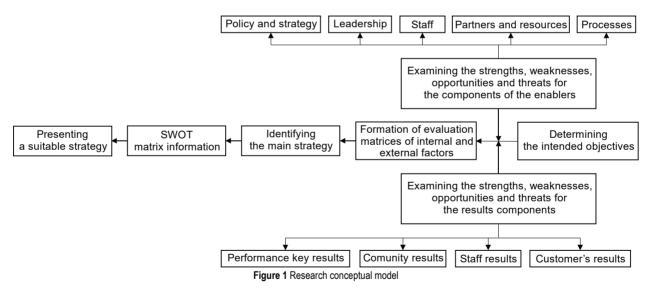
this issue, both in conceptual studies and within the executive offices of organizations. This comprehensive approach is referred to as multi-dimensional because it encompasses both financial and non-financial data, considering both the organization's internal and external environments. Furthermore, it must consider strategic objectives, review and assess acquired outcomes and outputs, and look ahead to the organization's future [22]. The primary objectives of performance evaluation are to enhance satisfaction, elevate performance levels, and ultimately improve the efficiency of an organization's operations. In other words, subjective judgment and hesitation have no place in the fundamental goals of conducting performance reviews, which should be geared towards growth and development, enhancing the performance of the organization and its personnel. These efforts pave the way for self-evaluation, the establishment of a scientifically sound system of rewards and penalties, steering the organization towards excellence, and ultimately achieving organizational goals more swiftly and effectively [3].

### 2.3 Generalities of the EFQM Excellence Model

One of the performance evaluation methods introduced in 1999 is the Organizational Excellence Model [21]. The EFQM Business Excellence Model generally consists of nine criteria: five enabling criteria, including Leadership, Strategy and Policy, People, Partnerships and Resources, and Processes, and four results criteria, which are 1) Client Outcomes, 2) Employee Outcomes, 3) Community Outcomes, and 4) Key Performance Indicators [10]. The enabling criteria describe what an organization accomplishes and represent the elements that contribute to achieving outstanding outcomes, effectively communicating the successes of correctly applying these enablers. The outcomes are achieved as a consequence of the application of these enablers. Implementing these enablers yields the desired benefits, and through learning from the outcomes, the enablers continue to evolve and improve [16].

### 2.4 SWOT Analysis

The primary strategy analysis technique known as SWOT analysis assesses an organization's external opportunities and threats, as well as its current strengths and weaknesses. In the SWOT matrix, the internal attributes and characteristics of the company are categorized as strengths and weaknesses, while the external environment's features and characteristics are classified as opportunities and threats to the business. Strengths encompass internal resources that a firm possesses and utilizes to capitalize on opportunities and mitigate external challenges, such as financial resources, technology, and motivation. Any internal deficiency hindering the organization from achieving its objectives is considered a weakness [24]. Opportunities refer to favorable occurrences in the organization's external environment, while threats denote adverse challenges emerging from the external environment [13]. The analysis of both the internal and external environments yields a vast amount of information for the management team, which can sometimes be overwhelming or disconcerting when viewed collectively [5].



**Figure 1** Research conceptual model

### 2.5 Explanation of the Reason for Using SWOT and EFQM Integrated Method in the Studied Company

It appears that the limitations of both models can be addressed by integrating the EFQM approach with the SWOT method. This combined approach allows for a systematic examination of both external and internal environments, enabling the identification of strengths, weaknesses, opportunities, and threats. It provides a means to accurately assess the organization's status and its impact on stakeholders. On the other hand, employing the SWOT method rectifies a primary shortcoming of the EFQM approach, which lacks a straightforward method for translating enablers into strategies and executive directives. To outline and convert the identified criteria into a strategy, specific steps are followed. In the new analytical model

created by merging these two methodologies, the strengths, weaknesses, opportunities, and threats of the organization are first evaluated in accordance with the nine EFQM criteria. Instead of using a simple Likert scale to assess the state of each component, the SWOT approach is applied during the self-evaluation phase. Following the principles of this methodology, each component is assigned a coefficient and score, and through the phases of the SWOT method, essential plans for the company's future are proposed. The research's analytical model is depicted in Fig. 1.

## 2.6 Literature Review

In this study, we focused on power plants within the researched organization to conduct a performance evaluation and determine relevant strategies using a combination of EFQM and SWOT approaches. Tabs. 1 and 2 indicate that there has been limited research in this area, primarily focused on internal and external factors.

**Table 1** The domestic research conducted in the field of research

|   | Scholars | Year | Research title |
|---|----------|------|----------------|
| 1 | Sadeghi et al. [23] | 2018 | Evaluating excellence in chain stores based on EFQM |
| 2 | Rahaii, [1] | 2023 | Performance evaluation of Al-Zahra University based on EFQM organization's excellence model |
| 3 | Akbarian, et al [8] | 2022 | Presenting an innovative model to evaluate and select the market based on fuzzy SWOT analysis and multi-criteria decision making |
| 5 | Kolarai [6] | 2021 | Identifying and evaluating the eco-tourism potential of desert areas using SWOT and AHP models |
| 6 | Murshidi [7] | 2019 | Measuring the organizational excellence of the Islamic Republic of Iran Airlines (Homa) based on the EFQM model |
| 7 | Oladi [9] | 2017 | Evaluation of the performance of the agricultural Jihad proposal system in Fars province using the EFQM model |
| 8 | Longbottom [18] | 2008 | How to implement a balanced scorecard of human resources in a service organization with SWOT and BSC |

**Table 2** International research conducted in the field of research

|   | Scholars | Year | Research title |
|---|----------|------|----------------|
| 1 | Neir et al. [19] | 2018 | Performance evaluation of Shahid Beheshti Hospital in Qom based on EFQM organizational excellence model |
| 2 | Roghani, et al. [12] | 2014 | Application of EFQM model in measuring organizational performance |
| 3 | Fan et al. [14] | 2015 | Applying fuzzy quantified SWOT technique for environmental assessment of an international distribution center |
| 4 | Farhadi et al. [15] | 2023 | Self-evaluation of the European organizational excellence model using a questionnaire approach |
| 5 | Jose et al. [17] | 2007 | The use of enablers in the European organizational excellence model for the management of higher education institutions |
| 6 | Azar et al. [10] | 2020 | Implementation of organization excellence model in higher education institutions |

## 3 METHOD

Based on the research's purpose, it falls under the category of applied research, while in terms of methodology, it is categorized as descriptive-survey research. The statistical population for this study comprises twelve managers and experts from the firm being investigated in power plants. Simple random sampling was employed since the statistical population was relatively small. The statistical population's sample consists of eleven managers and specialists from the organization under study, and due to the importance of the topic, interviews were conducted with all of them. The following are the key techniques used to gather data for this study:

1) Library study: This section involved researching theoretical underpinnings and research literature using library resources, journals, required texts, and the global information network (Internet).

2) Field research: When using the field technique, the researcher interacts with individuals, groups, and institutions to gather information. They complete their data collection by asking questions, conducting interviews, observing, photographing, and collecting data outdoors. In this study, EFQM questionnaires and interviews were employed as data collection strategies. The guiding professors and advisers of this study were provided with a copy of the research questionnaire to validate its content, and adjustments were made as needed. These individuals also confirmed the questionnaire's accuracy through the necessary revisions. The reliability of the questionnaire was determined using the Cronbach's alpha formula. The average Cronbach's alpha obtained from the study questionnaire is equal to 0.751, which is above the 0.7 threshold, confirming the questionnaire's reliability. SPSS software was used for data analysis in this study.

### 3.1 Research Questions

1) What opportunities and challenges, strengths and weaknesses, and enabling criteria does the company face?
2) What opportunities, risks, and weaknesses does the company confront in terms of the outcomes criteria?
3) Which phase is the organization in general (offensive, defensive, preventative, etc.) based on the appraisal of the situation?
4) What tactics should the firm employ to improve its circumstances in light of the SWOT method's guiding principles?
5) Analysis of results and suggestions.

### 3.2 Characteristics of the Respondent Community

Tab. 3 provides a summary of the general characteristics of the respondent population.

Considering that only the dimension of critical performance results has a P-value higher than 0.05, while the P-values for the other components are all lower than 0.05, it can be concluded that all of the dimensions significantly

deviate from the mean level. Among these components, leadership, policy and strategy, relationships, and resources have all performed above average, indicating their positive state. In contrast, the components of human resources (employees), processes, customer outcomes, human resources results, and community results are all below average, while the component of key performance results is at the average level. To identify strengths, weaknesses, opportunities, and threats for all aspects of organizational performance from the EFQM perspective, the researcher gathered opinions from experts. Subsequently, using these expert opinions, weights were assigned to each of the strengths, weaknesses, opportunities, and threats within the nine dimensions. The top priorities from each of the strengths, weaknesses, opportunities, and threats identified in the first stage were chosen to construct the SWOT matrix. These tables will reveal how the organization can leverage its assets and environmental opportunities to strengthen its position, how it can mitigate environmental threats by utilizing its assets, how it can address weaknesses by

capitalizing on environmental opportunities, and ultimately, how it can overcome environmental threats and weaknesses.
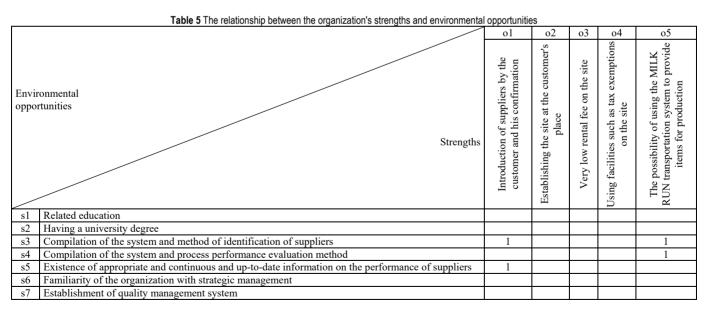
**Table 3** The general characteristics of the respondent population

| Working background | Frequency percentage | | |
|---|---|---|---|
| | Under 5 years | Between 5 and 10 years | Between 10 and 20 years |
| | 45.5 % | 27.3 % | 27.3 % |
| Age | Between 20 and 30 years | | Between 30 and 40 years |
| | 45.5 % | | 54.5 % |
| Gender | Female | | Male |
| | 9.1 % | | 90.9 % |
| Education level | Diploma | Upper diploma | Undergraduate | Graduate |
| | 18.2 % | 9.1 % | 45.5 % | 27.3 % |

During the determination of the connecting points in these tables, six interviewers were present at the meeting. The researcher employed the saturation approach to justify the selection of this number, avoiding additional labor and research once data gathering had reached its optimal level. Based on the discussion during this meeting, the company's core strategies were chosen to preserve and enhance the company's strategic position.

**Table 4** General characteristics of the respondents

| Variable | Number of specimens | Average (number of questions multiplied by 2/5) | T-value | Degree of freedom | P-value |
|---|---|---|---|---|---|
| Leadership | 11 | 15 | 1 / 57 | 10 | 0 / 000 |
| Policy and strategy | 11 | 12 / 5 | 0 / 665 | 10 | 0 / 000 |
| human resources (employees) | 11 | 12 / 5 | −1 / 78 | 10 | 0 / 000 |
| Partnerships and resources | 11 | 10 | 1 / 59 | 10 | 0 / 000 |
| Processes | 11 | 20 | −0 / 19 | 10 | 0 / 000 |
| Customer (client) results | 11 | 15 | −1 / 21 | 10 | 0 / 000 |
| Results of human resources | 11 | 12 / 5 | −1 / 67 | 10 | 0 / 000 |
| Community results | 11 | 12 / 5 | −2 / 54 | 10 | 0 / 000 |
| Key performance results | 11 | 15 | 0 / 000 | 10 | 1 / 000 |

**Table 5** The relationship between the organization's strengths and environmental opportunities

| Environmental opportunities | | Strengths | o1 Introduction of suppliers by the customer and his confirmation | o2 Establishing the site at the customer's place | o3 Very low rental fee on the site | o4 Using facilities such as tax exemptions on the site | o5 The possibility of using the MILK RUN transportation system to provide items for production |
|---|---|---|---|---|---|---|---|
| s1 | Related education | | | | | | |
| s2 | Having a university degree | | | | | | |
| s3 | Compilation of the system and method of identification of suppliers | | 1 | | | | 1 |
| s4 | Compilation of the system and process performance evaluation method | | | | | | 1 |
| s5 | Existence of appropriate and continuous and up-to-date information on the performance of suppliers | | 1 | | | | |
| s6 | Familiarity of the organization with strategic management | | | | | | |
| s7 | Establishment of quality management system | | | | | | |

The relationship between environmental hazards and the organization's shortcomings is illustrated in Tab. 6. In this table, the number one denotes the presence of a connection, while the number zero signifies its absence. At the conclusion of this section, each expert completed a specially designed questionnaire that required them to rank and assign weights to each of the significant internal strengths-weaknesses and external opportunities-threats variables. These coefficients were assessed on a relative scale, ranging from zero (unimportant) to one (extremely important). The coefficient

indicates the component's importance in relation to other factors concerning the organization's success. The coefficients should sum up to one. Subsequently, each component received a score ranging from one to four. These ratings, determined using an ordinal scale, reflect how effectively the firm's strategies responded to the relevant factor (for external variables) or the company's strengths and weaknesses (for internal factors).

- A score of 4 indicates that the factor was exceptionally influential (for internal factors) or the response was excellent (for external influences).
- A score of 3 suggests that the response was above average due to external or internal factors, respectively.
- A score of 2 indicates a moderate response (for external factors) or a slight weakening (for internal factors).
- A score of 1 suggests that the component has a fundamental weakness or that the response is weak due to external circumstances (for internal factors).

**Table 6** The relationship between weaknesses and environmental threats of the organization

| Environmental opportunities / Strengths | T6 The existence of competing companies that have the ability to attract the organization's personnel | T7 Lack of commitment of personnel to improve the system situation in the long term | T8 The existence of competitors and the provision of the organization's products in the event that the customer's needs and satisfaction are not met | T9 The lack of support of the board members from the ideas of executive management | T10 Failure of managers to welcome innovation in technology |
|---|---|---|---|---|---|
| w1 Lack of proper appreciation of the employees' activities | | 1 | | 1 | 1 |
| w2 Absence of a suitable software system to evaluate suppliers | | 1 | | 1 | 1 |
| w3 The slowness of the organization in changing strategies | | | | | |
| w4 Lack of incentive and punishment system | | | | 1 | |
| w5 Lack of cost management | | 1 | | | |
| w6 Poor communication with customers | | 1 | | | |
| w7 The low scores related to welfare facilities and employee satisfaction | | 1 | | | |
| w8 Decrease in employee satisfaction | | 1 | | | |
| w9 The inability of the organization to properly identify changes | | 1 | | | |
| w10 The lack of specialization in the process of recruiting and hiring personnel | | 1 | 1 | | |

## 3.3 Examining the Internal and External Matrix (IE)

The internal-external matrix (IE) in the SWOT analysis divides various organizational departments into 9 categories or houses. This matrix considers two primary dimensions. The x-axis represents the sum of the final scores from the assessment matrix of internal factors, while the y-axis represents the sum of the final scores from the evaluation matrix of external factors. We assess these axes using the following scale, as previously mentioned, since the sum of these numerical ratings falls between one and four (1-4). The nine newly established categories are numbered from 1 to 9, starting in the upper left corner. Organizations positioned in the first, second, or fourth category should adopt growth and expansion-oriented strategies. These units should consider targeted strategies such as market penetration, product and market development, as well as vertical-up, vertical-down, and horizontal-integration-based strategies. Organizations in the third, fifth, or seventh category should opt for strategies that maintain the status quo. These entities should consider plans related to product development and market penetration.

The various organizational departments are divided into 9 houses by the internal-external matrix (IE) in the SWOT analysis. Two primary dimensions are taken into account in this matrix. The x-axis represents the sum of the final scores for the assessment matrix of internal factors, and the y-axis represents the sum of the final scores for the evaluation matrix of external factors. We evaluate these axes using the scale below because, as we previously said, the sum of these

numerical ratings falls between one and four (1-4). The nine newly built residences are numbered from 1 to 9 starting in the upper left corner. Organizations that are positioned in the first, second, or fourth house should select growth and construction-oriented strategies. These units must to think about targeted strategies, market penetration, product and market development, or vertical-up, vertical-down, and horizontal-integration-based strategies. Organizations in the third, fifth, or seventh house should opt for methods that preserve the status quo. Product development and market penetration plans should be taken into account by these entities.

**Table 7** Internal and external matrix (IE) of the studied company in power plants

| The final score of the internal factor evaluation matrix (IFE) | | | | | |  |
|---|---|---|---|---|---|---|
| 1 | 2 | 2.5 | 3 | 4 |  | |
| 3 | 2 | | 1 | | 4 / 3.25 / 3 | The final score of the External Factors Evaluation Matrix (EFE) |
| 6 | 5 | | 4 | | 2 | |
| 9 | 8 | | 7 | | 1 | |

Organizations placed in the sixth, eighth, or ninth categories must adhere to harvest-or-drop policies. These units need to consider targeted strategies such as market penetration, product development, or vertical, horizontal, and/or vertically integrated strategies. In the figure above, the organization being investigated is located in house number 2. According to the guidelines for formulating a strategy using the SWOT analysis, a focused expansion and development

plan should be adopted for house number 2. The most suitable strategies include market penetration, product development, or strategies based on vertical-up integration, vertical-down integration, and horizontal integration. If the company succeeds in implementing its vertical integration methods, it should aim to expand its market dominance through smaller divisions, either within or outside the company. The organization's structure should focus more on its subsidiaries and any potential competitive actions related to them. Suppliers of raw materials are regulated in line with the application of downward vertical integration methods in manufacturing and commercial businesses to achieve control objectives [20].

## 3.4 Suggestions

• Suggestions for the Leadership Dimension: Based on the results obtained from successive interviews with organizational experts, it is recommended that senior managers of the studied company first prioritize efforts in addressing the weaknesses related to utilizing the organization's facilities optimally, becoming familiar with the capabilities of personnel, granting necessary authority, closely monitoring relevant managers, informing managers about the organization's values, mission, and vision, involving other managers in formulating the mission, and appropriately recognizing efforts and achievements. In the second stage, it is essential to emphasize the advantages of having a university degree, relevant training, the right work experience, and appropriate education. Providing opportunities for professional development for both managers and employees, welcoming fresh perspectives, and increasing their experience in power generation plant-related work are also important.

• Suggestions for the Human Resources (Employees) Dimension: Based on the results obtained from successive interviews with organizational experts, it is recommended that senior managers of the studied company pay more attention to addressing weaknesses such as hiring personnel without work experience, employing non-specialized personnel, inadequate recognition of employee activities, absence of a continuous personnel performance evaluation process, lack of specialization in the personnel recruitment process, recruitment based on relationships, managers' lack of commitment to promote deserving personnel, and a misalignment between the organization's strategic plan and personnel-related plans. Additionally, it is important to emphasize opportunities such as attracting job seekers with reasonable income expectations, offering cost-effective training courses, utilizing workers' houses and their facilities, tapping into the pool of university-educated job seekers, leveraging the organization's strong bargaining power in hiring, considering the abundance of job seekers with diverse backgrounds, and engaging educated individuals looking for opportunities to work on projects and theses.

• Suggestions for the Processes Dimension: Based on the results obtained from successive interviews with organizational experts, it is suggested that senior managers of the studied company place more emphasis on addressing weaknesses such as recruiting new personnel unfamiliar with quality management systems, implementing partial solutions in the systematic improvement of processes, and the lack of integrated quality management system software provided by the organization. Furthermore, it is important to highlight opportunities such as setting up on-site locations at the customer's site for quick identification and resolution of quality problems, resolving numerous quality issues at the customer's site, maintaining a favorable rating among suppliers, considering the limited number of suppliers with this rating, conducting regular audits of the quality system by certification bodies, and implementing a customer program and strategy for suppliers to align with ISO/TS standards and EFQM implementation.

• Suggestions for the Key Results Dimension: Based on the results obtained from successive interviews with organizational experts, it is recommended that senior managers of the studied company address weaknesses such as not measuring the performance of processes and activities, lack of cost management, and failure to differentiate the results of various parts of activities and services to illustrate performance variations. In the second stage, it is important to capitalize on opportunities, including the establishment and implementation of specific requirements from senior customers through method development and continuous employee training, the organization's minimal budget requirements based on its activity type, and enhanced quality assurance due to performance improvements.

• Suggestions for the Customer Results Dimension: According to the results obtained from successive interviews with organizational experts, it is suggested that senior managers of the studied company first address weaknesses related to poor communication with customers and the inability to leverage bargaining power regarding product prices. In the second stage, it is crucial to emphasize opportunities such as implementing the organization's quality performance monitoring system at the customer's site and the organization's on-time delivery performance monitoring system at the customer's site to further enhance these aspects.

## 4 CONCLUSIONS

The purpose of this study was to assess performance and select the best course of action for the electricity and energy sector's power plants by integrating SWOT strategies with the Organizational Excellence Model (EFQM). According to the study's findings, among the EFQM variable aspects, leadership, policy, and strategy, as well as partnerships and resources, were rated above average and in good shape. It is essential for every organization to promptly evaluate the value and quality of its operations, especially in complex and evolving contexts. Conversely, the absence of an assessment and control system within an organization indicates a disconnection from its internal and external environments, leading to organizational aging and eventual decline. It is recommended that researchers in the fields of evaluation, diagnosis of complications, prioritization of improvement projects, and comparison of superior organizations conduct further research using the EFQM model in comparison to other performance evaluation models. This is crucial as there has been limited research in the field of performance evaluation. Exploring how this paradigm influences other management categories is another avenue for research.

Additionally, by conducting further research on the EFQM and SWOT models and assessing the effectiveness of governmental organizations using these methodologies, it lays the groundwork for their adoption and implementation across the nation. This can enhance organizational competitiveness, improve performance, and drive progress toward excellence. However, this study has some limitations. Due to the nature of the EFQM model and its established criteria and domains, obtaining certain information related to specific criteria has been challenging. Additionally, the lack of simultaneous examination of the Balanced Scorecard (BSC), SWOT, and EFQM methods, limited sharing with relevant platforms, and restricted access to articles in electronic journals have also posed limitations.

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# PID Control of Hybrid DC-DC Converter System in Complex Load with Double Reference Time

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Abstract: DC-DC converters are circuits that are widely used in energy distribution systems, in industry and technology applications, as well as in household appliances such as computers and televisions, and in uninterruptible power supplies used to feed all these systems. For the design and optimization of DC-DC converter circuits, it is important to create and analyze mathematical models according to the load it is connected to. Simple load structures and circuit structures have been examined and control units have been designed in studies carried out to date. In this study, while the DC-DC converter with a more complex load structure is discussed, mathematical analysis and PID control of DC-DC converters with Buck-Boost feature are performed with the same modulation index in different time periods. In the results obtained, it is shown how to create the mathematical models of a system that provides DC-DC energy conversion with a complex load structure and how to formulate the PID control in a system with this complex load structure.

Keywords: analyze mathematical models; complex load structure; DC-DC converters; uninterruptible power supplies

## 1 INTRODUCTION

DC-DC converters are power circuits that provide a variable dc voltage to the load they feed, different from the source voltage level applied to them [1-3]. These power circuits can perform balancing tasks between variable input power supplies and the load as in[4-7]. The performance of switched power circuits enables power conversion between the ac source and batteries in devices with low-power household appliances such as computers while minimizing the battery structure of the system in the circuits [8]. Since solar photovoltaics are renewable energy sources that are easy to install, they can be preferred for electrical devices as a suitable method for battery charging [9]. DC-DC converters are needed to connect solar cells to electrical devices and to provide energy balance [10, 11]. In order to increase efficiency and stability in energy systems, the design, analysis, and control of power circuits that provide transformation in the system are of great importance [12, 13]. In order to optimize and control the DC-DC converter structures, the mathematical structure of the system should be analyzed and created [14, 15]. Although there are DC-DC converter studies for many important applications, DC-DC converters with complex loads in the studies presented so far are limited to presenting the analysis and mathematical structure of the structure [15, 16]. Although this converter structure is examined in open loop control, traditional converter time-dependent mathematical models and losses in MOSFET structure are examined for simple load structure [17]; Closed-loop PID controlled transfer functions in the S domain have not been investigated in the complex load structure. Therefore, this article examines the PID control of a multi-reference DC-DC converter structure with a complex load structure. Mathematical models of circuit structure with complex load structures such as R, RL, RLC, and parallel series R//RL are derived. The mathematical functions of the PID control are built into the extracted mathematical models of the circuit. PI and PID applications of circuits are made in Matlab Simulink, and converters with complex loads are optimized. In the results obtained, while the mathematical circuit model analysis of the converter with complex load

structure was obtained, satisfactory results were obtained in terms of both the current and voltage level on the used loads and the residence times.

## 2 HYBRID BUCK BOOST CONVERTER MATHEMATICAL MODELS AT DIFFERENT COMPLEX LOADS AND SIMULATION STUDIES

In Fig. 1a, the circuit structure of the hybrid DC-DC converter with $R$ load is given. In Fig. 1b, the block diagram showing the control of the R-loaded circuit is given.

There are two transfer functions $F_{S1}$ and $F_{S2}$ for the two time slots that give the working characteristics of the proposed circuit. $I_{L1}$ is the current of coil $L_1$ while $I_{L2}$ is the current of coil $L_2$. $V_o$ is output voltage. $F_{S1}$ and $F_{S2}$ are transfer functions that represent circuit models during periods of different reference values. The circuits represented by these functions are different converter structures. $F_{S1}$ can be arranged as in the equations below.

$$V_{dc} = V_i = L_{L1}\left[L_1 s + \left(\frac{1}{R} + Cs\right)^{-1}\right] \tag{1}$$

$$V_{dc} = V_i = L_{L1}\left[L_1 s + \left(\frac{1 + RCs}{R}\right)^{-1}\right] \tag{2}$$

$$V_{dc} = V_i = L_{L1}\left[\frac{R + L_1 s + L_1 sRCs}{1 + RCs}\right] \tag{3}$$

$$V_i = L_{L1}\left[\frac{R + L_1 s + RCL_1 s^2}{1 + RCs}\right] \tag{4}$$

$$V_o = L_{L1}\left[\frac{R}{1 + RCs}\right] \tag{5}$$

$$F_{S1} = \frac{V_o}{V_i} = \frac{L_{L1}\left[\dfrac{R}{1 + RCs}\right]}{L_{L1}\left[\dfrac{R + L_1 s + RCL_1 s^2}{1 + RCs}\right]} \tag{6}$$

$$F_{S1} = \left[\frac{R}{1+RCs}\right]\left[\frac{1+RCs}{R+L_1s+RCL_1s^2}\right] \tag{7}$$

$$F_{S1} = \left[\frac{R}{R+L_1s+RCL_1s^2}\right] \tag{8}$$

For $F_{S2}$, system transfer function calculated as below:

$$V_{dc} = V_i = L_{L2}L_2s \tag{9}$$

$$V_o = L_{L2}\left[\frac{R}{1+RCs}\right] \tag{10}$$

$$F_{S2} = \frac{V_o}{V_i} = \frac{L_{L2}\left[\frac{R}{1+RCs}\right]}{L_{L2}L_2s} \tag{11}$$

$$F_{S2} = \left[\frac{R}{1+RCs}\cdot\frac{1}{L_2s}\right] \tag{12}$$

$$F_{S2} = \left[\frac{R}{L_2s+RCL_2s^2}\right] \tag{13}$$

When the total $t$ time is considered as the working time of the two modes, the working rates to be determined by the time durations of the two functions are as given in the matrix form below.

$$\begin{bmatrix} F_{S1} \\ F_{S2} \end{bmatrix} = \begin{bmatrix} \dfrac{R}{R+L_1s+RCL_1s^2} & 0 \\ 0 & \dfrac{R}{L_2s+RCL_2s^2} \end{bmatrix}\begin{bmatrix} \dfrac{t_1}{(t_1+t_2)} \\ \dfrac{t_2}{(t_1+t_2)} \end{bmatrix} \tag{14}$$



a)



b)
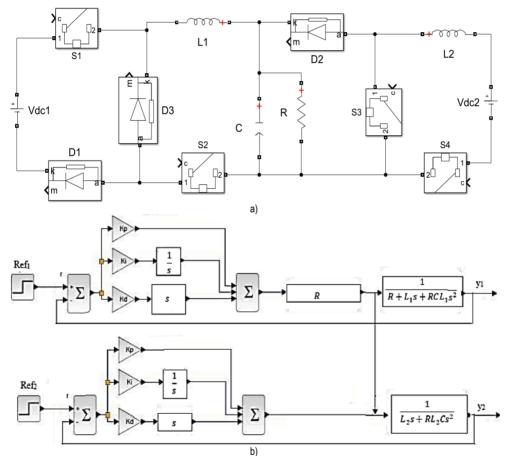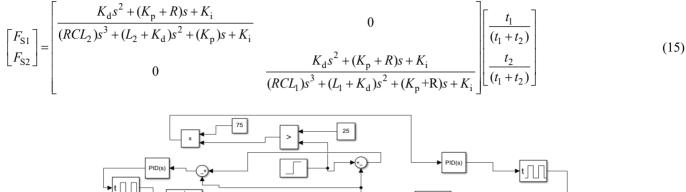
**Figure 1** a) Hybrid buck boost converter for $R$ load, b) block diagram of the control of the system for $R$ load

Arrangements are made to provide PID control of the system to the multi-time transfer functions of the power circuit. PID (Proportional Integral Derivative) is one of the most used control methods today. P represents proportional controller; I represent integral controller and D represents derivative controller. $K_p$ is gain for Proportional, $K_i$ is gain for Integral, $K_d$ is gain for Derivative. To create a system control where the error is close to zero, the output signal of the controlled system is fed back and compared with the

specified reference signal. A driver signal obtained based on the comparisons between the input and output signals is calculated by the PID controller and applied to the system to reduce the error to zero. In this way, the error value is tried to be brought to zero. However, while resetting the error, attention should be paid to the overshoot and settling time values of the system. There are many different methods to find the coefficients of the PID controller. In slow and lagging systems such as temperature control, Ziegler-Nichols

should be preferred because it is easy to use and also gives a good starting point to reach suitable PID coefficients [16, 18]. PID can be applied to the mathematical model of the

generated power circuit for $R$ load as shown in the equation matrix below.

$$
\begin{bmatrix} F_{S1} \\ F_{S2} \end{bmatrix} = \begin{bmatrix} \dfrac{K_d s^2 + (K_p + R)s + K_i}{(RCL_2)s^3 + (L_2 + K_d)s^2 + (K_p)s + K_i} & 0 \\[4ex] 0 & \dfrac{K_d s^2 + (K_p + R)s + K_i}{(RCL_1)s^3 + (L_1 + K_d)s^2 + (K_p + R)s + K_i} \end{bmatrix} \begin{bmatrix} \dfrac{t_1}{(t_1 + t_2)} \\[3ex] \dfrac{t_2}{(t_1 + t_2)} \end{bmatrix} \tag{15}
$$



**Figure 2** The MATLAB Simulink model of the created power circuit for $R$ load

The MATLAB Simulink model of the created power circuit for the $R$ load is given in Fig. 2. There are 2 DC voltage sources of 50 V in the circuit. While $I_{L1}$ and $I_{L2}$ are 0.1 mH, $C$ is 3 mF. A 3-ohm resistive load is used as a load. Square PWM is used to control the semiconductor power switches in the system. Although the operating ratio ($D$) for these PWMs is determined as 50%, the PID closed loop control differentiates the operating ratios by comparing the reference values with the output values. When the system is controlled with $P = 5$ and $I = 1$ values and PI controls, the current and voltage on the load are formed as given in Fig. 3a. The settling time of current and voltage takes place in 0.04 s. For Boost mode, while 101 V voltage is applied to the load, the current passing through the load is 33.6 A. The electrical energy power conversion obtained for RL load in boost mode is 3393.6 W. For Buck mode, while a voltage of 33 V can be applied to the load on the load, a current of 11 A flows over the load. The electrical energy power conversion obtained for RL load in boost mode is 363 W. When the system is controlled by PID controls with $P = 5$, $I = 1$ and $D = 0.2$ values, the current and voltage on the load are formed as given in Fig. 3b. The settling time of current and voltage takes place in 0.01 s. This provides a 75% improvement in the settling time. For Boost mode, while 101 V voltage is applied to the load, the current passing through the load is 33.6 A. For Buck mode, while a voltage of 33 V can be applied to on the load, a current of 11 A passes through the load.

The circuit model of the converter circuit for $R$ and $L$ load is given in Fig. 4. The mathematical models of the transfer function of the circuit according to the series connected RL load can be arranged as follows.



**Figure 3** a) PI control for R load, b) PID control for R load

$$
V_{dc} = V_i = L_{L1}\left[ L_1 s + \left( \frac{1}{R + Ls} + Cs \right)^{-1} \right] \tag{16}
$$

$$
V_{dc} = V_i = L_{L1}\left[ L_1 s + \left( \frac{1 + RCsLs + RCs}{R + Ls} \right)^{-1} \right] \tag{17}
$$
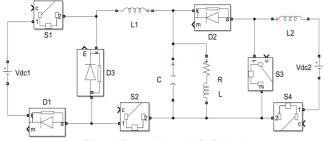
**Figure 4** Power circuit model for RL load

$$V_i = L_{L1}\left[L_1 s + \left(\frac{R+Ls}{RCLs^2 + RCs + 1}\right)\right] \tag{18}$$

$$V_i = L_{L1}\left[\frac{RCLL_1 s^3 + RCL_1 s^2 + (L_1+L)s + R}{RCLs^2 + RCs + 1}\right] \tag{19}$$

$$V_o = I_{L1}\left(\frac{R+Ls}{RCLs^2 + RCs + 1}\right) \tag{20}$$

$$F_{S1} = \frac{I_{L1}\left(\dfrac{R+Ls}{RCLs^2 + RCs + 1}\right)}{I_{L1}\left(\dfrac{RCLL_1 s^3 + RCL_1 s^2 + (L_1+L)s + R}{RCLs^2 + RCs + 1}\right)} \tag{21}$$

$$F_{S1} = \left(\frac{R+Ls}{RCLs^2 + RCs + 1}\right)\left(\frac{RCLs^2 + RCs + 1}{RCLL_1 s^3 + RCL_1 s^2 + (L_1+L)s + R}\right) \tag{22}$$

$$F_{S1} = \left(\frac{R+Ls}{RCLL_1 s^3 + RCL_1 s^2 + (L_1+L)s + R}\right) \tag{23}$$

For $F_{S2}$, system transfer function calculated as below:

$$V_{dc} = V_i = L_{L2}L_2 s \tag{24}$$

$$V_o = I_{L2}\left(\frac{R+Ls}{RCLs^2 + RCs + 1}\right) \tag{25}$$

$$F_{S2} = \frac{V_o}{V_i} \frac{I_{L2}\left(\dfrac{R+Ls}{RCLs^2 + RCs + 1}\right)}{I_{L2}L_2 s} \tag{26}$$

$$F_{S2} = \left[\frac{R+Ls}{RCLs^2 + RCs + 1} \cdot \frac{1}{L_2 s}\right] \tag{27}$$

$$F_{S2} = \left[\frac{R+Ls}{RCLL_2 s^3 + LL_2 s^2 + L_2 s}\right] \tag{28}$$
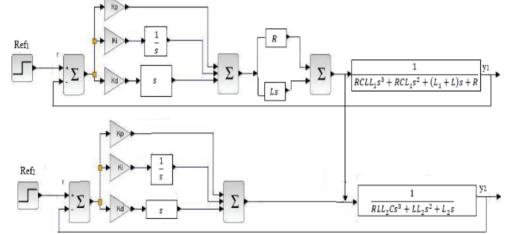


**Figure 5** Block diagram of the control of the system for RL load

$$\begin{bmatrix} F_{S1} \\ F_{S2} \end{bmatrix} = \begin{bmatrix} \dfrac{R+Ls}{RCLL_1 s^3 + RCL_1 s^2 + (L_1+L)s + R} & 0 \\ 0 & \dfrac{R+Ls}{RCLL_2 Cs^3 + LL_2 s^2 + L_2 s} \end{bmatrix} \begin{bmatrix} \dfrac{t_1}{(t_1+t_2)} \\ \dfrac{t_2}{(t_1+t_2)} \end{bmatrix} \tag{29}$$

$$\begin{bmatrix} F_{S1} \\ F_{S2} \end{bmatrix} = \begin{bmatrix} \dfrac{(L+K_d)s^2 + (K_p+R)s + K_i}{RCLL_1 s^4 + RCL_1 s^3 + (L_1+L_2+K_d)s^2 + (R+K_p)s + K_i} & 0 \\ 0 & \dfrac{(L+K_d)s^2 + (K_p+R)s + K_i}{RCLL_2 s^4 + LL_1 s^3 + (L_2+K_d)s^2 + (K_p)s + K_i} \end{bmatrix} \begin{bmatrix} \dfrac{t_1}{(t_1+t_2)} \\ \dfrac{t_2}{(t_1+t_2)} \end{bmatrix} \tag{30}$$

When the total $t$ time is considered as the working time of the two modes, the working rates to be determined by the

time durations of the two functions are as given in the matrix as in Eq. (29). PID can be applied to the mathematical model

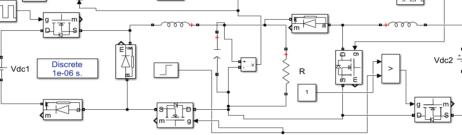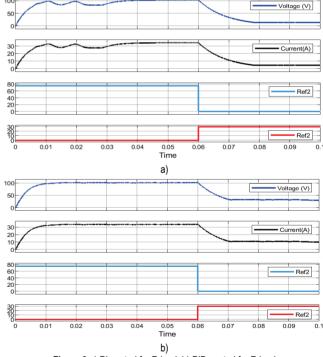of the generated power circuit for *R* load as shown in the equation matrix as in Eq. (30). The block diagram of the application of the controller to the system at the RL load is as given in Fig. 5.
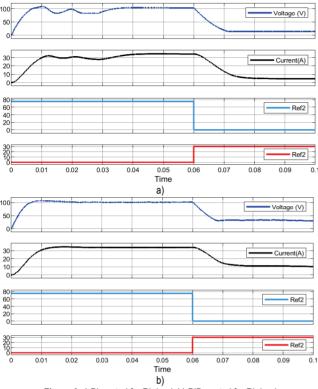


**Figure 6** a) PI control for RL load, b) PID control for RL load

For the RL load, the mathematical models of the transfer functions are created in the application of the circuit, where $R = 3$ ohm and $L = 10$ mH. When the system is controlled with $P = 5$ and $I = 1$ values and PI controls, the current and voltage on the load are formed as given in Fig. 6a. The settling time of current and voltage takes place in 0.038 s. For Boost mode, while 102 V voltage is applied to the load, the current passing through the load is 33.9 A. The electrical energy power conversion obtained for RL load in boost mode is 3457.8 W. For Buck mode, while a voltage of 33 V can be applied to the load on the load, a current of 11 A flows over the load. The electrical energy power conversion obtained for RL load in buck mode is 363 W. When the system is controlled by PID controls with $P = 5$, $I = 1$ and $D = 0.2$ values, the current and voltage on the load are formed as given in Fig. 6b. The settling time of current and voltage takes place in 0.01 s. This provides a 73.6% improvement in the settling time. For Boost mode, while 101 V voltage is applied to the load, the current passing through the load is 33.6 A. For Buck mode, while a voltage of 33 V can be applied to on the load, a current of 11 A passes through the load.

In Fig. 7, the PID Controlling signal outputs of the RLC and the PWMs controlled by the Controllers are given. The first PID controller, which controls the boost mode for up to 0.6 s, after the active control signals on the system for 0.6 s, the Second PID control for Buck mode at load of RL is

activated and controls the system. Fig. 8 shows the controller output signals and controlled PWMs while the PI for RL of load is controlling the system. The first PI controller, which controls the boost mode up to 0.6 s for RL load, the Second PI is runnig for the Buck mode and controls the system for RL load. Since PI Control is not sufficient for the boost mode, the PWMs cannot control enough to give the desired output and It is observed that the PWM is given to the system equally and linearly. It is observed that the linearity of the PWMs changes in cases where the controller is made effective, but the linearity of the PWMs does not deteriorate in cases where effective control is not provided.

The circuit model of the converter circuit for *R*, *L* and *C* load is given in Fig. 9. The mathematical models of the transfer function of the circuit according to the series connected RLC load can be arranged as follows.

$$V_{dc} = V_i = L_{L1}\left[L_1 s + \left(\cfrac{1}{R + Ls + \cfrac{1}{Cs}} + Cs\right)^{-1}\right] \quad (31)$$

$$V_{dc} = V_i = L_{L1}\left[L_1 s + \left(\cfrac{1}{\cfrac{RCs + CsLs + 1}{Cs}} + Cs\right)^{-1}\right] \quad (32)$$

$$V_i = L_{L1}\left[L_1 s + \left(\cfrac{Cs}{RCs + CsLs + 1} + Cs\right)^{-1}\right] \quad (33)$$

$$V_i = L_{L1}\left[L_1 s + \left(\cfrac{Cs + CsRCs + CsCsLs + Cs}{RCs + CsLs + 1}\right)^{-1}\right] \quad (34)$$

$$V_i = L_{L1}\left[L_1 s + \left(\cfrac{RC^2 s^2 + LC^2 s^3 + 2Cs}{RCs + CsLs + 1}\right)^{-1}\right] \quad (35)$$

$$V_i = L_{L1}\left[L_1 s + \left(\cfrac{RCs + CLs^2 + 1}{RC^2 s^2 + LC^2 s^3 + 2Cs}\right)\right] \quad (36)$$

$$V_i = L_{L1}\left(\cfrac{C^2 LL_1 s^4 + L_1 RC^2 s^3 + 2L_1 Cs^2 + RCs + CLs^2 + 1}{RC^2 s^2 + LC^2 s^3 + 2Cs}\right) \quad (37)$$

$$V_i = L_{L1}\left[\cfrac{C^2 LL_1 s^4 + L_1 RC^2 s^3 + (2L_1 C + CL)s^2 + RCs + 1}{RC^2 s^2 + LC^2 s^3 + 2Cs}\right] \quad (38)$$

$$F_{S1} = \cfrac{I_{L1}\left(\cfrac{RCs + CLs^2 + 1}{RC^2 s^2 + C^2 Ls^3 + 2Cs}\right)}{I_{L1}\left(\cfrac{C^2 LL_1 s^4 + L_1 RC^2 s^3 + (2L_1 C + CL)s^2 + RCs + 1}{RC^2 s^2 + C^2 Ls^3 + 2Cs}\right)} \quad (39)$$

$$F_{S1} = \left(\cfrac{RCs + CLs^2 + 1}{RC^2 s^2 + C^2 Ls^3 + 2Cs}\right)\left(\cfrac{RC^2 s^2 + C^2 Ls^3 + 2Cs}{C^2 LL_1 s^4 + L_1 RC^2 s^3 + (2L_1 C + CL)s^2 + RCs + 1}\right) \quad (40)$$

$$F_{S1} = \left[\cfrac{CLs^2 + RCs + 1}{C^2 LL_1 s^4 + RC^2 L_1 s^3 + (2L_1 C + CL)s^2 + RCs + 1}\right] \quad (41)$$
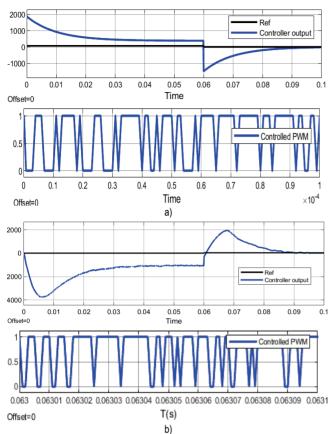
**Figure 7** a) PID control signal and controlled PWMs in RL load of my system in boost mode, b) a) PID control signal and controlled PWMs in RL load of my system in buck mode

For $F_{S2}$, system transfer function calculated as below:

$$V_{dc} = V_i = I_{L2}L_2 s \tag{42}$$

$$V_o = I_{L2}\left(\frac{CLs^2 + RCs + 1}{RC^2 s^2 + C^2 Ls^3 + 2Cs}\right) \tag{43}$$

$$F_{S2} = \frac{V_o}{V_i} = \frac{I_{L2}\left(\dfrac{CLs^2 + RCs + 1}{RC^2 s^2 + C^2 Ls^3 + 2Cs}\right)}{I_{L2}L_2 s} \tag{44}$$

$$F_{S2} = \left(\frac{CLs^2 + RCs + 1}{C^2 L_2 Ls^4 + RC^2 L_2 s^3 + 2L_2 Cs^2}\right) \tag{45}$$

When the total $t$ time is considered as the working time of the two modes, the working rates to be determined by the time durations of the two functions are as given in the matrix form below.
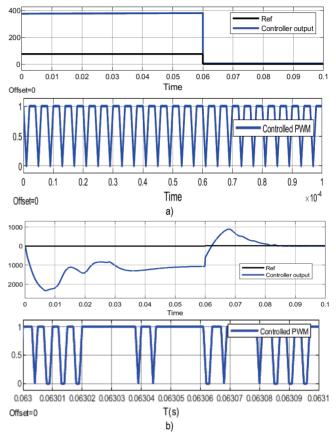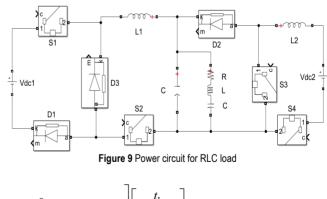


**Figure 8** a) PI control signal and controlled PWMs for RL load of system in boost mode, b) a) PI control signal and controlled PWMs in RL load of system in buck mode



**Figure 9** Power circuit for RLC load

$$\begin{bmatrix} F_{S1} \\ F_{S2} \end{bmatrix} = \begin{bmatrix} \dfrac{CLs^2 + RCs + 1}{C^2 LL_1 s^4 + RC^2 L_1 s^3 + (2CL_1 + CL)s^2 + RCs + 1} & 0 \\ 0 & \dfrac{CLs^2 + RCs + 1}{C^2 LL_2 s^4 + RC^2 L_2 s^3 + 2CL_2 s^2} \end{bmatrix} \begin{bmatrix} \dfrac{t_1}{(t_1 + t_2)} \\ \dfrac{t_2}{(t_1 + t_2)} \end{bmatrix} \tag{46}$$

Fig. 10 gives the control block diagram of the system at the RLC load. For the RLC load, the mathematical models of the transfer functions are created in the application of the circuit, where $R = 3$ ohm, $C = 50$ mF and $L = 10$ mH. When the system is controlled with $P = 5$ and $I = 1$ values and PI controls, the current and voltage on the load are formed as given in Fig. 11a. The settling time of current and voltage takes place in 0.038 s. For Boost mode, while 106 V voltage

is applied to the load, the current passing through the load is 30 A. For Buck mode, while a voltage of 37 V can be applied to the load on the load, a current of 10A flows over the load. When the system is controlled by PID controls with $P = 5$, $I = 1$ and $D = 0.2$ values, the current and voltage on the load are formed as given in Fig. 11b. The settling time of current

and voltage takes place in 0.02 s. This provides a 47.6% improvement in the settling time. For Boost mode, while 106 V voltage is applied to the load, the current passing through the load is 30 A. For Buck mode, while a voltage of 30 V can be applied to on the load, a current of 10 A passes through the load.
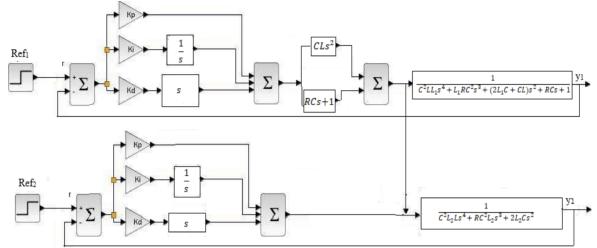


Figure 10 The control block diagram of the system at the RLC load
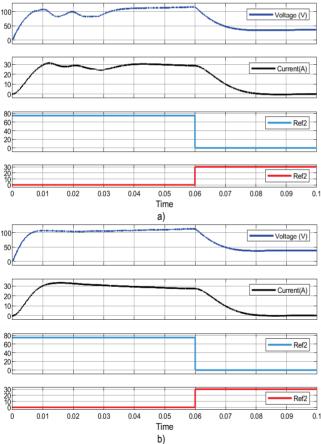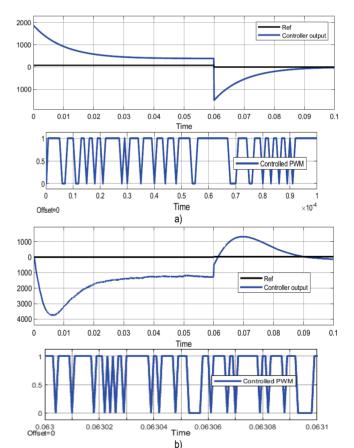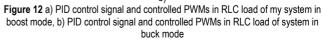


Figure 11 a) PI control for RLC load, b) PID control for RLC load



Figure 12 a) PID control signal and controlled PWMs in RLC load of my system in boost mode, b) PID control signal and controlled PWMs in RLC load of system in buck mode

In Fig. 12, the PID Control signal outputs at the RLC load connected in the system and the PWMs controlled are

given. The first PID controls the boost mode for up to 0.6 s in the first reference value, after the control signals are operated on the system for 0.6 s, the Second PID for buck mode is operated and controls the system for RLC load in the other reference.

Fig. 13 shows the controller output signals and controlled PWMs when the PI controller for RLC load controls the system. The first PID controller is operating the boost mode up to 0.6 s at RLC load. After the active control signals are on the system for 0.6 s at the first part reference value, the Second PID control is activated for the buck mode and controls the system at the second part reference value. In obtained the results, the PWMs cannot control enough to give the desired output since PI Control is not sufficient for the boost mode and it is observed that the PWM is given to the system equally and linearly.



a)



b)
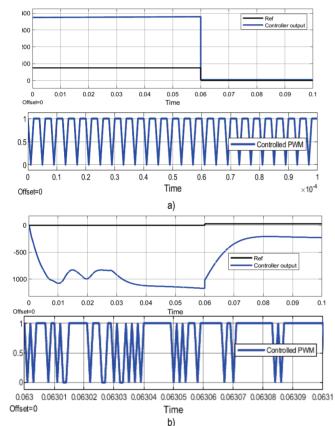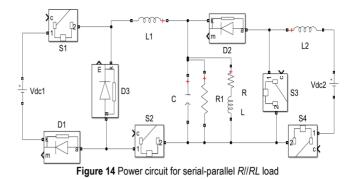
**Figure 13** a) PI control signal and controlled PWMs in RLC load of my system in boost mode, b) PI control signal and controlled PWMs in RLC load of system in buck mode

The circuit model for the application formed by parallel loads is given in Fig. 14. One of the parallel connected loads is the series RL load. R values at load are equal. The mathematical models of the transfer function of the circuit according to the series and parallel connected $R$ and RL loads can be arranged as follows.



**Figure 14** Power circuit for serial-parallel $Rl/RL$ load

$$V_{dc} = V_i = L_{L1}\left[L_1 s + \left(\frac{1}{R + Ls} + \frac{1}{R} + Cs\right)^{-1}\right] \quad (47)$$

$$V_i = I_{L1}\left[\frac{CLL_1 s^3 + (L_1 R^2 C + LL_1)s^2 + (2RL_1 + L)s + R}{LCs^2 + (R^2 C + L)s + 2R}\right] \quad (48)$$

$$V_o = I_{L1}\left[\frac{R^2 + Ls}{LCs^2 + (R^2 C + L)s + 2R}\right] \quad (49)$$

$$F_{S1} = \frac{I_{L1}\left[\dfrac{R^2 + Ls}{LCs^2 + (R^2 C + L)s + 2R}\right]}{I_{L1}\left[\dfrac{LL_1 Cs^3 + (L_1 R^2 C + LL_1)s^2 + (2RL_1 + L)s + R^2}{LCs^2 + (R^2 C + L)s + 2R}\right]} \quad (50)$$

$$F_{S1} = \left[\frac{R^2 + Ls}{RLL_1 Cs^3 + (L_1 R^2 C + LL_1)s^2 + (2RL_1 + L)s + R^2}\right] \quad (51)$$

For $F_{S2}$, system transfer function calculated as below:

$$V_{dc} = V_i = I_{L2} L_2 s \quad (52)$$

$$V_o = I_{L2}\left[\frac{R^2 + Ls}{LCs^2 + (R^2 C + L)s + 2R}\right] \quad (53)$$

$$F_{S2} = \frac{V_o}{V_i} = \frac{I_{L2}\left[\dfrac{R^2 + Ls}{LCs^2 + (R^2 C + L)s + 2R}\right]}{I_{L2} L_2 s} \quad (54)$$

$$F_{S2} = \left[\frac{R + Ls}{LL_2 Cs^3 + (L_2 R^2 C + L_2 L)s^2 + 2RL_2 s}\right] \quad (55)$$

When the total $t$ time is considered as the working time of the two modes, the working rates to be determined by the time durations of the two functions are as given in the matrix form as in Eq. (56). PID can be applied to the mathematical model of the generated power circuit for $R$ load as shown in matrix form as in Eq. (57).

$$\begin{bmatrix} F_{S1} \\ F_{S2} \end{bmatrix} = \begin{bmatrix} \dfrac{R^2 + Ls}{RLL_1 Cs^3 + (L_1 R^2 C + LL_1)s^2 + (2RL_1 + L)s + R^2} & 0 \\ 0 & \dfrac{R + Ls}{LL_2 Cs^3 + (L_2 R^2 C + L_2 L)s^2 + 2RL_2 s} \end{bmatrix}\begin{bmatrix} \dfrac{t_1}{(t_1 + t_2)} \\ \dfrac{t_2}{(t_1 + t_2)} \end{bmatrix} \quad (56)$$

$$\begin{bmatrix} F_{S1} \\ F_{S2} \end{bmatrix} = \begin{bmatrix} \dfrac{(L+K_d)s^2 + (K_p + R^2)s + K_i}{RLL_1Cs^4 + (L_1R^2C + LL_1)s^3 + (2RL_1 + L + K_d)s^2 + (R^2 + K_p)s + K_i} & 0 \\[4mm] 0 & \dfrac{(L+K_d)s^2 + (K_p + R^2)s + K_i}{RLL_2Cs^4 + (L_2R^2C + LL_2)s^3 + (2RL_2 + K_d)s^2 + (K_p)s + K_i} \end{bmatrix} \begin{bmatrix} \dfrac{t_1}{(t_1+t_2)} \\[4mm] \dfrac{t_2}{(t_1+t_2)} \end{bmatrix} \quad (57)$$

After the transfer function equations created for serial parallel RL load, 3-ohm values for $R$ load values and 10 mH values for $L$ load values are selected. When the system is controlled with $P = 5$ and $I = 1$ values and PI controls, the current and voltage on the load are formed as given in Fig. 15a. The settling time of current and voltage takes place in 0.028 s. For Boost mode, while 74 V voltage can be applied to the load, the current passing through the load is 49.5 A. For Buck mode, while a voltage of 32 V can be applied to the load on the load, a current of 20 A flows over the load. When

the system is controlled by PID with $P = 5$, $I = 1$ and $D = 0.2$ values, the current and voltage on the load are formed as given in Fig. 15b. The settling time of current and voltage takes place in 0.01 s. This provides a 64.28% improvement in the settling time. For Boost mode, while 74 V voltage is applied to the load, the current passing through the load is 20 A. For Buck mode, while a voltage of 30 V can be applied to on the load, a current of 10 A passes through the load. PI and PID controller performance results of DC-DC converses with complex load structures are given in the Tab. 1.

**Table 1** PI and PID controller performance results of DC-DC converses with complex load structures

| | R-load | | | | RL-Load | | | |
|---|---|---|---|---|---|---|---|---|
| | Current | Voltage | Power | Settling time | Current | Power | Voltage | Settling time |
| PI | 33.6 A | 101 V | 3393.6 W | 0.04 s | 33.9 A | 3457.8 W | 102 V | 0.038 s |
| PID | 33.6 A | 101 V | 3393.6 W | 0.01 s | 33.9 A | 3457.8 W | 102 V | 0.016 s |
| | RLC Load | | | | Seri-Parallel R/RL Load | | | |
| | Current | Voltage | Power | Settling time | Current | Power | voltage | Settling time |
| PI | 30 A | 106 V | 3180 W | 0.38 s | 49.5 A | 3663 W | 74 V | 0.3 s |
| PID | 30 A | 106 V | 3180 W | 0.2 s | 49.5 A | 3663 W | 74 V | 0.1 s |
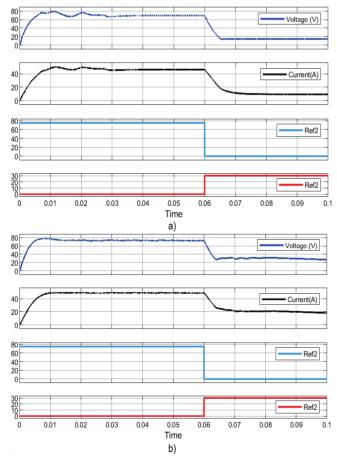


**Figure 15** a) PI control for parallel $Rl/RL$ load, b) PID control for parallel $Rl/RL$ load

## 3 CONCLUSIONS

This article gives mathematical applications of transfer functions of complex loaded DC-DC converter and PID control of this complex loaded power system. This converter provides two-way operation of the system by using two different fixed input references through power switches added to the converter's general structures. In the first application of the proposed system with $R$ load, PI control provides the settling time of the load current and voltage of the system in 0.04 s, while PID control provides the settling time as 0.01 s. In the applications to be made for RL and RLC, mathematical models of the circuit are derived for these complex load cases. In applications made for RL load, PI control ensures that the load current and voltage are settled at 0.038 s, while PID control provides 0.01 s of the settling time. In the studies, while the mathematical analysis of power circuits with complex load states is made, system improvement is achieved.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Acknowledgments

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# Battery Powered Grass Trimmer Life Cycle Assessment – Case Study

Goran Rozing, Dina Jukić, Hrvoje Glavaš*, Mirko Karakašić

**Abstract:** Batteries as a power source are the basis for all major hand tool manufacturers as vide variety of portable products became battery powered for more convenient usage. Manufacturers disable unapproved battery applications in their products by designing batteries specific for these products. In practice, the life of power tool batteries depends on two parameters: natural aging and the type of use. In a case study of a Battery Powered Grass Trimmer which battery broke after four years, the repair procedure for the package is shown. However, shortly after the repair, the Battery Powered Grass Trimmer suffered a bearing deformation that rendered it unusable. Due to its age and the unavailability of replacing electric engine, the Trimmer was scrapped and a detailed Life Cycle Analysis (LCA) applying SimaPro methodology is provided. Since the product under study is no longer on the market, a properly functioning, refurbished battery with significantly increased capacity is used in a new battery-powered grass trimmer from another manufacturer. The paper's final consideration underscores the need for an international standard that regulates battery compatibility and reduces waste, especially electronic waste.

**Keywords:** battery; battery protection; Life Cycle Analysis; maintenance; SimaPro; trimmer

## 1 INTRODUCTION

Power-driven hand tools are relying on Li-Ion batteries, increasingly. The main reason for this transition is elimination of a connection cord without significant increase of the mass that is characteristic for other battery forms, as illustrated in Fig. 1.
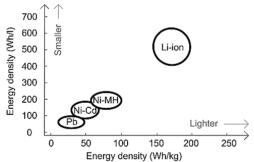


**Figure 1** Energy densities of technical solutions for some common batteries, [1].

Manufacturers have been compelling customers into using their battery packs, and offering a variety of products powered by one battery solution, [2]. Most manufacturers have their own patents on contacts; some have even introduced multiple contacts to prevent users from easily using other batteries. Small manufacturers have teamed up and formed the Cordless Alliance System [3], but the big ones hold the patent rights to the battery pack designs. These patents also extended to battery pack connections to improve output of a power tool by using battery packs which users have already had [4], as Fig. 2 shows.

To enable the adaptation of the device to receive batteries from different manufacturers, adapters such as the MakitaBL1830 battery conversion device [5] were patented. However, the Makita patent prevented wider use of adapters, and consequently prevented the idea advocated by the Cordless Alliance System. Within the European Union (EU), awareness of the problem is slowly growing, and the solution has started at the level of small devices such as mobile phones. The EU has published its new 'Common Charger' directive, [6].
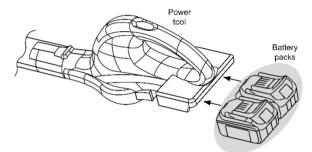


**Figure 2** Power tool using plural battery packs as power source, [4].

Starting December 28, 2024, every phone, tablet, camera, pair of headphones and earbuds, headset, handheld videogame console, portable speaker, e-reader, keyboard, mouse, and portable navigation system sold in the EU must have a USB Type-C port. If charging is higher than 15 W, it is also required to incorporate USB Power Delivery. One hopes that some form of the directive will be transferred to all battery-powered devices as to reduce the amount of electronic waste.

Note that this case study was carried out over 3 years course, while the need of unified standard was recognized as soon as the study began. Recently, the new Batteries Regulation [7] was brought to authors attention, which indicates that starting from 2025, "waste batteries will have to be recycled and high levels of recovery will have to be achieved, in particular of critical raw materials such as cobalt, lithium and nickel". In addition, batteries will be removable and replaceable starting from 2027 [7].

Motivation for the analysis presented in this paper is the failure of grass trimmer battery pack, which is no longer in production. The battery pack went through a repair process, but shortly after battery cells replacement, bearing of the electric engine was deformed, resulting with unusable device. Replacement engine was not available, whereas

adaptation of different engine was not economically viable as a new trimmer would cost less.

A new trimmer was adapted to the old battery, while the old trimmer was disassembled, and recyclability analysis as well as Life Cycle Analysis (LCA) were performed. The work presented in the paper follows the timeline of procedures mentioned in the previous paragraph and is divided into three parts of maintenance: repairment of the existing battery, adaptation of the battery to the new trimmer, and analysis of the old trimmer recyclability. Analyses were performed within the frame of the SimaPro software.

## 2 RESEARCH METODOLOGY

The trimmer under study is MEROX, model MX-CL-18, shown in Fig. 3. It was purchased in 2013 for the price of 100.75 € and was provided with two batteries. Specification of the trimmer are: 18 V d.c. / 1.5 Ah rot 9000 m$^{-1}$ $\varnothing$260 mm. After 4 years of use, it was determined that battery pack is damaged. Prior to battery pack replacement, housing was never altered due to warranty. The battery pack was replaced with newly purchased one which provided 13 % more capacity (based on comparison of data provided by the manufacturers). However, opting for new battery pack was not determined on the basis of higher capacity, rather it was the most cost-efficient option.



**Figure 3** Subject of the study MEROX MX-CL-18 grass trimmer. Enlarged details show battery pack features.

After little over a year of use with the new battery pack, damages of the head support were noticed; in other words, engine was not operational. Investigation of prices and available battery-powered trimmers in chain stores revealed that MEROX MX-CL-18 was not available for purchase. Optimal option was to purchase new trimmer with no battery included, as often power tools are sold in this manner in the chain stores, and adapt previously repaired battery pack to the newly purchased trimmer. Lack of battery standard made

the adaptation challenging as new trimmer had different battery connections in comparison to the old one. Technical realization of devices found in patent databases [8, 9] indicated that the additional contact on the new trimmer battery pack usually represents the thermistor protective element, which can be Negative Temperature Coefficient (NTC) or Positive Temperature Coefficient (PTC). To determine whether it is NTC or PTC, trimmer needed to be powered on, [10]. However, further research of patents showed that short-circuiting could damage semiconductors element in the start-up system, [11]. Therefore, it was opted for incorporating a common resistor instead of PTC. Trimmer was then in use until it reached end of its life cycle.

Widely favorable LCA [12-14] was applied to determine the environmental impact of the analyzed grass trimmer. To prepare the trimmer for the LCA as sugessted in [15, 16], it was disassembled into elements which masses were determined using analytical laboratory scale. Eco-indicators were assigned to each element based on their materials in the SimaPro 9 ecoinvent 3.5 software, [17]. Product development as well as sustainability objectives' environmental impact can be measured with the aid of Simapro, Life Cycle Assessment programme. According to ISO14040, LCA is a compilation and evaluation of inputs, outputs, and possible environmental effects of a product system during its life cycle, [18]. Numerous uses for the SimPro exist, including environmental protection, eco-design of products, carbon and water analyses, and Key Performance Indicators for ecological performance. For this contribution version SimaPro 9 with ecoinvent 3.5 database was used. Within the SimaPro software, we investigated recyclability of trimmer, environmental impact of the trimmer production, and environmental impact of trimmer life cycle based on eco-indicators, [19].

Trimmer recyclability was determined as follows, [20]:

$$R = \frac{\sum_{i=1}^{n} m_i \cdot b_i \cdot r_i}{M \cdot r_{max}} = \frac{9830.3}{2173.1 \cdot 5} = 0.9047, \tag{1}$$

where $m_i$ is the mass of the $i^{th}$ part expressed in grams, $b_i$ is the number of repetitions of the $i^{th}$ part in the product, $r_i$ is the recyclability rating of the $i^{th}$ part, $M$ is the total mass of the trimmer expressed in grams, and $r_{max}$ the highest recyclability rating.

Two sets of parameters were made in the SimaPro software interface's "Calculation setups" section in order to examine the environmental effects of trimmer production. The first set dealt with production, and the findings show how each material used to make the trimmer affects the environment. The second set made it possible to compare the product's environmental impact at every step of its life. The stages that were studied were: trimming tool production, trimming tool use, trimming tool disposal, and recycling of materials.

Lastly, trimmer life cycle was divided into four phases to investigate life cycle environmental impact: manufacturing, use, disposal, and material reuse.

## 3 TRIMMER BATTERY REPAIRMENT AND ADAPTATION

Grass trimmers are ideal for maintenance of sloped terrains impractical to approach with riding lawn mowers, and necessary for maintenance of marginal areas which the lawn mower cannot approach. As trimmers are small in mass, ones that are powered via connection cords are less versatile than the battery-powered trimmers. Cords may even cause disturbance in terrain maintenance. In addition, battery-powered trimmers guarantee ease of use without the worry about tilting which accompanies gasoline-powered solutions.

### 3.1 Battery Pack Repairment

The MEROX trimmer under study was sold with two included batteries of 1.5 Ah capacity, which used to provide up to 45 minutes of autonomy. Fig. 4 shows the charger JLH302101500G1 240 V/50 Hz 45 W and the battery BP09Li-180 18 V.

Li-Ion batteries have limited lifespan which does not necessarily depend on the declared number of charge and discharge cycles, [21]. Different configurations of battery packs are formed according to the required voltage for which the device is designed and the energy on which the autonomy of the device's operational state depends. Battery packs for almost all hand tools, electric bicycles, and certain cars are made of Li-Ion cells 18650 by the spot-welding process, [22].



**Figure 4** Charger and battery of the trimmer under study.



**Figure 5** Repairment of the defective battery pack with a nominal capacity of 1.5 Ah with new cells with a capacity of 3.4 Ah.

Reparation procedure by cell replacement is relatively simple and fast. Fig. 5 shows the inside of the battery pack. The original 18650 cells with capacity of 1500 mAh, after 4 years of use, were replaced with Panasonic NCR18650B

18650 cells with capacity of 3400 mAh, which is 13 % more capacity than both original batteries used to provide. Therefore, there was no need to renew the second battery. The cost of renovation was 36 €. For comparison, the EINHELL battery Power-X-Change Plus 18 V 3.0 Ah is 54.90 €, which renders maintaining the existing battery more cost-efficient.

### 3.2 Trimmer Adaptation

After battery repairment, the trimmer was in operation for a little over a year. After 5 years of overall usage, wear of the brass friction bearing was noticed. During the replacement procedure, the part of the head support that is pressed onto the shaft was damaged, as seen in Fig. 6.



**Figure 6** Damages on the head support of the trimmer under study.

Replacing the HRS775S-6221F.DC 18 V/R, 2011.01 engine which corresponds to the MEROX trimmer under study should be a simple procedure. However, the engine produced in 2011 was no longer available in 2019 when damages occurred. A similar engine that would require an additional adjustment costs 19 €, delivery included. A brand-new trimmer with a three-year warranty, but no battery included, was offered in store for 33.18 €. Eventually, it was bought for discounted price of 26.54 €. Unfortunately, the renewed battery pack of the MEROX trimmer did not fit the purchased trimmer as, instead of two contacts, the new trimmer had three, which is illustrated in Fig. 7.
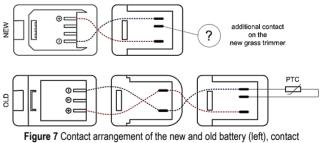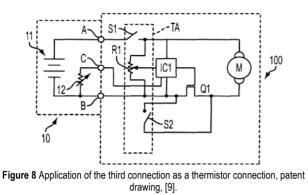


**Figure 7** Contact arrangement of the new and old battery (left), contact arrangement of the head support (middle), and arrangements of the protective element (right).
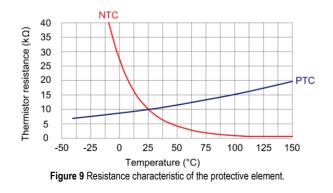
The purchased trimmer is powered by battery of up to 8 Ah capacity, whereas the MEROX trimmer was powered by battery of 1.8 Ah capacity. The additional contact usually represents the thermistor protective element, which can be Negative Temperature Coefficient (NTC) or Positive Temperature Coefficient (PTC). Sometimes, even more contacts can be found on the battery packs. For example, patent [8] from 2013 requests 5 contacts. That said, most of

simple devices like trimmers use only power supply and overheating protection [9], as they do not have regulations. Fig. 8 shows battery connections and how the third connector was used to connect the thermistor.



**Figure 8** Application of the third connection as a thermistor connection, patent drawing, [9].

Patent [9] explains Fig. 8 in detail: The conventional power tool battery pack 10 comprises a housing 13, cells 11 connected between first and second terminals A, B of the housing, and a thermistor 12 also connected between first and third terminals A, C of the housing. The drill 100 can be connected to such a power tool battery pack 10 via the terminals A and B.

The patent database with patent applications and approved patents represents a valid source of information on the technical realization of devices. However, for further insights devices have to be powered on. Specifically, when connecting the positive and negative poles of the new battery to the trimmer, device should be turned on. This provides following information: if device is turned on and immediately turns off, then the installed element is PTC; if NTC is installed then the device will continue running, as indicated in Fig. 8.

However, short-circuiting during the trimmer start-up test with an old battery is not an option, because damage to the device of the semiconductor elements in the start-up system are likely to occur in the case of incorrect termination, [11]. Based on information from the manufacturer of protective equipment [23], that the expected value of PTC resistance at ambient temperature is known to be 10 kΩ (Fig. 9).



**Figure 9** Resistance characteristic of the protective element.

Instead of incorporating a PTC, a common resistor was placed and the trimmer was successfully running on the old

battery. To preserve the warranty, the battery holder of the old trimmer was attached to the new one. The contacts secure it, springs and hilum in strips were used, as shown in Fig. 10. Fig. 10 shows the apparel of the new trimmer with the old battery and wiring. As the old battery has a unique layout, 3D printing of the adapter would take a lot of time. In the case of the Einhell battery on the new trimmer, one can obtain pre-made solutions which are visually and practically better than the realization shown in Fig. 10. In addition, numerous platforms for exchanging 3D models of layouts exist. For example, adapters can be found on the Thingiverse design community for making and sharing 3D printable things, [24]. The price of printed 3D adapters on the eBay platform ranges from 25 € to 37 €.



**Figure 10** New trimmer with the old battery. Enlarged detail shows the wiring.

## 4 LIFE CYCLE ASSESSMENT OF GRASS TRIMMER

The MEROX MX-CL-18 grass trimmer under study in this contribution has reach the end of its life cycle (Fig. 11). To determine its impact on the environment, the Life Cycle Analysis methodology was applied. To show the impact of specific materials on the environment as consistently as possible, it was necessary to record their entire life cycle cradle-to-grave by listing and analyzing all the elements shown in Fig. 11. Elements and their ratios are listed in Tab. 1. After this step, eco-indicators were defined. Application of the SimaPro software package allowed us to qualitatively assign the dimensionless eco-indicators corresponding to individual materials in a manner that higher indicator suggests greater environmental impact, [20].

**Table 1** Relative rations of trimmer MX-CL-18 materials.

| Material | Mass (g) | Ratio (%) |
|---|---|---|
| Polymer-ABS | 1118.11 | 51.45 |
| Steel | 287.80 | 13.21 |
| Aluminum | 263.60 | 12.13 |
| Li-Ion battery | 207.00 | 9.53 |
| Polymer-PC | 110.17 | 5.07 |
| Cooper | 93.02 | 4.28 |
| Magnet-Ferrite | 86.27 | 3.97 |
| Graphite | 8.00 | 0.37 |

**Figure 11** Trimmer under study disassembled and prepared for LCA.

### 4.1 Recyclability of Trimmer Elements

Masses of elements were determined by analytic scale Kern ALS 220-4N, sensitivity 0.01 g, before listing in SimaPro software. Furthermore, material types were chosen from predefined software resources, as well as ratings of recyclability. Analyzed trimmer has 41 elements of joined mass $M = 2173.1$ grams. Tab. 2 shows 12 out of total 41 elements.

Obtained value of trimmer recyclability upon accounting all trimmer elements is as high as 90 %, which is not surprising as half of trimmer total mass is due to Polymer-acrylonitrile butadiene styrene (ABS), highly recyclable and reusable material (Tab. 1).

**Table 2** Recyclability analysis of trimmer MX-CL-18 elements.

| Ordinal number | Element | Material | Mass of elements (g) | Pieces per product | Rating of recyclability |
|---|---|---|---|---|---|
| i | | | $m_i$ | $b_i$ | $r_i$ |
| 1 | Trimmer handle | Polymer ABS | 279.62 | 1 | 5 |
| 2 | Speed controller | Polymer ABS | 10.31 | 1 | 5 |
| 6 | Handle | Aluminum | 264.00 | 1 | 5 |
| 10 | Screw M6 | Steel | 19.03 | 1 | 5 |
| 16 | Shaft | Steel | 13.54 | 1 | 5 |
| 18 | Crank adjustment | Polymer PC | 6.88 | 1 | 5 |
| 22 | Rotating silk head | Polymer PC | 77.43 | 1 | 5 |
| 24 | Motor windings | Cooper | 88.00 | 1 | 5 |
| 36 | Tile | Cooper | 5.00 | 1 | 5 |
| 37 | Sliding contact | Graphite | 8.00 | 1 | 5 |
| 38 | Motor magnet | Ferrite | 86.27 | 1 | 5 |
| 41 | Battery | Hazardous | 336.00 | 1 | 0 |

### 4.2 Environmental Impact of Trimmer Production

To analyze the environmental impact of trimmer production two sets of settings were created in the "Calculation setups" of the SimaPro software interface. First set was related to production, the results of which represent environmental impact of individual material from which the trimmer is made. The second set allowed for comparison of all life stages of the product, and their impact on the environment. The observed phases were: production of

trimmer, use of trimmer, disposal of trimmer, and reuse of recycled materials.

Fig. 12 illustrates process three with mass balances for trimmer production. The thickness illustrates material negative impact on environment during manufacturing process. Greater thickness indicates higher impact. Process three shows that the magnet-ferrite, although not largest in mass, has the highest negative impact on the environment. On the other hand, polymer-ABS, has about three times less impact on the environment despite its mass which is 1.12 kg of total trimmer mass 2.17 kg.
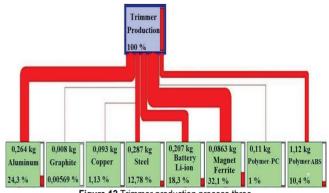


**Figure 12** Trimmer production process three.

Fig. 13 shows how each material impacts, relative to each other, three possible and different areas: human health, ecosystem, and resources.
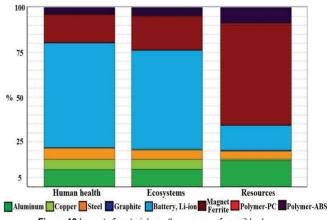


**Figure 13** Impact of materials on three areas of possible damage.
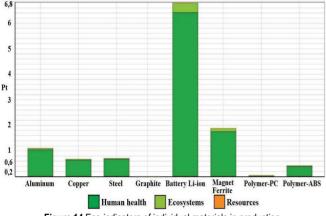
In Fig. 13, lighter shade of blue visualizes Li-Ion battery impact on these areas. As seen in Fig. 13, impact of the battery on first two is more than double of other elements combined. This is expected as toxic materials which are contained in batteries, such as lithium, cobalt and lead, could lead to serious health consequences to humans or any other exposed life form.

Dark shade of red corresponds to the magnet-ferrite, which significantly less, but still to a large extent, impacts the environment. Of the three areas of possible damage, the magnet-ferrite has the least impact on human health as exposure to the magnetic field, even for longer periods, does not have any long-term health consequences. Magnet

production affects resource consumption almost three times more than human health or ecosystem area. The reason for this is that magnets are made from different metals that are easy to magnetize (iron, cobalt, nickel), as well as from alloys of certain rare earth metals. Additionally, metals are not renewable resources.

Aluminum, indicated by color green, impacts the environment similarly as the magnet-ferrite, but in much smaller quantity. It has the least impact on human health, but frequent and long-term exposure to large amounts of aluminum, as well as inhalation of aluminum particles, still have negative effect on health. As it is often necessary to clear large areas of forest in order to build an aluminum mine, it impacts the ecosystem area to a slightly greater extent than the magnet-ferrite. Additionally, after extraction from the ground, aluminum processing plants can release harmful emissions into the atmosphere. Like other metals, it is a non-renewable resource; for the extraction and processing of aluminum it is necessary to invest a lot of electricity, which results in a greater consumption of resources.

Purple color indicates the Polymer-ABS which carries the most mass in the analyzed electric trimmer. However, it impacts the environment through all three areas to a much lesser extent than the previously mentioned materials of lower mass. As the polymer-ABS is a type of plastomer that does not burn when exposed to high temperatures, it does not cause emissions of harmful gases or other chemical compounds. In addition, it can be melted by heating and reshaped into a new product, making it almost 100 % recycled material.

Results of the analysis are often conveniently presented in the form of millipoints or points. Comparison of all the materials from which the trimmer was made in three areas of possible damage, and the comparison values are expressed in points (Pt), can be seen in Fig. 14.



**Figure 14** Eco-indicators of individual materials in production.

At first glance, it is apparent from the graph that all materials have the greatest impact on human health, significantly less on the ecosystem and almost negligible on the consumption of resources. Since this is an "isolated case", i.e., only one trimmer, it is expected that the impact of all materials and their production processes is much smaller than the impact on human health. The impact of the Li-Ion battery

on human health, as well as on the ecosystem, stands out due to the high toxicity of the materials from which it is made, and the unreliable or incorrect disposal methods.

## 4.3 Environmental Impact of Trimmer Life Cycle

Trimmer life cycle was analyzed in four phases, which are production of trimmer, usage, disposal and reuse of its materials. Results of the analysis can be seen in Fig. 15.
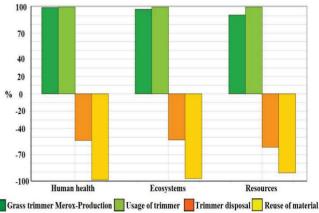


**Figure 15** Impact of trimmer life cycle phases on three areas of possible damage.

In Fig. 15, green illustrates values which impact the environment negatively, but they are expressed as positive numbers, whereas orange illustrate values which impact the environment oppositely, but they are expressed as negative numbers. Phases of production and usage of the analyzed trimmer have almost maximum values in all three areas of possible damage as they impact the environment negatively to the greatest extent. Furthermore, trimmer disposal phase includes transporting the disassembled parts of the trimmer to a location suitable for their disposal and the environmental burden of that disposal, therefore the load reduction in the trimmer disposal phase is slightly less than the phase of reusage of the material. Since the total trimmer recyclability is around 90 %, reuse of recycled material reduces environmental load through all three phases. This reduction is slightly less in the area of resource reuse due to battery, magnet-ferrite, and aluminum which are made from non-renewable resources.

Points which correspond to the impact of trimmer life cycle phases on three areas of possible damage are presented in Fig. 16.

Throughout all life stages shown in Fig. 16, the most accentuated category is human health, ecosystem category is gravely less, and the resource category is almost not visible on the graph. The stages of production and use of trimmer have approximately the same value as the stage of reuse of recycled material through all three areas of possible damage, but with opposing signs. These two phases individually increase the burden on the environment to almost the same extent that the reuse of recycled material reduces it due to high recyclability of trimmer.
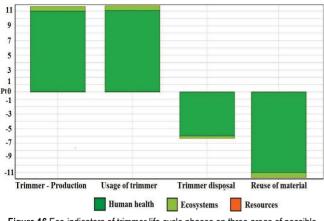
**Figure 16** Eco-indicators of trimmer life cycle phases on three areas of possible damage.

## 5    RECAPITULATION ANNOTATION

As the availability of lithium batteries increases, so does the number of devices which use them as power sources. Low mass and high energy density per unit of mass further promotes their usage. Different patent solutions complicate application compatibility, condemning users to follow one manufacturer as they invested in one type of battery holder. This problem is recognized on a global level, and the research presented in this paper has a positive epilogue. In August 2023, the European Union adopted the first provision related to the regulation of the battery market and unification of its application.

The Battery Powered Grass Trimmer presented in this paper, underwent battery repairment due to impossibility of buying a new one. Then, while attempting to repair the friction bearing, trimmer reached the end of its life cycle and was used for recyclability analysis. The battery, which was practically new at the end of trimmer life cycle, could not be used in other devices, and adapter was made from the old battery in order to use it on the new trimmer. During the adjustment process, effort was put towards bypassing the limitations of the trimmer manufacturer, which was reflected in the safety function of protection against overheating. The old solution did not have protection against overheating as the potential threat was smaller due to the capacity of the battery. Nevertheless, the new device did not lead to overheating either, so the same solution was bypassed. All procedures are described in detail and are applicable to most new devices.

A special part of this contribution is dedicated to the LCA of the trimmer, which was carried out using SimaPro, one of the most popular tools. Analyzed trimmer consisted mostly of plastic, followed by metals. Trimmer recyclability is relatively high at 90.47 %. The biggest negative impact on the environment is delivered by engine magnets, aluminum, and battery. In terms of impact on health and ecosystem, the battery represents the greatest threat, and should be disposed of properly. Therefore, the cells were replaced in the repairment stage and handed over to an authorized recycling company. The eco indicators of the battery are the highest, which is evident from the data presented in the paper. The second eco indicator corresponds to magnet-ferrite, and third to aluminum. Eco indicators for iron and copper are lower than aluminum, but higher than polymer.

The above indicators confirm the justification for the adoption of new European guidelines regarding the regulation of the battery market, but they also provide guidance on the possibility of maintaining and repairing battery-powered devices. A significant source of information on technical implementations is the patent database as detailed technical solutions can rarely be found in scientific papers. Initially battery-powered tools manufacturers also produced and sold battery adapters. At that time, battery powered tools were made in small numbers, hence only several manufacturers existed. With technological advancements, retail companies which own chain stores, like Lidl where trimmer under study was purchased, began to manufacture, and sell their own brands of battery powered tools. To protect their products, retail companies relied on patent rights. As a result, there are hundreds of distinct battery patents that may be found in patent databases and are hardly ever referenced in academic journals. Therefore, in this contribution we express a need for battery standard, which we show on an example of battery powered grass trimmer life cycle.

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# Comparison of Maximum Peak Pressures of Free Underwater Explosion by Numerical Modeling and Empirical Expressions

Toma Durdov, Damir Varevac*

**Abstract:** The article compares the results of empirical expressions for the maximum peak pressures of an underwater explosion and numerical models made in hydrocode software LS-DYNA. Spherical charge of 136.08 kg TNT explosive was chosen and observed distance was up to 15 m. An overview of empirical expressions is given and the results according to several authors are compared. The Cole expression was chosen as a reference for comparison. For the purpose of the numerical modelling, the influence of the size of the finite elements of the explosive, the size and shape of the volume of water and the size of the finite elements of water was examined. The size of the finite elements of the medium (water) was shown to be the most significant parameter that affects the magnitude of the pressure results, and recommendations for modelling were given.

**Keywords:** empirical expressions; maximum peak pressure; numerical modelling; underwater explosion

## 1 INTRODUCTION

Underwater structures, such as maritime, river and hydrotechnical structures and infrastructure are potential targets of terrorist attacks. Their demolition can result in the interruption of supply lines and communications, as well as material damage and human casualties. The construction of underwater structures resistant to the action of an underwater explosion, intentional or unintentional, contributes to the safety of the community.

Explosives are conditionally stable, and after initiation, they convert to a stable state through a chemical reaction [1] [2]. The explosion creates a temperature of about 3000 °C, a pressure of about 5000 MPa and an increase in the initial volume up to 1000 times [1, 3]. The high pressure generates a shock wave, the speed of which, after a few milliseconds, decreases to the speed of sound in water (1500 m/s) [4, 5]. After the shock wave, the gaseous products of the detonation form a gas bubble, which expands under high pressure and temperature [4, 6]. The gas bubble expands, while the pressure in it drops, and then contracts, which is repeated several times, which is called gas bubble pulsation [7, 8].

Significant experimental research cannot be carried out in laboratory conditions because the scaling law cannot be applied to an underwater explosion [1]. Therefore, experimental research must be carried out in realistic conditions, which requires the engagement of significant material resources and specialized human resources, along with certain risks. Pressure measurement is very complex, and the shock wave propagates according to the sound wave theory [1]. Pressure magnitude, in real conditions, depend on salinity, in seawater, hydrostatic pressure, water stream, and temperature distribution has a special influence. Differences in water temperature cause bending of the wave, and the potential creation of sound channels, shadows and reverberation.

Available experimental and results obtained using empirical expressions are limited, and at some distances from the centre of the explosion have deviations of up to 50% [1]. Solving the differential equations, which describe the underwater explosion, is complex even for simple models. Numerical modelling of the underwater explosion and verification of the obtained numerical results on experiments is imposed as the only way to solve this task. Numerical underwater explosion modelling research is described in this paper.

## 2 EMPIRICAL EXPRESSIONS FOR DETERMINING MAXIMUM PRESSURES OF UNDERWATER EXPLOSIONS

In the literature, there are several empirical expressions from different authors for the calculation of the parameters of an underwater explosion in an unbounded medium. It should certainly be pointed out that most of these terms were created based on the terms proposed by Cole [1]. Based on numerous experiments, Cole [1] determined the empirical correlation of the maximum pressure, the distance from the centre of the explosion, and the amount of explosives for the spherical shape of the charge:

$$P_{\mathrm{m}} = k \left( \frac{W^{\frac{1}{3}}}{R} \right)^{\alpha}, \tag{1}$$

where $P_{\mathrm{m}}$ is the maximum pressure, $k$ and $\alpha$ coefficients depending on the type of explosive, $W$ is the mass of the explosive and $R$ is the distance from the centre of the explosion. For TNT and its density 1.52 g/cm$^3$, Eq. (1) is:

$$P_{\mathrm{m}} = 52.39 \left( \frac{W^{\frac{1}{3}}}{R} \right)^{1.13} \quad (\mathrm{MPa}) \tag{2}$$

Alternatively, the author for close distances $R_0 < R < 6R_0$ gives the expression:

$$P_{m} = 38.29 \frac{W^{\frac{1}{3}}}{R} e^{0.1086 \frac{W^{\frac{1}{3}}}{R}} \quad (MPa) \qquad (3)$$

Where $R_0$ is the radius of the sphere of the explosive charge. Zamyshlyayev i Yakovlev [9, 10] propose the following expressions for the maximum pressure depending on the dimensionless distance $\frac{R}{R_0}$:

$$P_{m} = \begin{cases} 45 \left( \frac{W^{\frac{1}{3}}}{R} \right) & 6 < \frac{R}{R_0} < 12 \\ 53.3 \left( \frac{W^{\frac{1}{3}}}{R} \right)^{1.13} & 12 < \frac{R}{R_0} < 240 \end{cases} \quad (MPa) \qquad (4)$$

Vranješ [6] also proposes two expressions for the maximum pressure, depending on the dimensionless scaled distance:

$$P_{m} = \begin{cases} 53.3 \left( \frac{W^{\frac{1}{3}}}{R} \right)^{1.92} & 1 < \frac{R}{R_0} < 5 \\ 53.3 \left( \frac{W^{\frac{1}{3}}}{R} \right)^{1.13} & 7 < \frac{R}{R_0} < 1000 \end{cases} \quad (MPa) \qquad (5)$$

Furthermore, some authors in the Cole equation, where the maximum pressure depends on the mass of the explosive and the standoff distance at the point being measure, proposed different coefficients, for TNT, expressed Mousem [11], as (Reid, 1996):

$$P_{m} = 52.12 \left( \frac{W^{\frac{1}{3}}}{R} \right)^{1.18} \quad (MPa) \qquad (6)$$

and Moradi [12], as (Rajendran and Narasimhan 2006):

$$P_{m} = 52.16 \left( \frac{W^{\frac{1}{3}}}{R} \right)^{1.13} \quad (MPa) \qquad (7)$$

Based on the Eq. (1), various authors proposed other values of the coefficients $k$ and $\alpha$ [1] or determining the maximum pressure from the explosion of a spherical TNT charge (Tab. 1).

**Table 1** Coefficients $k$ and $\alpha$ [1, 11-14]

|  | Cole | Mousem | Ozarmut | Moradi | Grzadiela |
|---|---|---|---|---|---|
| $k$ | 52.39 | 52.12 | 52.40 | 52.16 | 52.30 |
| $\alpha$ | 1.13 | 1.18 | 1.13 | 1.13 | 1.13 |

Fig. 1 and Tab. 2 show the results of maximum pressures as a function of the distance from the centre of the charge obtained according to the expressions of Cole, Mousem and Moradi. Since the results are very similar along the entire observed front, the empirical expression Cole (1) and adopted coefficients $k = 52.39$ and $\alpha = 1.13$ will be used for further analysis and comparison of pressures.

However, the maximum pressure obtained by the Vranješ expression, at a distance of 1 m, is significantly higher from other maximum pressure values.



**Figure 1** Incident peak pressures with distance
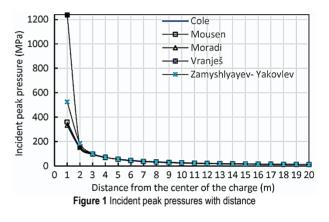
**Table 2 Incident peak pressures with distance**

| Distance (m) | Cole | Mousem | Moradi | Vranješ | Zamyshlyayev-Yakovlev |
|---|---|---|---|---|---|
|  | Pressure (MPa) | | | | |
| 1 | 333.4 | 360.0 | 331.9 | 1237.0 | 524.9 |
| 2 | 152.3 | 158.9 | 151.7 | 155.0 | 185.6 |
| 3 | 96.3 | 98.5 | 95.9 | 98.0 | 101.0 |
| 4 | 69.6 | 70.1 | 69.3 | 70.8 | 70.8 |
| 5 | 54.1 | 53.9 | 53.9 | 55.0 | 55.0 |
| 6 | 44.0 | 43.5 | 43.8 | 44.8 | 44.8 |
| 7 | 37.0 | 36.2 | 36.8 | 37.6 | 37.6 |
| 8 | 31.8 | 30.9 | 31.7 | 32.4 | 32.4 |
| 9 | 27.8 | 26.9 | 27.7 | 28.3 | 28.3 |
| 10 | 24.7 | 23.8 | 24.6 | 25.1 | 25.1 |
| 11 | 22.2 | 21.3 | 22.1 | 22.6 | 22.6 |
| 12 | 20.1 | 19.2 | 20.0 | 20.5 | 20.5 |
| 13 | 18.4 | 17.5 | 18.3 | 18.7 | 18.7 |
| 14 | 16.9 | 16.0 | 16.8 | 17.2 | 17.2 |
| 15 | 15.6 | 14.7 | 15.6 | 15.9 | 15.9 |
| 16 | 14.5 | 13.7 | 14.5 | 14.8 | 14.8 |
| 17 | 13.6 | 12.7 | 13.5 | 13.8 | 13.8 |
| 18 | 12.7 | 11.9 | 12.7 | 12.9 | 12.9 |
| 19 | 12.0 | 11.2 | 11.9 | 12.2 | 12.2 |
| 20 | 11.3 | 10.5 | 11.2 | 11.5 | 11.5 |

## 3 NUMERICAL SIMULATION OF A FREE UNDERWATER EXPLOSION

### 3.1 Numerical Models

Numerical models were created in hydrocode software LS DYNA [15, 16]. The models consist of two parts, water and explosive. Water is modeled as a fluid by Gruneisen's equations of state, without calculation of deviatoric stresses

[17]. Gruneisen's equations of state describes the relationship between pressure, density of water and its specific internal energy. For compressed water ($\mu > 0$), the pressure is:

$$p = \frac{\rho_0 C^2 \mu \left[1 + \left(1 - \frac{\gamma_0}{2}\right)\mu - \frac{\alpha}{2}\mu^2\right]}{\left[1 - (S_1 - 1)\mu - S_2 \frac{\mu^2}{\mu+1} - S_2 \frac{\mu^3}{(\mu+1)^2}\right]} + (\lambda_0 + \alpha\mu)e \quad (8)$$

where $\rho_0$ is the initial density of the medium, $\rho$ is the density of the medium, $C$ is the speed of sound in water, $\gamma_0$ is the Gruneisen coefficient, $S_1$, $S_2$ and $S_3$ are dimensionless coefficients, $\alpha$ is the correction coefficient and

$$\mu = \frac{\rho}{\rho_0} - 1 \quad (9)$$

Specific internal energy of water is calculated according to the expression:

$$e = \frac{\rho g h + P_0}{\rho \gamma_0} \quad (10)$$

where $h$ is the water depth, and $P_0$ atmospheric pressure. Tab. 3 shows the parameters of the water equation of state.

**Table 3** Parameters of the Gruneisen equation of state [13]

| $\rho_0$ (g/cm$^3$) | $C$ (m/s) | $S_1$ | $S_2$ | $S_3$ | $\gamma_0$ | $\alpha$ |
|---|---|---|---|---|---|---|
| 1.0 | 1480 | 1.75 | 0.0 | 0.0 | 0.28 | 0 |

The TNT explosive is modelled by the Jones – Wilkins – Lee (JWL) equation of state [17]:

$$p = A\left(1 - \frac{\omega}{R_1 \chi}\right)e^{-R_1 \chi} + B\left(1 - \frac{\omega}{R_2 \chi}\right)e^{-R_2 \chi} + \frac{\omega e}{\chi} \quad (11)$$

where $p$ is the pressure, $\chi$ is the relative volume, $e$ is the specific internal energy and $A$, $B$, $R_1$, $R_2$, $\omega$, are the constants of the equation of state determined experimentally. Tab. 4 gives the values of the parameters of the JWL equation of state.

**Table 4** Parameters of the JWL equation of state [13]

| $\rho_0$ (g/cm$^3$) | $A$ (kPa) | $B$ (kPa) | $R_1$ | $R_2$ | $\omega$ |
|---|---|---|---|---|---|
| 1.63 | $3.71\times10^8$ | $3.23\times10^6$ | 4.15 | 0.95 | 0.3 |

## 3.2 Multidimensional Parametric Analysis
### 3.2.1 The Influence of the Shape of the Observed Volume of Water

To obtain reliable results, it is necessary to carry out a multidimensional parametric analysis of how the size of the observed volume of water, the size of the finite elements of the explosive and the medium (water) affects the pressure results. The investigation of the underwater explosion was carried out on numerical models with the assumptions of homogeneity and isotropicity of water and explosive, as well as uniform temperature and salinity for seawater, where hydrostatic pressure was neglected. Computing time depends on the size of the model, therefore the aim is to reduce the model as much as possible. First, it will be examined whether the pressure results are affected by the reduction of the volume and shape of the observed water volume, using the spatial symmetry and permeable boundaries of the medium. The researched model is symmetrical around all three planes, and this fact was used in the modeling so that mirror boundary conditions were applied on the external SPH (smoothed particle hydrodynamics) surfaces, and the FEM nodes were constrained. Defining the type of outer model boundaries plays a critical role in the simulation and the resulting pressures. The outer boundary of the model can be defined as a no-slip and no-penetration boundary, in which case the velocity, pressure and temperature values of the particles remain preserved in the model. When modeling a free explosion in a water, as in this case, an outflow boundary was used where the particles retain their direction and speed at the boundary itself.

Water volumes with dimensions of 20×20×20 m (model 1), 20×5×5 m (model 2), 20×4×4 m (model 3), 20×3×3 m (model 4) and 20×2×2 m (model 5) were investigated, where the amount of explosives in the form of a sphere was 136.08 kg and was discretized into 1512 finite elements (Fig. 2). The size of the finite elements of water was fixed in all models and was 25×25×25 cm.
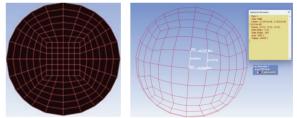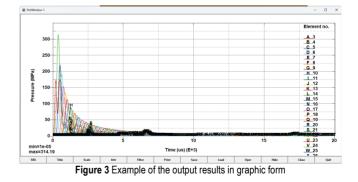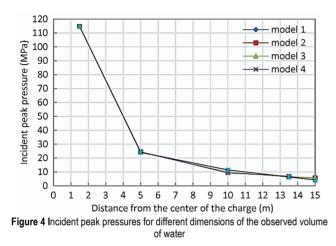


**Figure 2** Discretization of explosives, section (left) and surface (right)



**Figure 3** Example of the output results in graphic form

After the numerical processing of the previously adopted model, numerical results are obtained for various values of certain parameters of the underwater explosion in nodes, elements, etc. (Fig. 3). In addition to the possibility of viewing changes in individual parameters over time, the output data enables viewing the animation of the underwater

explosion in shades of different colors with different values of the selected parameters.

For pressure, the change in pressure value over time is obtained, which is equal on the entire finite element. Along with the pressure change diagram, the maximum pressure value is displayed, and other values can be read at certain times.

Fig. 4 shows the maximum pressures at distances of 1.5 m, 10 m, 13.5 m, 15 m and 20 m for all the models. Negligible deviations of maximum pressures are visible at distances from 15 m to 20 m where the pressures are very small.



**Figure 4** Incident peak pressures for different dimensions of the observed volume of water

By comparing the numerical results for these five models of different volumes, it can be concluded that the shape and size of the volume of the model has very little effect on the results of the maximum pressures. This fact will be used to minimize the calculation time since it increases exponentially with the volume of the space and the number of the finite elements.

### 3.2.2 Influence of the Size of the Finite Elements of the Explosive

As already mentioned, the TNT explosive in the form of a sphere with a radius of 27 cm and a mass of 136.08 kg was selected. To investigate the influence of the size of the finite elements of explosive, three sizes of finite elements were chosen, where the sphere was discretized into 3818, 7001 and 12097 elements. Tab. 5 shows the maximum pressures at a distance of 1.5 m from the centre of the explosion, where the volume of water is discretized into Hexahedral elements with edges of 10 cm, 12.5 cm, 20 cm and 25 cm. As is to be expected, the size of the maximum pressures depends on the fineness of the discretization of the water volume, but the size of the finite elements of the explosive has almost no influence on them. Therefore, the fineness of the explosive discretization does not have to be considered during further analyses. Anyway, in the further analysis the model with 12907 finite elements of the explosive will be used, because their number does not affect either the pressure results or the duration of the calculation, so any of the mentioned models could be chosen.
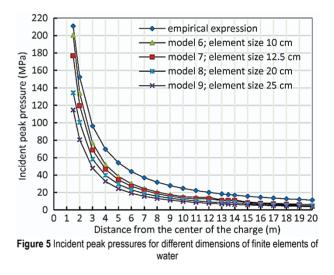
**Table 5** Incident peak pressures at a distance of 1.5 m from the centre of the explosion depending on the size of the finite elements of the explosive

| Number of finite elements of explosive | Size of the finite elements of water | | | |
|---|---|---|---|---|
| | 10 cm | 12.5 cm | 20 cm | 25 cm |
| | Pressure [MPa] | | | |
| 3818 | 200.44 | 177.65 | 133.67 | 114.66 |
| 7001 | 200.43 | 177.23 | 133.80 | 114.73 |
| 12097 | 200.41 | 176.81 | 134.48 | 114.76 |

### 3.2.3 The Influence of the Size of the Finite Elements of Water

The dependence of the size of the finite elements of water and maximum pressures was tested on the water volume model 20×5×5 m. The finite elements of water are 10 cm (model 6), 12.5 cm (model 7), 20 cm (model 8) and 25 cm (model 9), with discretization of explosives into 12907 elements.

Fig. 5 and Tab. 6 compare the maximum pressure values obtained by the empirical Eq. (1) and four pressure diagrams, based on the obtained numerical results, at distances from 1.5, 2.0 to 20.0 m, with a step of 1 m.



**Figure 5** Incident peak pressures for different dimensions of finite elements of water

The largest deviations in the value of the maximum pressures from the results obtained by the empirical expression are shown by the model with the size of the finite elements of water 25×25×25 cm. By reducing the size of the finite elements, deviations are also reduced, but even for elements of size 10×10×10 cm, these deviations are relatively large, especially in the interval between 3 m and 12 m. In the area of very high pressures at a distance of up to 3 m, these deviations are within the permissible limits for engineering purposes only for elements of 10 cm size, but all other results show a drastic underestimation of the maximum pressure values. It can be concluded that these sizes of finite elements are not suitable for application.

By further reducing the size of the finite elements of water, the results converge to empirical values. Fig. 6 compares the maximum pressure values for the size of the finite elements of water (3×3×3 cm, 5×5×5 cm and 6×6×6 cm). The diagram shows how by reducing the size of the finite elements of water, the pressure results approach the empirical ones.

**Table 6** Incident peak pressures for different dimensions of finite elements of water

| $R$ (m) | Emp. expr. | Size of the finite elements of water | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 10 cm | | 12.5 cm | | 20 cm | | 25 cm | |
| | $p$ (MPa) | $p$ (MPa) | $\Delta$ (%) | $p$ (MPa) | $\Delta$ (%) | $p$ (MPa) | $\Delta$ (%) | $p$ (MPa) | $\Delta$ (%) |
| 1.5 | 210.9 | 200.4 | 4.9 | 176.8 | 16.1 | 134.4 | 36.2 | 114.7 | 45.5 |
| 2.0 | 152.3 | 134.1 | 11.9 | 119.6 | 21.4 | 100.5 | 34.0 | 80.5 | 47.1 |
| 3.0 | 96.3 | 76.7 | 20.3 | 68.9 | 28.4 | 58.2 | 39.5 | 47.8 | 50.3 |
| 4.0 | 69.6 | 51.9 | 25.4 | 46.7 | 32.8 | 39.8 | 42.8 | 32.7 | 52.9 |
| 5.0 | 54.1 | 38.4 | 28.9 | 34.6 | 35.9 | 29.4 | 45.6 | 24.3 | 54.9 |
| 6.0 | 44.0 | 30.0 | 31.6 | 27.1 | 38.4 | 23.0 | 47.6 | 19.1 | 56.5 |
| 7.0 | 36.9 | 24.4 | 33.9 | 22.5 | 39.0 | 18.7 | 49.3 | 15.5 | 57.8 |
| 8.0 | 31.8 | 20.4 | 35.6 | 18.4 | 41.9 | 15.7 | 50.6 | 13.0 | 58.9 |
| 9.0 | 27.8 | 17.4 | 37.2 | 15.7 | 43.3 | 13.4 | 51.8 | 11.1 | 59.8 |
| 10.0 | 24.7 | 15.2 | 38.3 | 13.7 | 44.4 | 11.6 | 52.7 | 9.7 | 60.6 |
| 11.0 | 22.2 | 14.4 | 34.8 | 12.7 | 42.7 | 10.2 | 53.6 | 8.5 | 61.3 |
| 12.0 | 20.1 | 14.4 | 28.0 | 12.7 | 36.8 | 9.1 | 54.3 | 7.6 | 61.9 |
| 13.0 | 18.3 | 11.3 | 38.3 | 10.7 | 41.6 | 8.2 | 55.0 | 6.8 | 62.5 |
| 13.5 | 17.6 | 11.3 | 35.6 | 10.7 | 39.1 | 8.2 | 53.3 | 6.5 | 62.8 |
| 14.0 | 16.9 | 11.3 | 32.9 | 10.7 | 36.5 | 8.2 | 51.4 | 6.2 | 63.0 |
| 15.0 | 15.6 | 8.9 | 43.0 | 8.0 | 48.6 | 6.8 | 56.2 | 5.7 | 63.5 |
| 16.0 | 14.5 | 8.1 | 43.7 | 7.3 | 49.2 | 6.2 | 56.7 | 5.2 | 64.0 |
| 17.0 | 13.5 | 7.5 | 44.5 | 6.8 | 49.8 | 5.8 | 57.2 | 4.8 | 64.5 |
| 18.0 | 12.7 | 6.9 | 45.0 | 6.3 | 50.3 | 5.3 | 57.6 | 4.4 | 65.0 |
| 19.0 | 11.9 | 6.5 | 45.5 | 5.8 | 50.7 | 4.9 | 58.3 | 4.1 | 65.64 |
| 20.0 | 11.3 | 6.1 | 45.8 | 5.5 | 50.8 | 4.7 | 58.4 | 3.8 | 66.30 |
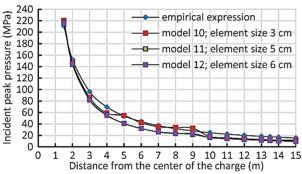


**Figure 6** Incident peak pressures for different sizes of finite elements of water

**Table 7** Incident peak pressures at distances up to 15 m from the centre of the explosion depending on the size of the finite elements of the explosive

| $R$ (m) | Emp. expr. | Size of the finite elements of water | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3 cm | | 5 cm | | 6 cm | |
| | $p$ (MPa) | $p$ (MPa) | $\Delta$ (%) | $p$ (MPa) | $\Delta$ (%) | $p$ (MPa) | $\Delta$ (%) |
| 1.5 | 210.9 | 220.5 | −4.5 | 216.0 | −2.4 | 215.4 | −2.1 |
| 2.0 | 152.4 | 146.9 | 3.6 | 143.8 | 5.6 | 145.0 | 4.8 |
| 3.0 | 96.4 | 86.0 | 10.8 | 82.3 | 14.6 | 81.7 | 15.2 |
| 4.0 | 69.6 | 59.0 | 15.2 | 55.5 | 20.3 | 55.1 | 20.9 |
| 5.0 | 54.1 | 54.6 | −1.0 | 40.9 | 24.4 | 41.1 | 24.1 |
| 6.0 | 44.0 | 42.1 | 4.4 | 32.1 | 27.1 | 32.1 | 27.0 |
| 7.0 | 37.0 | 35.2 | 4.7 | 26.1 | 29.4 | 26.0 | 29.8 |
| 8.0 | 31.8 | 33.8 | −6.1 | 23.9 | 24.8 | 23.2 | 27.0 |
| 9.0 | 27.9 | 32.6 | −6.9 | 21.9 | 21.4 | 23.2 | 16.8 |
| 10.0 | 24.7 | 18.0 | 27.1 | 16.3 | 34.0 | 16.2 | 34.4 |
| 11.0 | 22.2 | 15.9 | 28.4 | 14.4 | 35.1 | 14.4 | 35.3 |
| 12.0 | 20.1 | 14.2 | 29.3 | 12.9 | 36.1 | 12.8 | 36.5 |
| 13.0 | 18.4 | 12.8 | 30.2 | 11.6 | 37.0 | 11.5 | 37.6 |
| 13.5 | 17.6 | 12.2 | 30.8 | 11.0 | 37.5 | 10.9 | 37.9 |
| 14.0 | 16.9 | 11.6 | 31.3 | 10.5 | 37.8 | 10.4 | 38.2 |
| 15.0 | 15.6 | 11.6 | 25.7 | 9.7 | 38.1 | 9.6 | 38.8 |

The smallest deviation of the numerical results from the results obtained using the empirical expression is for the model with finite elements of water 3×3×3 cm. From Tab. 7

it can be seen that all three sizes of finite elements gave good results in areas of very high pressures, at a distance of up to 2 m, but by increasing the distance, up to 10 m, finite elements of size 3 cm give the best results. In the area of low pressures, over a distance of 10 m, the differences range from 31 % for the smallest finite elements to 38 % for the largest.

The results show a strong dependence of the pressure results on the size of the finite elements of water. Regardless of the increasing capacities of computers, numerical models are very complex and the same challenge always arises, how to reduce the amount of input data and obtain acceptable results. For engineering needs and the area of high pressures (up to 20$R$), the acceptable accuracy is 15 %, but for areas of low pressures (over 20$R$), the criteria can be relaxed [18].

## 4 CONCLUSIONS

Researching the impact of underwater explosions is very complicated and associated with risks and the commitment of significant resources. Most of these experiments are conducted under the auspices of the military services, so many results are not publicly available. Therefore, the best way to assess the impact on naval structures is numerical simulation, which, on the other hand, also hides numerous insecurities. In addition, numerical simulations require significant computing resources and computing time. For example, the calculation of a model with a volume of water 20×20×20 m and finite elements 25×25×25 cm takes about 16 minutes, and a model with a volume of water 20×2×2 m and finite elements 3×3×3 cm takes more than 10 hours (Intel Celeron P4600 processor and 4 GB DDR3). This article compares conventional empirical expressions with numerical results in order to optimize the ratio of computer time investment to the accuracy of the results.

The main parameter of the effect of an underwater explosion on underwater structures is the maximum pressure on the wave front. It mostly depends on the size and shape of the explosive charge and the distance from the centre of the explosion. Since the numerical modelling of an underwater explosion is a complex procedure that requires powerful computer resources, the explosion model should be made so that the calculation time is within reasonable limits, and the results are accurate enough for engineering needs. This research showed that the observed volume of water can be reduced to the form of an elongated cube with permeable boundaries and that this does not significantly affect the results. Also, the density of the mesh of finite elements of the explosive has no influence, but the results of maximum pressures largely depend on the size of the finite elements of water. Hexahedral finite elements of water 10 cm and larger have been shown to be unsuitable, and with further size reduction the pressures converge. For areas of very high pressures (up to 20$R$), finite elements of size 3 cm proved to be a reasonable compromise between calculation time and accuracy, and for areas of low pressures finite elements of size up to 6 cm can be applied.

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# Influence of the LPBF Process Parameters on the Porosity of the AlSi10Mg Alloy

Sanja Šolić*, Iva Sakač, Vlado Tropša, Mario Šercer

**Abstract:** Laser powder bed fusion (LPBF) process has a great ability to produce complex AlSi10Mg 3D components with uncommon degrees of freedom for broad span of applications in different industries. Presence of the microstructural imperfections such as porosity, dependent on the parameters of the process can be detrimental to the printed products for different engineering applications. Parameters of the process and different post-processing heat and surface treatments are recognized for decrease of the occurrence of microstructural defects and for the improvement of the mechanical properties. The influence of laser power by applying four different laser speeds at one layer thickness with a constant hatch distance, on the microstructure and microhardness of the AlSi10Mg alloy was examined in this paper. The goal of the research was to determine whether increasing the laser speed will have a significant impact on the change in microstructure and the appearance of porosity in the tested samples.

**Keywords:** additive manufacturing; AlSi10Mg; microstructure; microhardness; porosity; process parameters

## 1 INTRODUCTION

The development of additive manufacturing technologies widened the possibilities for the production of complex geometry products directly from 3D models. Compared to conventional manufacturing technologies, additive technologies present certain advantages such as short production times of complex and personalized geometries, high resolution and accuracy with almost no material loss and are mostly used today for tooling and prototyping, in the automotive, space and aerospace industries and also in the production of personalized biomedical products [1, 2]. The selective laser melting (SLM) process is one of the most used additive manufacturing processes today, characterized by a very fast solidification process with high cooling rates of 106 - 108 °C/s, which promotes the cellular growth of crystal grains with uniform crystallization of metastable phases and hybrid crystals [2, 3]. Due to the possibility of complete structural and topological optimization of the product, this process enables the creation of monolithic complex geometries of optimal stiffness with a reduction in product mass of up to 50 %. Considering the significant growth in the use of these technologies, the standardization of the basic principles and terminology associated with additive technologies has been started, and since 2015, according to ISO/ASTM 52900:2021, the process of selective laser melting in powder bed is defined as the Laser Powder Bed Fusion process (LPBF) [2].

In addition to exceptional advantages, the LPBF process also has certain disadvantages such as very high internal stresses, enhanced anisotropy, microstructural porosity and other microstructural defects that can be reduced to a certain level by performing subsequent heat treatments or surface engineering treatments.

Due to their very good technical properties, such as low density, the best electrical and thermal conductivity in relation to density, good corrosion resistance, ductility, high strength and hardness, in combination with acceptable price range, aluminium alloys are widely used as engineering materials. Although many alloys are successfully used in the application of the LPBF process, aluminium-based alloys are still quite demanding for the production of parts with additive technologies, primarily due to the high reflection of the laser beam on the aluminium powder, which significantly affects the efficiency of the laser, the rapid formation of an oxide layer on the surface of the molten material, and a wide range of solidification of the high strength aluminium alloys [4, 5]. AlSi10Mg alloy is the most commonly used aluminium alloy in the LPBF additive manufacturing process due to its very good weldability of the layers, excellent casting properties and high conductivity, excellent strength-density ratio, good mechanical properties and low solidification shrinkage, and is used in a wide range of industries including automotive and aerospace.

The largest impact on the microstructure and properties of the LPBF additively manufactured products have the parameters of the process, of which the influence of laser power and speed, hatch distance, layer thickness and scanning strategy are investigated the most [3].

The laser power affects the amount of energy delivered into the substrate and affects the amount of melted powder in a given layer thickness which depends on the material in the process. Partial melting causes solidification defects due to not filling the entire volume in a given layer thickness. The speed of the laser affects the speed of melting and solidification. The hatch distance during melting determines the level of overlap of the melted layers in one-layer thickness, which enables better melting of the layers. The thickness of the layer determines the height of the powder that will be melted in each pass of the laser. Large layer thicknesses affect incomplete melting and the occurrence of microstructural defects such as balling [6].

To evaluate the influence of the combination of the above parameters, the amount of heat input or the energy density of the laser, $E$, J/mm$^3$, is used, which is described by the equation:

$$E = \frac{P}{v \cdot h \cdot t},$$ 
(1)

where $P$, W, is the laser power, $v$, mm/s, the laser speed, $h$, mm, hatch distance and $t$, mm, the thickness of the melting layer [3].

The scanning strategy refers to the raster that the laser will pass through when building the product. It is possible to change it between layers based on the requirements for microstructure or geometry in a certain part of the product itself. This parameter has a very large role in determining the final properties of the product because microstructures, mechanical properties and the amount and type of residual stresses are a direct consequence of the scanning strategy [7].

The most significant influence on the mechanical properties of products obtained by the LPBF process is the degree of porosity, that is, the relative density of the workpiece in relation to the theoretical density of the material. Alloys with an almost theoretical density obtained by the LPBF process generally have better properties under tensile load, higher values of the impact toughness and better dynamic properties, therefore it is very important to know the influence of the process parameters on the occurrence and amount of porosity in the material [8, 9]. Given that the LPBF process is a relatively slow process that requires significant amount of time compared to the conventional technologies, especially for products of larger dimensions, in practice there is a tendency to increase the laser speed, with the aim of shortening the building time, which can affect the amount of porosity and reduce the mechanical properties of the product.

In this paper, the influence of laser power by applying four different laser speeds with one thickness of the melted layer with a constant hatch distance, on the microstructure and microhardness of the AlSi10Mg alloy was examined. The purpose of the research was to determine whether increasing the laser speed will have a significant impact on the change in microstructure and the appearance of porosity in the tested samples along with the influence on the microhardness of the samples.

## 2 MATERIALS AND METHODES

For the purposes of this research, eight test samples of the AlSi10Mg alloy in the shape of a prism with dimensions of 20 × 20 × 10 mm were printed by the laser powder bed fusion additive process on the EOS M270 3D printing machine. Metal powder of the AlSi10Mg alloy produced by EOS, with the chemical composition shown in Tab. 1, was used.

**Table 1** Chemical composition (% wt) of the AlSi10Mg powder

| Si | Fe | Cu | Mn | Mg | Ni | Zn | Pb | Sn | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| 9,0 – 11,0 | ≤0,55 | ≤0,05 | ≤0,45 | 0,2 – 0,45 | ≤0,05 | ≤0,1 | ≤0,05 | ≤0,05 | ≤0,15 | rest |

The parameters of the LPBF process with sample markings are shown in Tab. 2. In the building process, the thickness of the melted layer was 0,06 mm with a constant hatch distance of 0,2 mm.

Fig. 1 shows the test samples in powder bed during the cleaning process.

After separation from the plate, the test samples were prepared for further analysis by means of the standard metallographic procedure. The microstructural analysis of the samples was performed on the samples that were in the polished condition and after etching. For etching, Keller solution (2,5 mL $HNO_3$; 1,5 mL HCl; 1,0 mL HF and 95 mL deionized water) was prepared.



**Figure 1** Test samples in powder bed during the cleaning process

**Table 2** LPBF process parameters with sample markings

| Sample | Laser speed, mm/s | Laser Power, W | Energy density, J/mm³ |
|---|---|---|---|
| 1 | 1100 | 370 | 28,03 |
| 2 | 1200 | 370 | 25,69 |
| 3 | 1300 | 370 | 23,72 |
| 4 | 1400 | 370 | 22,02 |
| 5 | 1100 | 300 | 22,73 |
| 6 | 1200 | 300 | 20,83 |
| 7 | 1300 | 300 | 19,23 |
| 8 | 1400 | 300 | 17,86 |

The microstructure was analysed by means of the Olympus GX53F-5 light microscope equipped with a DP23-CU micro digital camera. The amount of porosity in the microstructure was determined with the image analysis software Image J. For the analysis of the porosity five images of every sample in polished condition at the magnification of 100 x were analysed and the presented results represent the mean value of five obtained results.

The Vickers hardness HV 1, HV 0,2 and HV 0,1, was measured on a KB 30 S microhardness tester (KB Prüftechnik GmbH). The presented results represent the mean value of five indentations with each applied load. Microstructural analysis and hardness measurement were performed at the Laboratory for material testing at University North.

## 3 RESULTS AND DISCUSSION

Fig. 2 presents the microstructure of the test samples in a polished condition. On almost all samples, melting lines are clearly visible indicating the building pattern of the samples. A certain proportion of porosity is visible on all samples, and the porosity is more pronounced on samples built with lower

laser power, with a significant increase in porosity in the samples printed with the lowest laser energy density (samples 6, 7 and 8).
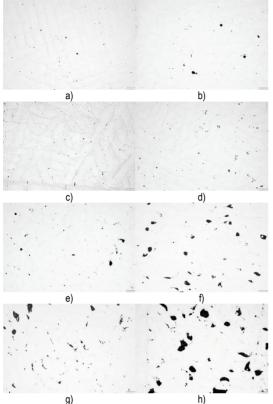


**Figure 2** Polished microstructures of the samples (magnification 50:1): a) 1, b) 2, c) 3, d) 4, e) 5, f) 6, g) 7 and h) 8

The amount of the measured porosity is presented in Tab. 3. The results show that the amount of the measured porosity rises almost four times with the increase of the laser speed of 100 mm/s for lower laser power, resulting with the decrease of laser energy density from 22,73 to 20,83 J/mm$^3$. Further increase in laser speed resulted in further increase of the porosity of the samples with the increase in porosity for more than seven times for the total of 300 mm/s increase in laser speed. Fig. 3 shows the influence of the energy density on the obtained porosity of the samples.

**Table 3** Porosity of the samples

| Sample | Porosity, % |
|---|---|
| 1 | 0,19 |
| 2 | 0,33 |
| 3 | 0,33 |
| 4 | 0,46 |
| 5 | 0,54 |
| 6 | 2,11 |
| 7 | 2,09 |
| 8 | 3,86 |

The obtained results show that the proper selection of the process parameters is very important for obtaining the required properties with minimum microstructural defects and that the increase in laser speed for the purpose of reduction in building time can have significant impact on the density of the products which is in accordance with the

literature; Limbasiya et al. [3] and Sabzi et al. [9] state that complete melting of the metal powder cannot be achieved with the low laser energy density which result in partial melting which leads to the increase of the porosity which reduces the relative density of the printed parts.



**Figure 3** Influence of the energy density on the porosity of the samples
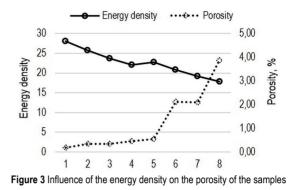
Fig. 4 shows the microstructure of the samples after etching with the Keller solution. The microstructure of the test samples was analysed in the transverse direction in relation to the printing direction (perpendicular to the $Z$ axis). On all test samples after etching, a banded morphology with clearly defined melting lines is observed, and the laser melting area in the direction of the $X$ and $Y$ axes is clearly visible.
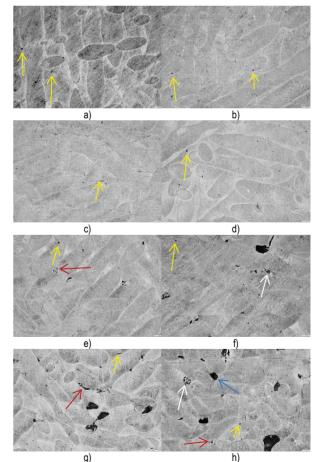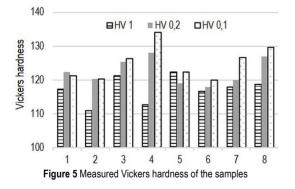


**Figure 4** Etched microstructures of the samples (magnification 100:1): a) 1, b) 2, c) 3, d) 4, e) 5, f) 6, g) 7 and h) 8

Microstructural analysis shows that the porosity (marked with yellow arrows) is present in all samples with the increase in the samples with lowest energy density (samples 6, 7 and 8). In addition to porosity, incomplete melting is also observed on the samples, which is indicated by red arrows in the figures. If a sufficient amount of energy is not introduced into the substrate, there is not a sufficient amount of energy to dissolve the metal powder, so the metal powder does not melt evenly, and even during solidification, the entire volume is not filled, which is why areas of incomplete melting are created [10]. The blue arrow shows other microstructural defects, cavities of larger dimensions that arise due to an insufficient amount of melt that should fill the space between the melting layers. All these defects are caused by improperly adjusted parameters. The lower the energy density of the laser, the weaker the power for melting of the powder, and if there is not enough energy to melt the powder, the formation of layers without porosity and other defects in the microstructure cannot occur. Most cavities of larger dimensions are present at samples 6, 7 and 8. Balling [6] was also observed and is indicated by white arrows on samples 6 and 8. Presence of multiple microstructural defects and increased porosity confirms that the proper selection of process parameters is very important for achieving desired properties of the additively manufactured products with less defects [11]. Low energy density will result in partial melting of the powder particles which will result in more porosity and reduction of the relative density of the built AM product. On the other hand, formation of the keyhole defects is caused due to the spatter and the turbulence in molten pools that occur at the high energy density. Choosing the optimum energy density is crucial for production of additively manufactured parts with high relative density [11].



**Figure 5** Measured Vickers hardness of the samples

The results of the microhardness measurement are presented in the Fig. 5. The results show that the range of the process parameters used within this research did not affect significantly the results of the hardness measurement. Generally, the LPBF products exhibits higher average hardness results compared to conventionally produced parts [12, 13]. However different LPBF process parameters affects differently the hardness values of the AlSi10Mg parts. Several research [13, 14] studied the influence of the LPBF process parameters on the hardness of the AlSi10Mg alloys. The results showed that increase in laser power decreases the microhardness of the samples produced, with the same trend

accomplished with the energy density increase. The cause was accredited to the reduction in grain size. Also it has been noticed that the increase in scanning speeds results with the high microhardness values due to increase in cooling rate [15].

## 4 CONCLUSION

Laser powder bed fusion process is one of the most widely used additive manufacturing processes today, which enables complete structural and topological optimization of the product, which makes possible to create the monolithic complex geometries with optimal stiffness while reducing product mass by up to 50 %.

In this paper, the influence of two values of laser power with the combination of four laser speeds with the constant thickness of the melted powder and the constant hatch distance on the microstructure and microhardness of the AlSi10Mg alloy was examined. The obtained results showed that the amount of laser energy density used in the melting process have a significant effect on the increase of the microstructural porosity. The primary influence has the laser speed, where each increase in the laser speed by 100 mm/s for every laser power caused the increase in porosity of the built samples which leads to conclusion that the selection of the optimal parameters of the process is the key for production of additively manufactured parts with high relative density. The laser energy density range studied in this paper and the increase in porosity did not significantly affect the changes in the hardness of the tested samples.

The wide application of the LPBF additive process is justified by the good properties of the workpieces and processing with minimal material loss. However, in order to realize the possibility of using such products in concrete exploitation conditions of mechanical load, it is necessary to achieve full density of the material with minimal porosity and microstructural defects, for which it is necessary to take care of the selection of optimal parameters of the LPBF additive process.

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# Detect People's Faces and Protect Them by Providing High Privacy Based on Deep Learning

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**Abstract:** Facial privacy is essential in our time due to the violations that occur due to the proliferation of social media and people's primary dependence on it. Facial features can be exploited to identify, track, or other matters without obtaining prior consent. This is increasingly important due to the increasing use of facial recognition technologies. Protecting the face and privacy is a challenging task, as the entire world is very widely connected through social networking sites in an uncensored manner, especially in countries with no electronic governance or oversight. Therefore, there is an urgent need to provide systems or research that focuses on the issue of facial privacy. In this paper, a system for providing privacy for people was proposed using the WIDER FACE data set, considered the most important among the data sets. The system aims to provide privacy for people by determining the destination that must be preserved and provided with privacy through three technical. The approach goes through several steps: The processing process of the image is achieved by enhancement of the images that are input in the training stage and then dividing the data into a test and training set, and the training stage through the YOLOv6 algorithm (looks only once), and privacy operations including encryption, decryption, mask and blurring in the test part of the data, and conducting an external test for personal photo. The final results of the proposed system were as follows: accuracy = 0.98 in training and 0.96 in testing.

**Keywords:** deep learning; facial; image; privacy; YOLOv6

## 1 INTRODUCTION

The privacy of people's faces in images is one of the essential topics that researchers are working on at present and shortly due to the increasing use of social networking sites, the Internet and various programs [1]. Various cases of privacy violations have emerged, including impersonation of people by changing facial images and through fake videos as well, as well as cases of security breaches by tracking people through their published images, or it is possible to use people's details such as faces in biometric fingerprints in very high-resolution photos, and on the other hand [2]. It violates privacy on social networking sites and programs when sending images [3]. Therefore, all of these reasons were enough to make researchers work on how to provide privacy for people in pictures. Facial privacy refers to the right to exercise authority over collecting, using, and disclosing personal data obtained from an individual's facial features. This includes both facial images and facial recognition data, which refers to a mathematical depiction of an individual's face that can be used for identification purposes [4]. The increasing prevalence of facial recognition technology has raised concerns about protecting facial privacy [5]. Facial recognition technology is currently used in many fields, such as law enforcement, surveillance, and marketing. However, facial recognition technology raises several privacy concerns [6]. The concern is that facial recognition technologies can surreptitiously monitor individuals without consent. This dramatically limits the ability to move and express oneself, which may cause feelings of fear or intimidation [7]. Another problem arises from the possibility that facial recognition systems engage in discriminatory practices. Facial recognition technologies have shown less accuracy in identifying individuals of colour. This may result in individuals from marginalized racial and ethnic groups being subject to a greater degree of scrutiny and discrimination by law enforcement or facing barriers to accessing essential services. There is a legitimate concern that facial recognition

data may be vulnerable to hacking or misuse. This could lead to identity theft or other types of damage. Given these issues, there are increasing efforts to protect individuals' facial privacy [8]. Many jurisdictions have implemented legislation or regulations limiting the use of facial recognition technology. California legally mandates that companies obtain consent before collecting or using facial recognition data [9]. This paper proposes a method to provide privacy by relying on face protection using three protected image techniques to provide face privacy through a deep learning algorithm (YOLOv6). This paper has been organized with clarification sections around how to detect faces and how the protection process is carried out through the face in the image, and a section that highlights the most important previous studies that had high citations and high results. The last section of the paper is an integrated part that is the proposed approach and the method for evaluating the results and drawing conclusions from this.

## 2 FACE RECOGNITION

Face recognition is a technique that involves recognizing or confirming the identification of a person by analyzing their facial features [10]. Face recognition systems can identify individuals in photographs, videos, or real-time. Mobile devices can be utilized by law enforcement to identify individuals during police stops [11]. However, face recognition data is susceptible to inaccuracies, which might falsely incriminate individuals for crimes they did not commit. Facial recognition software exhibits significant deficiencies in accurately identifying African Americans, other ethnic minorities, women, and young individuals [12]. It frequently misidentifies or fails to recognize these groups, disproportionately impacting specific demographics.

Moreover, facial recognition technology has been employed to specifically identify individuals who are participating in activities that are safeguarded under the right to freedom of speech. Face recognition technology is

expected to become increasingly prevalent shortly [13]. It can be utilized to monitor the activities of humans in the outside world, similar to how automatic license plate scanners track vehicles based on their plate numbers [14]. Face recognition systems employ computer algorithms to identify unique and distinguishing characteristics of an individual's face. Subsequently, these specific characteristics, such as the intraocular distance or the contour of the chin, are transformed into a mathematical depiction and juxtaposed with information from other facial profiles stored in a face recognition database [15]. A face template refers to the specific data about a face [16]. It is different from an image as it is specifically created to contain just certain information that can be utilized to differentiate one face from another [17]. Specific facial recognition systems are programmed to compute a probability match score between an unidentified individual and particular face templates recorded in the database rather than providing a definitive identification [18]. These systems will provide multiple potential matches, arranged in order of the probability of accurate identification, instead of only delivering one outcome [19]. Face recognition systems exhibit variability in their capacity to accurately identify individuals under challenging circumstances, such as inadequate illumination, low image resolution, and unfavourable viewing angles (e.g., a snapshot taken from above, capturing an unfamiliar person) [20].

## 3 PERSONAL PRIVACY VIOLATIONS IN IMAGES

Personal privacy in images is the right to control the collection, use and disclosure of photos that contain personal information about a person [21]. This includes physical images, such as photographs and videos, and digital images, such as those stored on computers and smartphones. The matter is fraught with numerous hurdles and obstacles, which can be succinctly where Facial recognition technology enables the identification and monitoring of individuals in public spaces and the ability to track their movements and unlock their mobile devices [22]. This technology can be employed to surveil individuals' actions, namely to tailor advertisements to them or trace their movements for illicit intentions. Facial recognition technology can potentially discriminate by targeting individuals based on their colour, ethnicity, gender, or other legally protected attributes [23]. For instance, it can be employed to restrict individuals' entry to employment, housing, or other advantageous prospects.
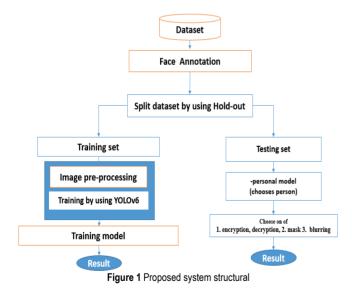
Furthermore, Cyber-attacks target recognition data, such as faces or bodily parts, due to their high value. In the event of data theft, the stolen information might be exploited for purposes such as identity impersonation, fraudulent activities, or even stalking [24]. Insufficient transparency is frequently, individuals are uninformed of the fact that their bodily components are being subjected to scanning or tracking. The absence of transparency might provide challenges for individuals in understanding the utilization of their data and safeguarding their privacy [7].

## 4 RELATED WORK

There are many studies on this topic, and the following are the most important studies related to the topic [25]. This study explores when users openly release photographs and videos of others to address privacy concerns. A mechanism for recognizing and filtering human traits in public photographs and videos is presented to safeguard privacy. The suggested method uses face filtering to improve privacy without affecting image sharing by considering visual content. The suggested system first recognizes a person's facial shape in a digital image or video. The software compares specified facial traits to its facial vector database. After face recognition, the suggested approach removes unrecognized people from the image. (Convolutional Neural Network - CNNs) have been utilized for face detection, whereas deep learning face embedding has been employed for face recognition. Both methods have high accuracy and are practical. Time. Gaussian face filtering, significantly blurring, is standard. For fast-processing applications, this approach is famous for its real-time performance. Users can also adjust distortion levels. Experimental results on three datasets show that the system can accurately identify faces in images and movies. Improved CNNs for facial detection achieve 91.3 % accuracy. The system uses the K-Nearest Neighbor (KNN) technique for facial recognition and scored 96.154 % on the I Privacy dataset. In ref. [24] a basic image privacy system and an improved disturbance generation network algorithm are introduced. Experiments show that generative networks may efficiently create adversarial perturbation while maintaining image quality. Candidate region filters during generative network training reduce interference from bad training samples and improve adversarial sample detection protection. Maintain image quality by cleverly preventing Deep Neural Network (DNN) detectors from detecting sensitive information like human features. Create an image privacy method by training and creating adversarial samples for each image to defend DNN detectors. Consider training an adversarial perturbation generative network to improve the prior model instead of training for each Image. Comparing the technique to others using mean average precision, average distortion, and time expended on a more extensive face dataset. The study found that the method upsets DNN detectors without affecting image quality. Additionally, the upgraded model generates adversarial perturbations faster. In ref. [26], a reversible facial recognition privacy method is proposed. Before uploading face photos to the cloud, apply a mosaic and train an encoder to create protected images using the original facial data. We'll train another classifier with protected photos for facial expression detection and create a decoder to restore the original facial images. Using protected images in cloud services limits malicious attackers' identifying information. The classifier can help low-privilege users conduct computer vision tasks with protected images. Authorized users' average facial photo use will not change after content recovery. Experimental results show that the facial image restoration method works. Furthermore, shielded images perform similarly in typical computer vision

tests. In ref. [27] proposed artefact removal Privacy-preserving blurring (DartBlur) uses a DNN architecture for feature blurring. DartBlur hides facial privacy and detection artefacts. It includes four training objectives to improve review and enhance the detection of artefact suppression. Add it to a second-order optimization pipeline and adversarial training scheme. WIDER FACE allows DartBlur to surpass the current face-replacement method in review convenience, accessibility, and training artefact suppression compared to blur-based methods. Tab. 1 summarises the related work mentioned above.

**Table 1** Summarized of Previous Studies.

| Year & RF. | Employed method | Method dataset | Aim of paper | Result of system |
|---|---|---|---|---|
| 2020 [25] | - CNN (detect the face region) - (Determined Maximum Likelihood -DML) was used for the feature extraction stage - (Support Vector Machine-SVM) and (KNN) were used for the face classification | - Grimace - FEI - I-Privacy - WIDER face | Use real-time facial recognition and blurring. OpenCV was used to create facial recognition algorithms. A CNN algorithm was pre-trained to identify facial regions. Pre-trained Deep Metric Learning (DML) extracted features next. Face recognition employs SVM and KNN for classification. | SVM accuracy = 88.462 %, and KNN accuracy = 96.154 % |
| 2021 [24] | - Faster R-CNN with (Visual Geometry Group -VGG-16 as the feature extractor - Deep neural network (DNN) detectors from detecting private information | - PASCAL VOC - visual object - WIDER face(set 100 randomly selected images in the simple verification set as test data set to verify the effectiveness of the improved algorithm) | Present an approach to prevent deep neural network (DNN) detectors from recognizing private information, such as human faces, while maintaining image quality. Specifically, provides an image privacy protection algorithm by training and creating adversarial samples for each image to defend the DNN detector. | - PASACL VOC mAP = Original image = 90 Gaussian blur = 89 Mosaic = 81 - WIDER face mAP = Original image = 83 Bose model = 35 |
| 2021 [26] | - Face detection (YOLO) - CNN AS classifier - Encoder and decoder both use U-Net | - CelebA for training - WIDER FACE (training YOLO for face detection) - (Labeled Faces in the Wild Home -LFW) for testing only | Transforms original photographs into protected images with face information before uploading to the cloud. Cloud photos can be used for facial expression recognition and restored to original photographs; attackers cannot identify individuals. | Accuracy Original image = 93.0702 % Protected Images = 92.9864 % |
| 2023 [27] | - YOLOv5 - PyramidBox | - WIDER FACE - FDDB - Crowd Human | The blur-based DartBlur approach balances accessibility, review convenience, and artefact suppression. According to experiments, DartBlur meets design goals and generalizes well across datasets and systems. | PyramidBox DartBlur per. Fid = 95.18 Post-hoc Fid = 75.16 Cycle Fid = 24.68 YOLOv5 DartBlur per. Fid = 96.17 Post-hoc Fid = 91.72 Cycle Fid = 37.15 |



**Figure 1** Proposed system structural

## 5 PROPOSED SYSTEM

Providing protection and privacy for the human face was the goal of the proposed system, where the number of faces in the images is distinguished and determined, and specific people are selected from within the group to provide them with privacy through the faces, and this is done using the (YOLOv6) algorithm. The proposed system chooses one method out of three to provide privacy during the prediction phase. Relying on the most famous types of global data sets is challenging for researchers due to its characteristics, most notably the many faces, close and very far. Fig. 1 illustrates the details of the proposed system.

### 5.1 Dataset

A WIDER facial is a popular facial detection algorithm benchmark. In "WIDER FACE: A Face Detection Benchmark" by Shuo Yang et al. [28], 32,279 Flickr pictures with over 80,000 faces tagged were used. Events, including sports, concerts, and street scenes, are represented by 61 event classes in the dataset. WIDER FACE helps face detection algorithm developers and researchers. WIDER FACE dataset, which uses images from the publicly available WIDER dataset, has been used to benchmark state-of-the-art face detection algorithms and drive the development of new and improved methods. The WIDER FACE dataset has 61 event classifications. The following Fig. 2 shows an example of the event of the image in the dataset [28].

**Figure 2** Example of the event of the image in the WIDER FACE dataset

Face annotations in the WIDER FACE dataset provide each image's face location, size, and occlusions. Face detection algorithm training and evaluation require these annotations. Text files with dataset photos contain these annotations. Each image has a text file with each face's bounding box and occlusion label. The WIDER facial dataset has excellent facial annotations. Because expert annotators painstakingly created the annotations. The annotators thoroughly inspected each image and categorized each face per standards. Face detection algorithms must be trained and evaluated using WIDER FACE's high-quality annotations. Annotations tell algorithms where and how big faces are in photos. The algorithms can be trained to detect faces better with this data. Annotations can also evaluate face detection systems. This is done by comparing algorithm detections against ground truth annotations. Best-performing algorithms have high detection rates and low false favourable rates. Many cutting-edge face detection algorithms have been trained and tested using WIDER FACE dataset face annotations. The dataset has spurred facial detection technology advancements. The data was divided using the holdout method, widely regarded as the most suitable approach for massive datasets. Keras is an integrated, robust, user-friendly, open-source Python toolkit designed to develop and assess deep learning models. It is an integral component of the TensorFlow library, enabling the concise definition and training of neural network models.



**Figure 3** Split dataset in the proposed system

Keras library using in (splitting dataset in the training set and testing set in topic Holdout). Fig. 3 shows the percentage of splitting datasets in the proposed system.

**Table 2** Splitting dataset to training and testing in the proposed system

| Training images | 12888 |
|---|---|
| Testing images | 3222 |

## 5.2 Training and Privacy Stage

The proposed system uses YOLOv6 because the algorithm is an innovative real-time object detection method that combines the precision of previous models with substantial enhancements in inference speed. It is based on the framework of YOLOv5 but has other novel characteristics that improve its overall performance. The advantage of this algorithm that chooses in the proposed system can summarized in the following point:

- Enhanced Precision: YOLOv6 exhibits superior accuracy on standard datasets compared to its previous versions, showcasing its efficacy in diverse object detection assignments.
- Improved Velocity: YOLOv6 surpasses its previous versions regarding inference speed, allowing for real-time object detection in challenging situations.
- Hardware Efficiency: YOLOv6 is precisely engineered to optimize hardware performance, making it highly compatible with various computer platforms, such as mobile devices and embedded systems.
- Features: YOLOv6 includes various cutting-edge features, including Path Aggregation Network (PANet), Efficient Channel Attention (ECA), Cross Stage Attention (CSA), FPN with Shared Attention (FPN SA), Edge Attention Mechanism (SAM), and IoU Aware Anchor Refinement. These features significantly enhance the performance of YOLOv6.

YOLOv6's amalgamation of precision, swiftness, and hardware optimization renders it a flexible instrument suitable for many applications. Three summarized the layer of YOLOv6 that is used in the proposed system (Tab. 3).

**Table 3** Layer of YOLOv6 in prosed system

| Layer | Description |
|---|---|
| Mosaic | Resizes and crops images to a uniform size, improving training efficiency. |
| MixUp | Randomly blends two images during training, enhancing data augmentation and improving generalization. |
| AutoShape | Dynamically resizes the input image to a suitable size for the network, adapting to different image resolutions. |
| CSPDarknet53 | The backbone network extracts features from the input image using a combination of residual connections and spatial attention modules. |
| PANet | Fuses feature from different network layers, providing context information for improved object detection. |
| SPP | Applies max pooling to features at different scales, enhancing the detection of objects at varying sizes. |
| YOLO Head | Performs object detection by predicting bounding boxes and class probabilities for each detected object. |
| NMS | Applies non-maximum suppression to filter out overlapping bounding boxes and retain only the most confident detections. |
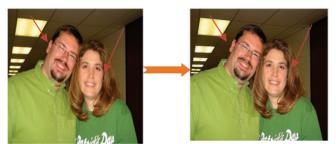


**Figure 4** Example image to showing the difference before and after use

In the training stage, the enhancement image operation is used to set training data before input into the training algorithm. In generated images using (Python image library - edge enhance), OpenCV (Open Source Computer Vision Library) is a popular library for real-time computer vision. It provides various functions for detecting edges and enhancing the image, and programmers widely use it because of the actual improvement it provides. Figs. 4 and 5. This is an example image to show the difference before and after use.



**Figure 5** Example image to showing the difference before and after use

After completing the training process comes the testing phase, which is the phase that takes place through face detection, people selection, and privacy determination in the proposed system, where the trained model is called, and privacy operations are performed on the result of people identification and face identification, where in the proposed system three methods are performed. Separately, no choice. Including (encryption and decryption through an algorithm in which the data is encrypted using the Advanced Encryption Standard (AES) and decryption, which is a symmetric critical encryption method and is considered one of the modern encryption algorithms with the highest level of

security as it is), (the mask method), and (the camouflage method). The following Figs. 6 and 7 show the final result of face privacy in the proposed system.
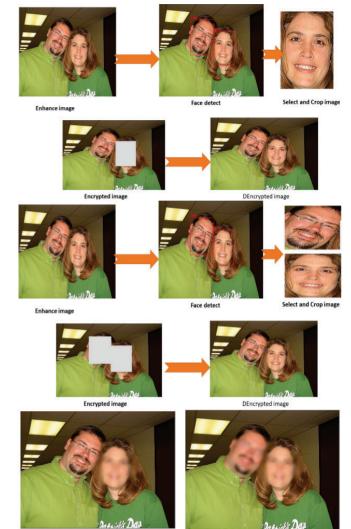


**Figure 6** Example of (decryption and encryption) and (blurring) for one or more Pearson in the proposed system

## 6 EVALUATION THE RESULT

In the proposed system, a confusion matrix comprehensively represents the results obtained from a classification forecast. In the past, numbers were utilized to enumerate and categorize the quantity of precise and imprecise predictions based on class. The proposed evaluation approach will be employed to interpret the confusion matrix. A confusion matrix concisely summarises the frequency with which a classification model correctly or incorrectly anticipated outcomes. *TP* represents the number of actual positive cases, *TN* represents the number of true negative cases, *FP* represents the number of false positive cases, and *FN* represents the number of false negative cases. A confusion matrix is an invaluable tool for assessing the efficacy of a system. The specific fundamental indicators differ based on the four categories.
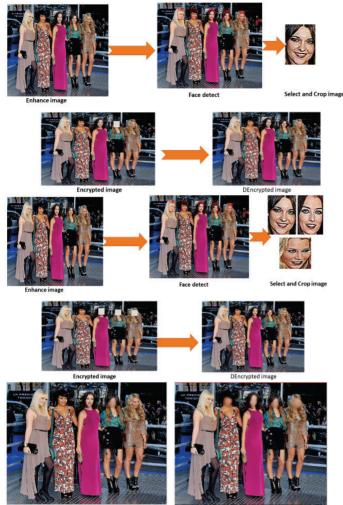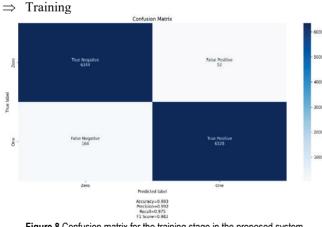
**Figure 7** Example two of (decryption and encryption) and (blurring) for one or more Pearson in the proposed system

The following Figs. 8 and 9 are the results of the proposed system from the training and testing stage:

⇒ Training



**Figure 8** Confusion matrix for the training stage in the proposed system
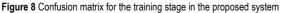
**Table 4** Result of confusion matrix in the proposed system in the training stage

| $TP = 6328$ | | $FP = 52$ | $FN = 164$ | $TN = 6344$ |
|---|---|---|---|---|
| Accuracy = (True positives + True Negatives)/(True positives + True negatives + False positives + False negatives) | | 0.983 | | |
| Precision = True positives/(True positives + False positives) | | 0.992 | | |
| Recall = Recall = True positives/(True positives + False negatives) | | 0.975 | | |
| Fl-score = 2 × [(Precision × Recall)/ (Precision + Recall)] | | 0.983 | | |

⇒ Testing
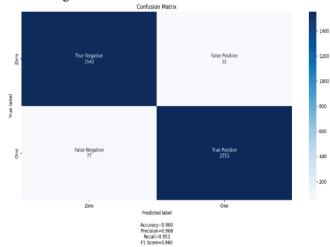


**Figure 9** Confusion matrix for the training stage in the proposed system

**Table 5** Result of confusion matrix in the proposed system in the training stage
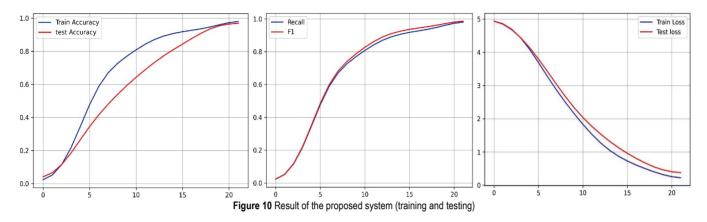
| $TP = 1551$ | | $FP = 52$ | $FN = 77$ | $TN = 1542$ |
|---|---|---|---|---|
| Accuracy = (True positives + True Negatives)/(True positives + True negatives + False positives + False negatives) | | 0.960 | | |
| Precision = True positives/(True positives + False positives) | | 0.968 | | |
| Recall = Recall = True positives/ (True positives + False negatives) | | 0.953 | | |
| Fl-score = 2 × [(Precision × Recall)/ (Precision + Recall)]. | | 0.960 | | |

Based on the above results obtained as an output of the proposed system, the following Fig. 10 represents results in a curved way to show the difference between the test and training results.

## 7 CONCLUSION

Protecting the face or privacy is considered one of the challenges for researchers because it is developing rapidly due to the development of technology. In the research paper, work was done on employing artificial intelligence in privacy by building a model that relies on the deep learning method with an algorithm considered the strongest in detection, YOLOv6, and performing a simple processing process. However, it has a practical effect in improving images through a ready-made library and applying it to training images, and it also provides two important features. It selects

specific people from within a group and applies three operations to them separately. The results were promising and good. In future work, we will add another fourth method

for diversity to experiment further and compare which method is most efficient in providing facial privacy protection.



**Figure 10** Result of the proposed system (training and testing)

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# Analysis Effect of Environmental Orientation and Organizational Innovation on Environmental Talent Development and Performance

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**Abstract:** Developing environmental strategies in the business provides an advantage for businesses to gain competitive advantage. It is also seen that these environmental orientations of enterprises provide performance advantages in today's competitive environment. In this sense, the concepts of environmental orientation, organizational innovation, environmental capability, environmental performance, market performance, financial performance and perceived quality are examined in the project and it is aimed to investigate the effects of these concepts on each other. The main body of the study consists of production enterprises operating in Erzurum. Convenience sampling method was used as the sampling method. According to the information received from the Chamber of Commerce and Industry, it has been determined that there are 138 production enterprises in Erzurum. In this sense, 98 questionnaire forms collected from businesses that accepted to fill out the questionnaire were evaluated. The collected data were analyzed with the help of SPSS 20.0 package program.

**Keywords:** environmental capability; environmental orientation; organizational innovation

## 1 INTRODUCTION

Today, the rapid increase in population, the development of technology, and the new sectors emerging because of this development, harming the environment in many respects cause an increase in concerns about sustainability and the environment. These concerns contribute to the increase of environmental awareness, the importance of environmentalism and the development of environmental strategies by bringing environmental awareness to the fore [11]. Increasing concerns about the sustainability of the natural environment seem to make environmental issues more important. Therefore, it is important for businesses to take initiatives towards environmentalist activities and adopt environmental strategies while carrying out their activities. It is not enough for businesses to adopt environmental strategies alone, but they also need to develop their environmental capabilities and create an appropriate organizational structure that can constantly adapt to environmental conditions [15]. The environmental orientations of businesses and the development of strategies in this context encourage businesses to be involved in green practices by providing an environmental culture in the business. In addition, this situation provides advantages to businesses in many aspects such as gaining competitive advantage and improving their performance, as well as benefiting the environment [22].

Although there are many environmental studies for businesses in the literature, it has been observed that there are limited studies examining the role of environmental orientation, organizational innovation, environmental ability and performance. For this reason, with this study, which was prepared to examine the perception of environmental orientation, organizational innovation and environmental talent development, the effect of environmental orientation and organizational innovation perceptions of production enterprises in Erzurum on environmental talent development and performance was determined, improving environmental capabilities, creating environmental awareness and understanding the importance of environmental sustainability. It is aimed to ensure that businesses create a roadmap that can encourage environmentalism. In addition, the findings obtained from the study will contribute to the promotion of enterprises in terms of environmental orientation and environmental talent development both now and in the future, will help them develop environmental strategies, and will lay the groundwork for new studies. Therefore in this study, revealing the effect of environmental orientations and organizational innovations of enterprises on environmental capability, it is aimed to investigate the effects of environmental orientation, organizational innovation and environmental capability on environmental performance, market performance, financial performance, and presentation quality. The study was supported by Atatürk University Scientific Research Projects (BAP) Coordination Unit with project number SBA-2021-8964. Within the scope of research purposes, face-to-face survey technique was applied to production enterprises operating in Erzurum province. The data were analyzed by help of SPSS 20.0 software.

## 2 LITERATURE

Environmental orientation: It is expressed as "managerial recognition of the business's impact on the environment and the need to minimize this impact". Environmental orientation, which is accepted as a basic concept for environmental management, is seen as an important business principle that guides environmental practices. Environmental orientation is divided into two as internal and external. Internal values and ethical standards for the level of commitment to environmental protection, such as the establishment of policies and procedures on environmental protection and adopting an environmentalist corporate culture by providing environmental training for employees, are defined as internal environmental orientation. External environmental orientation is expressed as the

perceptions of business managers about the need to meet the environmental demands of society, government, customers, and suppliers, known as external stakeholders [5]. Since it is possible to use resources more efficiently with environmental orientation, an advantage is provided to the business in terms of reducing operating costs, attracting new customers, encouraging innovation and gaining competitive advantage thanks to all these benefits [10].

Environmental orientation, an important aspect of environmentalism, reflects the degree to which the enterprise is sensitive to overcoming the environmental degradation created by it. The environmental orientations of businesses include various measures to reduce the harmful environmental impacts of their daily activities as well as to reduce the long-term environmental impacts [22]. In addition, environmental orientation, which expresses the responsibility of the enterprise towards the environment, underlines the meeting of both economic goals and environmental and social needs at the same time [23].

Organizational innovation: It is expressed as the ability of the organization to introduce new products to the market or to create new markets by combining innovative behaviors and processes with compatible strategies. In today's conditions, organizational innovation is of great importance as it is possible for businesses to survive and gain competitive advantage only by being innovative. With organizational innovation, it is aimed to implement new ideas in the business, to create additional value for consumers, to create new or additional value in products, services, and business processes in the organization and in management and marketing systems [17].

The existence of organizations in a dynamic and intense environment causes organizations to have difficulties in their activities. For this reason, many organizations need to adopt organizational innovation, which is seen as the source of their competitive leadership [1].

Beyond producing products and services with organizational innovation, new management models such as business models, management techniques, management strategies, organizational structures and total quality management are expressed. The understanding of organizational innovation enables the organization to accept different ideas and to adopt an organizational atmosphere that is open to innovation and encourages thinking by creating brainstorming among employees [8].

Environmental capability is defined as the capacity of an enterprise to use human, business, and technology resources environmentally to improve its performance and protect the natural environment [16]. The first objective of environmental capability is to minimize the ecological impact that may occur because of the activities of the enterprise. Environmental capability consists of a multidimensional structure based on the possession and use of appropriate resources that reduce ecological impact while creating value and increasing business performance [12].

Businesses take environmental initiatives in line with their environmental capabilities. Environmental capability can create new business opportunities for the business as a result of the increase in the demand for environmental

awareness and provides a sustainable future by compensating for the environmental damages caused by industrialization [11].

Increasing interest in environmental sustainability causes businesses to shape their inputs, outputs, and processes in an environmental sense. This situation results in the addition of new green positions to the enterprise and the emergence of green tasks by expanding the limits of responsibility. Therefore, the concept of environmental initiative gains importance [2].

Performance, information obtained because of a purposeful and planned activity, etc. It is defined as the qualitative or quantitative expression of outputs. Performance also indicates the degree of fulfillment of goals and objectives. Evaluation of whether businesses reach their goals is possible with performance measurement [13].

Evaluation of all the direct and indirect effects that businesses have created on the environment through their activities is expressed as environmental performance. Within the scope of environmental performance; Criteria such as energy consumption, raw material usage rate, water usage rate, solid wastes, and wastes released to the soil, on the environment, are controlled. Developing environmental management policies and applying environmental management systems or standards are among the ways businesses can control their environmental performance [21].

Market performance: It expresses the success of the enterprise in the market and is seen as the achievements obtained because of the implementation of the competitive strategies created by the enterprise to achieve its goals or the gains achieved in this process [7].

Financial performance: It reveals the difference between the targeted financial situation of the enterprise and the actual financial situation. Thanks to the measurement of financial performance, the business can take various measures according to the results by comparing itself with the competitors in the market [19].

Perceived quality is defined as consumers' expectations for the brand and consumer perceptions and feelings about various alternatives. It shows the value consumers place on the product or service and expresses the degree to which the product or service achieves the expected goals. While perceived quality encourages consumers to buy the product, it also enables them to accept the superiority of the product in general [6].
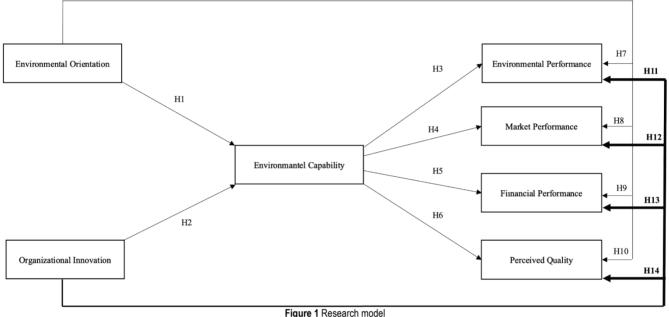
It is seen that perceived quality has a significant effect on the purchasing decision process of the consumer. In addition, the success and failure of any business shows the rate of acceptance of products / services depending on perceived quality [18].

Perceived quality, as a result of the consumer seeing the current product as different from competing products, ensures the purchase of the product and contributes to customer value. The company also has duties in terms of quality perception and it is of great importance that they make a positioning that emphasizes the aspects that they are different from their competitors in order to be perceived as high quality [20].

## 3 METHODOLOGY AND APPLICATION

In this study, it is aimed to investigate the effect of environmental orientation and organizational innovation of production enterprises operating in Erzurum province on environmental capability, and to investigate the effects of environmental orientation, organizational innovation and environmental capabilities on environmental performance, market performance, financial performance, and perceived quality. The scope of the research consists of production enterprises registered in Erzurum Chamber of Commerce and Industry. Therefore, the results obtained from the study cannot be generalized for Turkey.

Variables in the research model; environmental orientation, organizational innovation, environmental capability, environmental performance, market performance, financial performance, and perceived quality. The variables used in the research, the number of questions of the variables and the sources of these variables are as follows: environmental orientation (7), organizational innovation (3), environmental capability (13), market performance (3), financial performance (3), perceived quality (3) [12] and environmental performance (4) [4].

The model developed for the purpose of research by examining the literature is shown in Fig. 1 below.



**Figure 1** Research model

In line with the research purpose and model, the following hypotheses have been developed.
H1: Environmental orientation influences environmental ability.
H2: Organizational innovation has an impact on environmental capability.
H3: Environmental capability has an impact on environmental performance.
H4: Environmental capability has an impact on market performance.
H5: Environmental capability has an impact on financial performance.
H6: Environmental ability has an impact on perceived quality.
H7: Environmental orientation has an impact on environmental performance.
H8: Environmental orientation has an impact on market performance.
H9: Environmental orientation has an impact on financial performance.
H10: Environmental orientation has an impact on perceived quality.

H11: Organizational innovation has an impact on environmental performance.
H12: Organizational innovation has an impact on market performance.
H13: Organizational innovation has an impact on financial performance.
H14: Organizational innovation has an impact on perceived quality.

The main mass of the study is the production enterprises operating in Erzurum. Convenience sampling method was used in the study. According to the information received from the Chamber of Commerce and Industry, it has been determined that there are 138 production enterprises in Erzurum. In this direction, 98 questionnaire forms collected from businesses that accepted to fill in the questionnaire were evaluated.

Research data were obtained using face-to-face survey technique. The questionnaire form consists of 40 questions. Regarding the research variables in the prepared questionnaire, it was stated that 36 questions on environmental orientation, organizational innovation, environmental capability, environmental performance, market performance, financial performance, and perceived

quality. There are 4 questions to determine demographic characteristics.

# 4 ANALYSIS OF DATA

A frequency test was conducted to determine the demographic characteristics of respondents regarding their field of activity, number of employees, duration of activity and environmental documents they hold. The results obtained are summarized below.

The frequency values related to the field of activity of the enterprises are shown in Fig. 2 below.
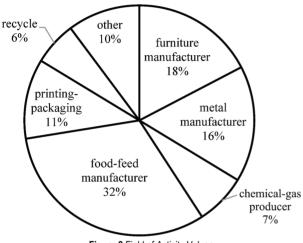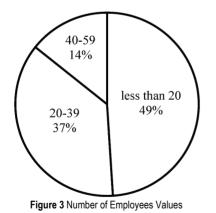


**Figure 2** Field of Activity Values

The frequency values related to the number of employees of the enterprises are shown in Fig. 3 below.



**Figure 3** Number of Employees Values

The frequency values related to the operating periods of the enterprises are shown in Fig. 4 below.

The frequency values for enterprises to have environmental certificates are shown in Fig. 5 below.

Confirmatory factor analysis was performed to test the suitability of the scales in the research model with the sample. In confirmatory factor analysis, there are "goodness of fit indices" that are widely used to determine model fit. These indexes, which take values that can vary between 0 and 1, include acceptable limits for model compatibility [9, 14, 3].



**Figure 4** Activity Period Values
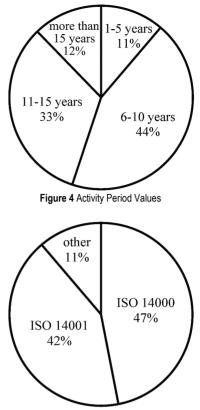


**Figure 5** Environmental Certificates Values

To test the environmental orientation scale, confirmatory factor analysis was performed and because of confirmatory factor analysis, it was seen that the model fit values of 7 variables under environmental orientation were not at an acceptable level. As a result of the analysis, suggested modifications were made and the post-modification fit values are shown in Tab. 1 below.

**Table 1** Compliance values of the environmental orientation scale

| | Absolute Fit Values After Modification | Acceptable Fit |
|---|---|---|
| *Chi-square* | 14,52 | |
| *Degrees of freedom* | 11 | |
| *Chi-Square / SD* | 1,32 | 1-5 |
| *GFI* | 0,96 | $0,90 < GFI < 0,95$ |
| *AGFI* | 0,89 | $0,85 < AGFI < 0,90$ |
| *SRMR* | 0,04 | $\leq 0.10$ |
| *RMSEA* | 0,06 | $0,05 \leq RMSR \leq 0,08$ |
| *CFI* | 0,99 | $0,95 < CFI < 0,97$ |
| *NNFI* | 0,98 | $0,95 \leq NNFI \leq 0,97$ |
| *NFI* | 0,96 | $0,90 \leq NFI \leq 0,95$ |

Since the difference between the specified values and acceptable fit values is statistically low, it can be said that the values of the study are among the acceptable fit criteria.

In the study, ANOVA test was performed to understand whether the regression model is significant in estimating the dependent variable and to determine its suitability with the existing data. According to the results obtained, it was concluded that the significance level for the dependent variable was below 0.001, and it was concluded that the regression model was significant.

Multiple regression analysis was conducted to examine the environmental orientations and the impact of organizational innovations on environmental capability of production enterprises operating in Erzurum province, and the effects of environmental orientation, organizational innovation and environmental capabilities on environmental performance, market performance, financial performance, and perceived quality.

The results of the regression analysis conducted to examine the effect of environmental orientation and organizational innovativeness on environmental capability are given in Tab. 2 below.

**Table 2** Multiple regression analysis for environmental capability

| Variables | Environmental Capability | | | | Correlations | | |
|---|---|---|---|---|---|---|---|
| | Beta | t | p-Value | VIF | Zero Sequence | Partial | Part |
| Environmental Orientation | 0,36 | 3,87 | 0,00 | 1,35 | 0,54 | 0,37 | 0,31 |
| Organizational Innovation | 0,35 | 3,77 | 0,00 | 1,35 | 0,54 | 0,36 | 0,30 |
| R | 0,62 | | | | | | |
| $R^2$ | 0,38 | | | | | | |
| Adjusted $R^2$ | 0,37 | | | | | | |

In Tab. 2, the R value is seen as 0.62. The $R^2$ value was obtained as 0.38. Accordingly, environmental orientation and organizational innovation can explain environmental capability by 38 %. It was concluded that the environmental orientation (0.00) and organizational innovativeness (0.00) variables included in the model and whose significance values are less than 0.05 influence environmental capability, and the related hypotheses (H1, H2) were accepted.

The results of the regression analysis conducted to examine the effects of environmental orientation, organizational innovativeness and environmental ability variables on environmental performance are given in Tab. 3 below.

**Table 3** Multiple regression analysis for environmental performance

| Variables | Environmental Performance | | | | Correlations | | |
|---|---|---|---|---|---|---|---|
| | Beta | t | p-Value | VIF | Zero Sequence | Partial | Part |
| Environmental Orientation | 0,33 | 3,11 | 0,00 | 1,56 | 0,49 | 0,30 | 0,25 |
| Organizational Innovation | 0,02 | 0,20 | 0,84 | 1,55 | 0,32 | 0,02 | 0,02 |
| Environmental Capability | 0,32 | 2,99 | 0,00 | 1,62 | 0,49 | 0,29 | 0,25 |
| R | 0,56 | | | | | | |
| $R^2$ | 0,32 | | | | | | |
| Adjusted $R^2$ | 0,29 | | | | | | |

In Tab. 3, the R value is seen as 0.56. The $R^2$ value was obtained as 0.32. Accordingly, environmental orientation, organizational innovation and environmental capability can explain environmental performance by 32 %. It was concluded that the environmental orientation (0.00) and environmental ability (0.00) variables included in the model and whose significance values are less than 0.05 influence environmental performance, and the related hypotheses (H3, H7) were accepted. The hypothesis (H11) that the

organizational innovativeness (0.84) variable with a significance value greater than 0.05 influences environmental performance was rejected.

The results of the regression analysis conducted to examine the effects of environmental orientation, organizational innovativeness and environmental capability variables on market performance are given in Tab. 4 below.

**Table 4** Multiple regression analysis for market performance

| Variables | Market Performance | | | | Correlations | | |
|---|---|---|---|---|---|---|---|
| | Beta | t | p-Value | VIF | Zero Sequence | Partial | Part |
| Environmental Orientation | 0,09 | 0,76 | 0,45 | 1,56 | 0,27 | 0,08 | 0,07 |
| Organizational Innovation | 0,01 | 0,13 | 0,90 | 1,55 | 0,23 | 0,01 | 0,01 |
| Environmental Capability | 0,32 | 2,65 | 0,01 | 1,62 | 0,38 | 0,26 | 0,25 |
| R | 0,39 | | | | | | |
| $R^2$ | 0,15 | | | | | | |
| Adjusted $R^2$ | 0,12 | | | | | | |

In Tab. 4, the R value is seen as 0.39. The $R^2$ value was obtained as 0.15. Accordingly, environmental orientation, organizational innovation and environmental capability can explain market performance by 15 %. It was concluded that the environmental ability (0.01) variable in the model with a significance value less than 0.05 influenced the market performance and the related hypothesis (H4) was accepted. The hypotheses (H8, H12) that environmental orientation (0.45) and organizational innovativeness (0.90) variables with a significance value greater than 0.05 influence market performance were rejected.

The results of the regression analysis conducted to examine the effects of environmental orientation, organizational innovativeness and environmental capability variables on financial performance are given in Tab. 5 below.

**Table 5** Multiple regression analysis for financial performance

| Variables | Financial Performance | | | | Correlations | | |
|---|---|---|---|---|---|---|---|
| | Beta | t | p-Value | VIF | Zero Sequence | Partial | Part |
| Environmental Orientation | 0,05 | 0,46 | 0,65 | 1,56 | 0,31 | 0,05 | 0,04 |
| Organizational Innovation | 0,16 | 1,42 | 0,16 | 1,55 | 0,36 | 0,14 | 0,13 |
| Environmental Capability | 0,33 | 2,83 | 0,01 | 1,62 | ,044 | 0,28 | 0,26 |
| R | 0,47 | | | | | | |
| $R^2$ | 0,22 | | | | | | |
| Adjusted $R^2$ | 0,19 | | | | | | |

In Tab. 5, the R value is seen as 0.47. The $R^2$ value was obtained as 0.22. Accordingly, environmental orientation, organizational innovation and environmental capability can explain financial performance by 22 %. It was concluded that the environmental ability (0.01) variable in the model, with a significance value less than 0.05, influenced financial performance and the related hypothesis (H5) was accepted. The hypotheses (H9, H13) that environmental orientation (0.65) and organizational innovativeness (0.16) variables with significance values greater than 0.05 have an impact on financial performance were rejected.

The results of the regression analysis conducted to examine the effects of environmental orientation, organizational innovativeness and environmental ability variables on perceived quality are given in Tab. 6 below.

**Table 6** Multiple regression analysis for perceived quality

| Variables | Perceived Quality | | | | Correlations | | |
|---|---|---|---|---|---|---|---|
| | Beta | t | p-Value | VIF | Zero Sequence | Partial | Part |
| Environmental Orientation | 0,21 | 1,77 | 0,08 | 1,56 | 0,34 | 0,18 | 0,17 |
| Organizational Innovation | 0,08 | 0,67 | 0,51 | 1,55 | 0,27 | 0,07 | 0,06 |
| Environmental Capability | 0,16 | 1,34 | 0,18 | 1,62 | 0,32 | 0,14 | 0,13 |
| R | 0,38 | | | | | | |
| R² | 0,14 | | | | | | |
| Adjusted R | 0,12 | | | | | | |

In Tab. 6, the $R$ value is seen as 0.38. The $R^2$ value was obtained as 0.14. Accordingly, environmental orientation, organizational innovation and environmental capability can explain the perceived quality by 14 %. Hypotheses (H6, H10) that environmental orientation (0.08), organizational innovativeness (0.51) and environmental ability (0.18) variables in the model with significance values greater than 0.05 have an effect on perceived quality, (H14) was rejected.

## 5 CONCLUSION AND RECOMMENDATIONS

The increase in environmental problems necessitates environmental activities to gain importance and businesses as well as people to carry out their activities in an environmentally sensitive manner with environmental responsibility. As a result of the literature review, although there are studies on the concepts of environmental orientation, organizational innovation, environmental ability and performance, it has been seen that there is not enough work to examine the effects of these concepts on each other and on performance. This study was the first study applied to the production enterprises in Erzurum by considering the model variables.

In this study, the concepts of environmental orientation, organizational innovation, environmental capability, environmental performance, market performance, financial performance and perceived quality were examined, and the hypotheses created were tested. In this direction, it is aimed to reveal the effect of environmental orientation and organizational innovation of enterprises on environmental capability and to investigate the effects of environmental orientation, organizational innovation and environmental capability on environmental performance, market performance, financial performance, and perceived quality. As a result of the analyzes made in accordance with the purpose of the research, it was concluded that environmental orientation was effective on environmental ability and environmental performance; organizational innovation has an impact on environmental capability; It has been concluded that environmental capability is effective on environmental performance, market performance and financial performance.

In line with these results, it is seen that the improvement of the environmental capabilities of the enterprises provides many advantages to the enterprises and the environment when the benefits provided by these capabilities are considered. The advantages of improving the environmental capabilities of the enterprises are listed below.

- The businesses of the future will be those that support sustainable life and develop green core capabilities in this regard.
- Developing an enterprise's environmental capabilities, increasing the market share in the business will contribute to the increase in customer retention and growth in sales.
- In terms of financial performance, it will contribute to the high current and expected return on investment in the business and the expected average profit per customer.
- In terms of environmental performance; by preventing the unconscious consumption of our resources and the great damage to the environment, it will facilitate the success of the enterprise in eliminating waste and emissions, maximizing the efficiency and productivity of resources, and preventing environmental pollution.
- Environmental capabilities make a significant contribution to strengthening the image of the enterprise, it will contribute to the company's chance to enter new markets, customer satisfaction, and efficiency.
- Adopting an environmental understanding in the business will contribute to the environmental awareness of the employees and increase their commitment and motivation to the business.
- It will help the business gain a significant competitive advantage over its competitors.
- Since businesses are seen as a part of the society and environment in which they live, fulfilling their responsibilities towards the environment will provide a more liveable world for the future by protecting the natural environment.
- Increasing awareness of the society and consumers about the environment day by day will enable businesses that improve their environmental capabilities to continue their existence for a longer period.

These advantages listed above can encourage businesses to be environmentally friendly. For this reason, businesses should first consider these advantages in developing their environmental capabilities. The following suggestions can be made for businesses to improve their environmental capabilities and acquire environmental awareness to direct them towards environmentalism.

- To create an environment-oriented organizational culture for the business to change its perspective, goals, and behaviors in an environmental sense by placing the philosophy of environmental protection in the business culture,
- Creating new job descriptions based on environmental principles with an understanding of organizational innovation,

- To create environmental internal values and ethical standards by adopting an environmentalist corporate culture,
- To carry out studies on environmental awareness in various functional activities of the enterprise,
- To determine effective sustainable strategies and environmental policies in the enterprise to achieve environmental improvements,
- To provide trainings to increase the environmental awareness of the employees and to ensure the continuity of these trainings,
- To encourage employees to think about the environment and to develop measures, and to reward their success,
- To support the use of environmentally friendly technologies in the enterprise and R&D studies for the protection of the environment,
- Preferring the reusable raw materials to be used,
- Participating in an environmental organization,
- Collaborating with trade unions on the environment,
- It can be expressed as introducing the environmental policy of the enterprise to the society.

These advantages and suggestions will contribute to the establishment of a roadmap on environmental issues and will facilitate their survival as the businesses of the future by encouraging them to environmentalism. For this reason, in today's conditions, the issue of environmentalism should be seen as an issue that should be taken into account in terms of businesses.

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# Development and Utilization of Smart Projected Beam Advertising System for Public Transportation
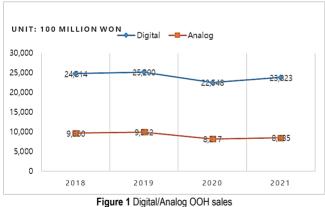
Jun-Ho Kwon

**Abstract:** The purpose of this study is to present and develop a practical advertising model that minimizes transport advertisements, indiscriminate banners and flyers, and logo light installation problems with smart advertisements using projected beams. In order to develop an integrated smart advertisement that is convenient and inexpensive for companies operating at night, the scope of the research is determined as a practical advertisement that identifies the problems of existing bus and taxi smart advertisements and the needs of customers. The smart projected beam advertisement that the author claimed is a customized advertisement that solves the advertising problems of customers and local governments in Korea based on business hours, locational information, and big data. The projected beam outdoor advertising system developed by the author was designed to reduce environmental and resource waste, avoid unnecessary advertisement exposure for consumers, and obtain necessary information for businesses. Moreover, it was developed to reduce advertising costs for businesses. This is a very appropriate solution as an alternative to reduce the night time flyers and banners that local governments in Korea are struggling with. Consumers can avoid unnecessary advertisement exposure and obtain customized information, while advertisers who use the service can directly insert their sales information into advertisements in real-time using various media at a low cost.

**Keywords:** beam projector; big data; locational information; smart advertisement; transport advertisement

## 1 INTRODUCTION

In the current economic downturn in Korea due to the Corona virus, competition among small business owners is getting fiercer, and the outdoor advertising market is a large market with a size of 3.35 trillion won, and we are living in an era of advertising competition. Fig. 1 shows the size of the digital outdoor advertising market and the analog advertising market. In particular, digital outdoor advertising is showing growth, although the change is not too significant, with 248.1 billion won in 2018 and 252 billion won in 2019.



**Figure 1** Digital/Analog OOH sales

However, the biggest problem with the current advertising business is that advertisers are burdened with advertising costs due to high advertising unit prices, and accordingly, business operators have difficulties in selling advertising media. Also, in recent bus advertisements, it was suggested that the media management of advertisements outside the bus was neglected and poor. Advertisements should be kept visually clean and good looking while they are posted. The fact that the visual appeal of advertisements is declining was pointed out as a major problem [1]. Therefore, the purpose of this study is to specifically study the development and utilization of smart advertising media using convenient and efficient public transportation for small business owners.

The purpose of this study is to develop convenient and efficient smart advertisements for small businesses, through the development of public transportation smart advertisement media using Projected Beam. For this reason, the following four research methods and scopes are established.

1) Analyze the concept of smart advertisement using traffic advertisement and project beam based on literature data.
2) Compare and analyze the problems of outdoor advertisements and seek solutions.
3) Search for customized smart advertising methods through cases using domestic and overseas smart advertising systems.
4) Present a smart advertising business model using Project Beam, which is convenient for small business owners

## 2 RELATED WORKS

### 2.1 Concept of Smart Advertisements using Transport Advertisement and Projected Beam

Transport advertisements refer to advertisements that display texts, figures, etc. on transportation facilities (underpasses, railroads, subways, airports, harbors, and expressways), or installation and display of posting facilities such as wood, acrylic, and metal materials, and advertisements that display text and figures on the outside of transportation means (trains, subways, cars, airplanes) [2]. In other words, advertisements installed using transportation facilities or installed inside or outside transportation means such as buses or taxis can be regarded as transport advertisements.

In addition, domestic traffic advertising falls within the category of outdoor advertising in terms of legal and sector. Projected Beam Advertisement literally refers to an

advertisement system that uses the light emitted from a device to display phrases and images containing products or specific topics. It is also extended to a format that transmits information by connecting to various external devices as well as PC. Smart advertisement can be referred to as a comprehensive information system that interacts with users by using a digital video device in a specific place, and providing various information through a network. [3] The advantage is that people who come across advertisements can autonomously accept collective information, including advertisements, and interact with their devices.

Personalization of smart advertisements is developing into predictive advertisements that recognize and provide services that consumers want in advance and native advertisements that naturally permeate into services and minimize consumer rejection, which also contains infinite possibilities. However, if coercion enters into these interactions, it may cause problems in imprinting and lowering the effectiveness and impact of the advertisements.

## 2.2 Functions and roles of transport advertisement

Fig. 2 shows advertisements inside and outside of buses and taxis. Transport advertisements have individual selectivity and high reach for a wide selection of contract periods, and posters can easily reach passers-by, car or bus passengers, dealers, and wholesale/retailers, thereby fulfilling the role of an effective local poster. [4] Compared to other advertisements, transport advertisements have a high advertising effect and high cost because they have a greater chance of being exposed to an unspecified number of people. Currently, it is one of the most popular outdoor advertisements worldwide.



**Figure 2** Transport advertisement attached inside and outside of public transportation

## 2.3 Functions and Roles of Projected Beam Advertising (Including Logo Lights) and Smart Advertising

By using the projected beam, it is possible to expand the scope to a more dynamic and active role that provides various stories or dramatic elements by projecting three-dimensionally or creating an optical illusion effect [5]. The logo light beam advertisement used in general stores has problems such as the device installation location problem and the decrease in clarity due to the light reflection of the illuminated signboard in the commercial district. Also, when used indiscriminately on the street, it can become the main culprit causing light pollution to passing citizens.

Advertising activities for events or promotions using Projected Beam are generally suitable for use during the event period and require a high cost. However, if advertising using Projected Beam is developed in the direction of maximizing efficiency and reducing costs, it can be suitable as a future advertising medium in that it does not consume unnecessary resources.



**Figure 3** Installation case logo light and smart signage

It is also used for promotions, boasting excellent visuality and visibility, and creating high advertising effects. Such advertisements become landmarks in the area, such as Times Square in New York, creating cultural value beyond commercial purposes. The most easily accessible advertisement among projected beam advertisements is the logo light advertisement. It is a method of transmitting specific phrases or images using LEDs on the wall or floor, and serves to provide publicity and attractions to tourists and residents [6].

Fig. 3 is shown in the upper left image, local governments currently play a role in preventing crime and encouraging residents by illuminating dark alleys, bridges, and places where residents do not move. In addition, night time businesses use projected beams to attract customers by advertising themselves at the entrance, when their establishment is located on the second floor or underground and it is difficult to identify them. The most core functions of smart advertisement are real-time information and location-based information of those exposed to advertisements, and they provide advertising services that match the information they want to obtain. This gives people who come across the advertisement an expectation of the advertisement information, thereby increasing the credibility of the advertisement medium.

## 3 PROBLEMS OF EXISTING OUTDOOR ADVERTISING
## 3.1 The Problem with Transport Advertisements

Transport advertisements have the advantage of being able to expose a lot to passers-by as the means of transportation move. But behind this great advantage, there are also several problems. First of all, the exposure target of inside transport advertisements should be limited to passengers. In addition, if advertisements are installed on

dirty buses or taxis, the quality of advertisement products may be damaged, and there are major disadvantages in that advertisements must be regulated in terms of their content.

## 3.2 Problems with Flyers and Banner Ads

On-site advertising typically includes banners and flyers, and most small businesses are conducting illegal advertising using flyers and banners. This undermines the aesthetics of the street in the way that those who receive the flyer are semi-forced and they would throw it away. As a result, local governments have to pay huge costs to collect them.



**Figure 4** Collecting illegal banners

As shown in Fig. 4, local government of each city, county, and district across the country, including Seoul, is responding to civil complaints by regularly taking down illegal banners, etc. For example, in the case of Seoul, the average number of complaints related to the removal of illegal banners is 172,000 per year.

An official from Seoul said that since 2015, they have been operating a mobile maintenance team to take down illegal banners on a regular basis. In addition, the official said that a compensation system for collecting illegal banners is being implemented, and a budget of 1.28 billion won has been reserved this year [7]. Those who set up illegal banners do it illegally to get a short publicity effect for temporary advertising before they are collected. To install a banner in a designated place, there must be a waiting time during the application process, which is also one of the causes of illegal banner installation.

**Table 1** General OOH price

| (Unit: case) | Removal | Warning |
|---|---|---|
| Public facilities advertisement | 215 | 21 |
| Transport facilities advertisement | 32 | 4 |
| Transport advertisement | 191 | 134 |
| Notice | 45,511,947 | 818,446 |
| Leaflet | 104,281,687 | 113,437 |

Tab. 1 is a table showing the general outdoor advertising cost. In a situation where many businesses have no choice but to use flyers and banner advertisements, which are cheaper than other outdoor advertisements, in order to maintain their business in a downturn, the price of advertising products can be said to be the absolute criterion for success.

Tab. 2 is the total status of administrative dispositions for removal and warning measures for illegal advertisements in 2017. It can be seen that illegal flyer advertisements record a higher number than other illegal advertisements. It is also pointed out that the problem is that the behavior of people who illegally distribute or attach leaflets is becoming more

sophisticated, and that the fine for illegal leaflets described in the Misdemeanor Punishment Act is less than 100,000 won. Various illegal flyers and leaflets that harm the aesthetics are expanding beyond environmental problems to social problems.

**Table 2** Administration disposition present condition of illegal advertisement in 2017

| (Unit : USD) | | Average price |
|---|---|---|
| Leaflet (A4) | One time (3.2sheet) price | 56 - 80 |
| | labor price | 120 |
| Banner | 1 m² by 3.2 - 4 | sheet by 25.2 |
| | installation price | 16 |
| Bus advertisement | Outside advertisement price | 480 - 1,279 |
| | Inside advertisement price | 1 sheet by 20- 48 |
| | Inside video advertisement price | 15 s :19,185 |
| | | 20 s : 25,580 |
| | | 30 s : 38,370 |
| Taxi advertisement | Outside advertisement price | 1 unit monthly 72 |
| | Inside advertisement price | 1 unit monthly 24 |

For example, in the first quarter of 2019, the upper limit of compensation was adjusted from 2.5 million won to 1.5 million won in the second quarter due to the excessive budget involved in the compensation system for collecting illegal advertisements in Jecheon City. An official from Jecheon City explained the background, saying, "This year, the budget for the compensation system for collecting illegal advertisements was 50 million won, but 14 million won was paid in the first quarter alone, which exposed the problem of budget shortage [8]". In addition, the government of Haeundae-gu in Busan greatly reduced the amount of compensation to a quarter compared to the pilot implementation of the ordinance for compensation for collection of illegal advertisements. This is because too much budget was spent, i.e., 34 million won being paid in one month [9]. As such, it can be seen that the cost of collecting illegal advertisements continues to increase nationwide.

## 3.3 Problems of Smart Advertising Using Public Transportation

In Fig. 5, the two upper images are examples of smart digital advertisements in Korea, and the image on lower left is a picture of a bus advertisement in New York, while the one on lower right is an advertisement inside a taxi in Japan. In particular, the last image is a unique service that allows you to use a taxi for free if you see the advertisement. Developed countries are adopting smart digital advertisements for transportation due to the more advanced media environment, expansion of the transportation advertisement market, and image creation.

Smart digital technology was also introduced in domestic traffic advertisements. LED billboards are installed on both sides of the bus to advertise, while commercial and public service advertisements are displayed using taxi lights. In the case of digital taxi advertisement, a digital information display is installed on a taxi indicator in operation and real-time location-based technology is used. Therefore, it can be used for disaster warnings in addition to advertisements, according to the desired area and time [12]. However, only

side and still image ads are allowed, and the duration of the screen must be at least 1 minute and the screen transition time must be less than 2 seconds. In addition, billboards must be equipped with a controller for which brightness is limited to a certain level in accordance with the Light Pollution Prevention Act standards, and they must undergo a safety inspection conducted by the Korea Transportation Safety Authority [13]. It is a big problem to be subject to many restrictions on administrative rules such as specifications, materials, weight, and materials. Furthermore, in addition to advertising expenses of about 100,000 won per month, there is also a cost problem that a fee is charged for vehicle structure and device changes or inspections. Recently, the size of the display has been increased due to insufficient visibility, but the heavier weight and wind resistance during driving are expected to accompany the problem of reduced fuel efficiency of the vehicle. In the current transition period when smart digital advertising is introduced, a method to solve the above problems is urgently required. The author expect that it will be possible to create an optimal customer-tailored advertisement form if an advertising company exposes advertisements by combining business hours and location information, and compares and analyzes the advertisement patterns exposed to the company's sales.



**Figure 5** Digital advertisement on buses and taxis

## 4 EXAMPLES OF ADVERTISEMENTS USING SMART ADVERTISING
### 4.1 Domestic Cases Using Smart Advertising

Big data, which can collect a large amount of information and use it to analyze results, is a key technology in the smart digital advertising industry. In particular, advertising companies are establishing sophisticated advertising strategies by deriving information such as who our customers are, what behavioral patterns they have, what messages are effective, and what contact points to use [10]. As a precedent, in the past, the Seoul Metropolitan Government has analyzed encrypted data excluding KT and personal information to analyze where people are at 1 a.m. and where they wait for taxis and night buses, in order to expand the night bus routes around places with high demand. In addition, NEI&COMPANY, which operates a cloud-based transportation integrated advertising platform, connects advertisers and transportation advertising agencies through the platform, and also measures the effectiveness of transportation advertisements using transportation big data

[11, 15, 16, 17]. In this way, smart advertising not only presented a new platform in Korea, but also brought about a change in the shape of the domestic outdoor advertising market.

### 4.2 Overseas Cases using Smart Advertising

The left image in Fig. 6 is a connected bus stop in Barcelona, Spain, which helps outdoor advertising companies to collect and analyze a wide range of big data by using the hotspot function. Outdoor advertising companies can learn about various figures about people at bus stops, and use this to create advertisements more effectively and earn a lot of profits.



**Figure 6** Connected bus-stop and taxi loaded with GPS

As shown in the image on the right, US media signage provides a service that combines digital outdoor advertising with location information. Advertisements for places passing by are shown on advertisement displays such as buses and taxis.

## 5 CONSIDERATION FOR IMPROVEMENT DIRECTION
### 5.1 Presenting a Smart Advertising Business Model Using Projected Beam

Until now, lighting advertisements could not be installed on transportation means such as buses in accordance with the domestic outdoor advertisement law. However, the Regulatory Exceptions Review Committee has decided to make a special exception to these regulations.



**Figure 7** Smart projector beam on the floor when open the taxi door

Therefore, it is possible to use location information to send out local-customized advertisements such as nearby stores [14], but the administrative norms that require

permission for viewing of digital display advertisements are still specified.

In order to encourage this, there is the task to prepare a system for the system.

Fig. 7 is a smart taxi advertisement using Projected Beam, which the author reconstructed with Photoshop. When passengers get out of the taxi, a projector installed inside the door displays advertisements on the floor. Advertisements are companies located in the vicinity, and customized advertisements for companies and consumers are performed based on business hours, location information, and big data.
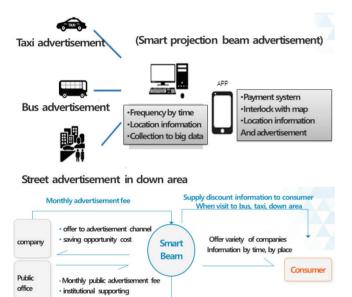


**Figure 8** System operation of projected beam advertisement

Fig. 8 is a configuration diagram in which the smart advertisement business model collects consumer location information and time-specific information, and performs advertisement delivery functions through projected beams and applications. Through this, it can be seen that businesses, government offices, and consumers interact and find each other's needs. Smart beam projector advertisement system is a technology that can provide customers with general information and discount information from nearby businesses based on the current time and location by providing advertisement videos of nearby businesses through the beam projectors installed in taxis, buses, and public advertising zones in commercial areas. At the same time, it can maximize the number of visiting customers by providing effective advertising services for business owners. Specifically, the database stores the advertisement videos and matches the advertisement videos with the desired time and location of the business to be displayed. The beam projector system is composed by including a communication unit for transmitting and receiving information to and from the database, and a GPS receiver to identify the current time and location of the beam projector. The beam projector is installed on one side of the passenger side and the right rear door of the taxi, and on the exit door of the bus. Accordingly, when a passenger in a taxi or a bus disembarks, the GPS

receiver of the beam projector identifies the current time and location of where the taxi passenger's right rear door is opened or where the bus exit door is opened. The identified information is then transmitted to the database through the communication unit. If the advertisement video from the company requesting the advertisement service stored in the database is matched with the time and location information for the advertisement to be displayed, the database would transmit the advertisement video to the beam projector. The beam projector would then display the received advertisement video on the floor so that passengers can see it. As a result, passengers can get the information by watching advertisement videos of nearby businesses as soon as they disembark.

By using a single integrated service, business owners don't have to pay a lot of money to use various types of general advertisements such as flyers and banners, thereby reducing advertisement costs and at the same time using effective advertisement service. At this time, the advertisement video generated when a passenger is getting off the taxi or bus also functions to create a yellow zone that notifies nearby motorcycles and other vehicles that passengers will get off, thereby guiding passengers to disembark safely. Furthermore, in addition to advertising services for taxi and bus passengers, installing beam projectors in commercial areas where companies are densely populated would make it possible to eliminate indiscreet advertisements and provide beneficial advertisements for each time period to consumers, by forming a public advertisement zone and displaying advertisement videos of nearby companies that are mainly operating at the current time. On the other hand, it is also possible to provide a dedicated application to consumers through the app operation server. In case consumers want to get more detailed information when they get off the taxi or bus, or after watching an advertisement in a public advertising zone, it is possible to provide them with an advertisement video containing more detailed general information and discount information from the business, by executing a dedicated application and searching for the particular business to obtain information through the location-based service.



**Figure 9** Process of projected beam advertisement

The smart advertisement that the author proposes is as described in Fig. 9. It goes through the process of requesting an inquiry, executing an advertisement, acquiring information, and visiting a company. It also provides integrated online and offline services through a mobile application. Based on this, it creates an advertisement zone in the commercial area to guide customers, or provides discount information of nearby businesses by time to

customers approaching the commercial district by taxi or bus. For companies, it provides a service that can maximize the

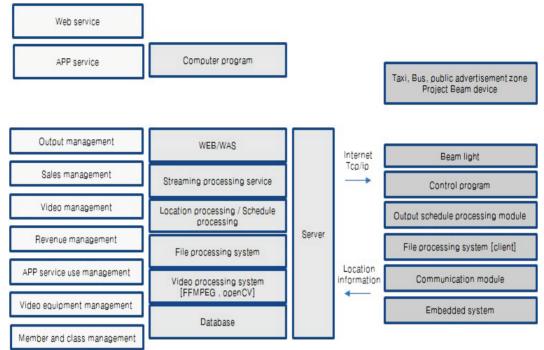number of visitors by effectively advertising to the customers who need it.



**Figure 10** Smart advertisement system elements with projected beam



**Figure 11** Street advertisement, bus advertisement, and app advertisement using smart beam

Fig. 10 shows the system components of smart advertisement using Projected Beam. In the web or app service, a computer server that manages various information and customers and uses location information transmits the discount information of the company along with video advertisements in real time. People who arrive near the company using smart beam advertisements in taxis, buses,

and public advertising zones can visit the company and enjoy discounts. Big data also stores the route of traffic and the frequency of advertising locations. It provides a service that can compare advertisement pattern history and sales to the company's management, and handles various real-time events and free transportation fee payment service for consumers.

## 5.2 Smart Beam Projector System Advantages and Uses

The advantages of smart advertisement (Fig. 11) that the author proposes are that it is not affected by the weather, it has a natural gaze fixation effect in the advertisements, it is inexpensive to transmit videos and images, and it also has various directing effect compared to the unit cost ratio. In addition, advertisements using the Smart Beam Projector System can target all age groups due to the advertisement effect targeting an unspecified number of people, while advertisements by region and route are made possible using GPS location-based technology.

## 5.3 Addressing Natural Environment and Economic Problems

Just because illegal flyers are made of paper, it doesn't mean they're all recyclable. It is impossible to recycle coating paper or magnetic leaflets, which have been widely used recently. This is also the reason why smart advertisements using projected beams are urgently needed to minimize waste. Since it is not an object but a form of light, there is no waste of material and resources required for printing. It can

also be displayed at night time, to replace eventful flyers and banners. Therefore, it is expected that it will be able to save local governments' budget costs for collecting illegal advertisements. Again, smart advertisement using project beam provides business owners with an all-in-one method that integrates multiple types of outdoor advertisements into a single service; provides the effect of directly reducing environmental problems caused by thrown-away flyers and banners, as well as reducing resource costs that the government offices have to spend to deal with the problem; and provides customers visiting business districts with opportunities to learn about general information and discount information of the nearby business through the video

## 6 CONCLUSION

Recently, the overall outdoor advertising market and digital outdoor advertising market are growing. However, ironically, despite the overflow of advertisements, small business owners feel burdened with advertising costs due to high advertising unit prices, while consumers who consume advertisements have the opinions that smart advertisements using existing public transportation are neglected and poorly managed. Flyers and banners, which are on-site advertisements, are not only making the urban environment messy and distracting, but they are also subject to initial intrusion and are expensive for local governments to deal with.

Therefore, the development of cheap smart advertisements that are convenient and efficient for small businesses is the most important issue in the advertising industry. It is an improvement of resource waste and cost problems in advertising method. Smart advertisement using Projected Beam, for which patent the author claimed, collects consumer location information and time-specific information, and delivers advertisements through Projected Beam and applications. Through this, businesses, government offices, and consumers may interact to find each other's needs. In the web or app service of the system presented by the author, a computer server that manages various information and customers, and uses location information to transmits the discount information of the company, along with video advertisements in real time.

People who arrive near the company using smart beam advertisements in taxis, buses, and public advertising zones can visit the company and enjoy discounts. Big data also stores the route of traffic and the frequency of advertising locations. It provides a service that can compare advertisement pattern history and sales to the company's management, and handles various real-time events and free transportation fee payment service for consumers. In conclusion, smart advertising using Projected Beam is very appropriate as an alternative solution to reducing advertisements for flyers and banners at night, which local governments in Korea are struggling with. Consumers can avoid unnecessary advertisement exposure and obtain customized information, while advertisers who use the service can directly insert their sales information into advertisements in real time using various media at a low cost.

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# Reducing Change Resistance: Stakeholder-based Approach for Extended Reality (XR) Implementations

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**Abstract:** As digitalization progresses, assistance systems in the field of XR are now also increasingly finding their way into industry. This and the advancements in this area make it more and more interesting for industrial companies. However, it is not only the maturity of the technology in the form of hardware and software that is decisive for its use in combination with suitable corporate use cases, but above all the acceptance of the employees who are supposed to integrate this new technology into their everyday work routine. In this context, it is of utmost relevance to identify all necessary stakeholders at an early stage. Therefore, a model for XR implementation projects will be developed to identify stakeholders and derive appropriate measures in terms of change communication and participation.

**Keywords:** change management; extended reality; participation; stakeholder integration; technology acceptance

## 1 INTRODUCTION

With the digital transformation, a large number of technological developments has reached market maturity. One area are extended reality (XR) technologies, which have been used since the 1960s, particularly in the military environment [1], but have only gained relevance for industry in recent years. For instance, according to McKinsey [2], the global extended reality market will grow by almost a quarter by 2035. This is due to the constant technological advances and the correspondingly increasing industrial application areas along the entire value chain. This presents companies with the question of where which XR solution could be ideally used and how the implementation of such a system could be successful in the long run. Where applies to the possible areas of application and use cases in selected departments such as maintenance or production, and which refers to the XR hardware (e.g. mobile device or head mounted device) and software combination that is to be used.

XR technologies are used to simplify everyday work by making information available in a content-oriented, local and timely manner [3]. XR solutions thus represent assistance technologies for humans. However, this poses a double challenge in implementation. On the one hand, the focus is on the application itself, i.e. the added value and benefits that it generates for the user (e.g. for the person responsible for change management or the XR implementation) in terms of content. On the other hand, usability is a possible challenge that must be addressed during the implementation process. These aspects are part of technology acceptance research. The aim of this scientific discipline is to determine the factors influencing human acceptance of new technologies. The most common approach is based on the research of Venkatesh & Davis (2000) who developed the technology acceptance model. According to this, there is a willingness to use the respective technology if it is seen as useful and easy to use by the user. Also they derived some influencing factors on the perceived usefulness and perceived ease of use such as job relevance, experience or output quality [4]. The model represents a generic approach that does not distinguish between different technology directions. For the area of XR, further relevant influencing variables were determined in a

qualitative supplementary study. Protected learning opportunities, data protection and the strategic anchoring of the technology play an important role [5].

Also from the perspective of change management, a strategic framework and a high commitment are decisive for an efficient and successful change [6, 7]. Especially the commitment of employees is crucial. It has been scientifically proven that resistance from employees is the main reason why implementation projects fail [8, 9]. To deal with that, Krüger postulates a strong employee involvement right from the beginning of the implementation process. A high level of active participation leads to a better understanding for the change and respectively to a higher acceptance for the new solution [7].

The present paper contributes to this initial situation. As part of a funded collective research project, a stakeholder analysis tool was developed together with companies. The aim was to systematically localize the people crucial to an XR implementation based on an XR strategy, to group them according to their degree of participation and to derive group-specific communication and participation plans. Within this paper, the development process is described in detail and insights on the tool developed are given.

## 2 STAKEHOLDER MANAGEMENT FOR XR-PROJECTS

Changes caused by the technology implementation often faces underestimated or not considered challenges. Reasons are a missing commitment of the management, barley to no communication about the project, fear towards the technology or in transparent reasons why the change is necessary [10]. The main aspects of technology acceptance have already been highlighted in the introduction. It is therefore possible to deduce that varying needs of the affected individuals subsequently lead to a differentiated set of measures. This to ensure a high level of technology acceptance.

Not taking these factors into account could lead to negative effects within the project from missing deadlines to fail in achieving the set targets up to abortion of the project. In any case the company has to deal with wasted resources,

lost synergies and missing benefits from the XR technology [11].

In this respect it is crucial to identify the affected stakeholders already at the beginning of the planned implementation [12]. Stakeholders are interest groups or individuals who have a special motivation for the development of a company, project or process [13]. In the context of an XR implementation, internal (e.g. future key users, IT department, process engineers) and external (such as provider hardware/software, consultants, government and regulations, to name a few) stakeholders need to be considered [14, 15]. These stakeholders differ not only in terms of whether they are crucial to the content of the XR project or not. Also the position within the company is different, e.g., through their hierarchical level and the associated decision-making power or/and through their collegial reputation in the company. Those differences also affect the influence and importance of the stakeholder, in the project. The areas of influence include resource decisions concerning time and budget, but also social influence in the sense of a multiplier role [16].

Thus, it is relevant, to know all important stakeholders (on professional and social side) to realize a XR implementation successfully. In this respect it is crucial not only to identify the stakeholders but also to gather information about their opinion and their attitude towards the change. Based on this information, specific measures can be taken in terms of communication and participation [17]. Those measures address different causes of resistance such as fears of job loss or of the technology itself, technical and functional concerns, or personal bad experiences with projects of this kind. The aim is to support the stakeholder and help them to overcome the outlined individual change barriers. Furthermore, through ongoing communication synergies can be detected in terms of expertise or relevant information regarding the planned change [18].

In this respect it becomes clear why industrial companies should increasingly focus on actively managing their stakeholders by providing each of them with appropriate information about the project, the opportunity for feedback and actively participate in the change. These aspects will be discussed in more detail in the following.

## 3 CHANGE COMMUNICATION AND PARTICIPATION

This chapter deals with the relevance of communication and participation during a change process. The communication and participation during a change process constitute key components of the concept described within this paper.

Information (e.g. facts or data) is a component of communication and can be enhanced through participation. Thus, the terms information, communication and participation cannot be used synonymously. Concerning the realization in operative business, these three differ significantly. While simply forwarding information unidirectional via mail requires few resources, communication is bi- or multidirectional and allows the participants to re-question and discuss the information [19]. Involving all crucial stakeholders in the project demands even more resources to realize different participation methods [20].

By consistently and systematically involving the stakeholders, it is possible to achieve significant advantages and synergies [21]:

- **Gaining understanding and acceptance:** Fears and concerns can be reduced through involvement in the project. Better knowledge about the new technology leads to an increase in technology acceptance.
- **Encourage early improvement:** Employees can express concerns and problems at an early stage, so that possible obstacles can be detected in advance and solutions can be developed.
- **Increasing efficiency:** Getting to know the technology before implementation supports the individual learning curve of the users, which means that work can be done more efficiently as soon as the productive phase begins.
- **Increasing motivation:** By participating in the implementation process of new technologies and feeling that their opinions and ideas are being heard, employees feel more motivated and are more committed.
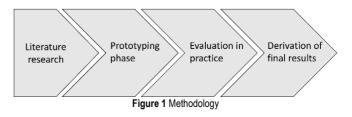
Taking systematic actions in the field of communication and participation that are tailored to the needs of the stakeholders, ensures resource efficiency as well as the effectiveness of the measures taken. It is important to address detected crucial stakeholders and especially those who are collaborators of the new solution [7]. Measures therefore can be in terms of communication (such as discussions or face to face meetings) and participation (e.g. workshops or taskforces) [22].

The arguments raised above, underline the necessity for industrial companies to plan an XR implementation knowing their stakeholders and to be able to take appropriate measures for them to successfully contribute to the project.

The findings from a comprehensive literature research showed that there is currently no generic tool for identifying and assigning stakeholders in XR change processes and providing support for users with suitable measures for execution. Accordingly, the contribution described within this paper tends to fill the current gaps in literature. The developed tool should offer the possibility to record and categorize all stakeholders and provide a catalogue of suitable measures. The aim is to support XR project managers to obtain an overview of possible communication and participation opportunities, based on their stakeholders.

## 4 METHODOLOGY

The methodological approach is divided into four phases as shown in Fig. 1: literature research, prototyping phase, evaluation in practice, and derivation of the final concept.



**Figure 1** Methodology

These stages are listed chronologically and explained in detail in this chapter.

## 4.1 Literature Research

Starting with a literature research was necessary to build up fundamental knowledge in addressed areas such as technology acceptance, stakeholder management, and ways to communicate and participate effectively. Basic findings on these areas were covered and explained in the previous chapters. Aggregating the insights, two significant questions arose:
1. Who are the relevant stakeholders for the XR implementation?
2. How must these stakeholders be served in terms of information, communication, and participation?

These questions are considered guiding questions for the development of the stakeholder tool. Together with the elaborated content, they form the basis for the development of the prototype.
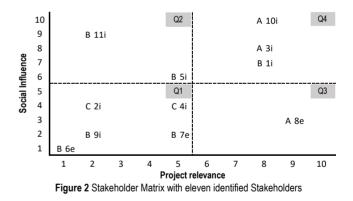
## 4.2 Prototyping Phase

To systematically work on those questions, an Excel tool was developed to conduct a stakeholder analysis. Based on this result a communication and participation concept was designed targeting different types of stakeholders and taking their individual role within the change process into account.

The **Stakeholder analysis** of change relevant stakeholders was realized by a VBA (Visual Basic Application) Excel tool. The Stakeholder analysis is divided into four parts:

1) **General information**: When working with a tool, some introduction and general information is important to support the understanding of the tool and point out some important aspects when working with the tool. Thus, general information about the tool and the definitions used can be found in the first register. In this respect, ensuring a common understanding of the three dimensions *project relevance*, *impact* and *attitude* are most crucial. The term project *relevance* is used to evaluate the importance of the stakeholder for the project. An example of this is a developer for the XR application, who may not have much influence on other stakeholders, but plays an important role in the implementation of the XR project. *Influence* references to social influence through status, reputation, or other aspects. An employee who has been with the company for 20 years usually has his or her personal network within the company and thus may enjoy greater social influence than one who is part of the company only a short period of time. The term *attitude* represents the opinion and mindset of the stakeholder towards the upcoming XR launch. This dimension can take three forms: A-positive, B-neutral, or C-negative as shown in Fig. 2.
2) **Categorization**: The first step is to think about which types of stakeholders could be crucial for the planned

XR implementation. Therefore, the first tab of the tool distinguishes between internal and external stakeholders. Within this differentiation, stakeholder groups are formulated, depending on the corporate environment, and setting. Internal stakeholder groups could be key accounts, departments or management and external stakeholder groups could be suppliers or customers.

3) **Stakeholder identification:** Based on the predefined stakeholder-groups/categories, the actual people representing project-relevant stakeholders are recorded. In addition, the stakeholders are evaluated based on the aforementioned criteria *project relevance*, *influence*, and *attitude* towards the XR-implementation. The result is a list of change-relevant stakeholders that have been assessed in relation to the XR implementation project. It should be noted here that the result of every stakeholder regarding the three dimensions can change during the implementation process. For this reason, a stakeholder analysis must be carried out continuously during the XR implementation.

4) **Visualization using a stakeholder map:** In the last tab, the collected information is processed to a stakeholder matrix using a VBA macro as shown in Fig. 2. This macro organizes stakeholders anonymously according to the three dimensions outlined. Anonymity is guaranteed by assigning abbreviations (i for international or e for external) and by adding individual IDs. In this way, only the creator of the matrix can assign the numbers to the stakeholders.



**Figure 2** Stakeholder Matrix with eleven identified Stakeholders

This matrix forms the starting point for targeted communication and participation during the XR change process. To give a clearer idea of the evaluation in the in the intended application, here is an example: the stakeholder with the ID "A 10i" is classified in Q4 due to his position in the company (project relevance e.g. IT department) and renown among the employees (social influence). This stakeholder is open to XR technology and interested in driving change, hence the letter A. The number ten signifies that he was the tenth recorded stakeholder and i means that this person belongs to the staff of the company (internal).

Depending on the position of the stakeholder in the matrix, different measures for efficient communication and participation are recommended. These actions are explained addressing the second question: *How must these stakeholders*

*be served in terms of information, communication, and participation?*



**Figure 3** Participation Building Kit

The second part of the tool, the **Information, Communication and Participation Plan** provides suggestions for activating the detected stakeholders. According to literature, the boundary between communication and participation is difficult to determine. Communication functions without participation, but participation only with communication [23]. For clarity and to make companies aware of this difference the *Participation Building Kit* was developed (Fig. 3). This kit consists of various elements (so called *drawers* within the model) that reference different forms of information, communication, or participation. Every drawer contains measures for addressing the stakeholders in a targeted manner suitable for the individual positions within the change process. Thus, the *Participation Building Kit* is a toolbox consisting of five levels: information, explanation, consultation, discussion, and participation, with the three middle levels representing the communication level.

Based on this construction kit, measures were worked out that can be applied within these drawers. The concept of information, communication and participation is therefore divided into the following areas:

- General overview of communication and participation options
- Catalog of actions
- Detailed consideration of linked norm strategies.

These areas are discussed in detail in chapter 5, which also shows the results using a use case example.

## 4.3 Evaluation in Practice

To ensure not only scientific quality but also take the requirements of companies into account, the developed prototype was evaluated with industrial companies from different sectors. This was done in a twostep approach. The first step was to gather remarks from as many different companies as possible on a more general level. Whereas the aim of the second step was to get detailed information about

the tool from individual companies. Subsequently, a brief explanation of how the two steps were carried out is given next.

At the first step, the macro-based Excel stakeholder tool was presented at a user group meeting as part of the aforementioned funded research project. After giving a short overview of the tool in general the company representatives from industry were asked to give feedback on the tool from different perspectives. Those were, for example content, usability or clarity. All remarks were collected in a list. Afterwards, they were evaluated according to their relevance for the tool, the number of mentions and the feasibility (limitation due resources). The handling of all remarks (whether incorporated, relevant for later development or not relevant) was documented. Subsequently, the remarks were used to adapt the tool as part of the feedback process. In total, 17 representatives from different companies participated in this evaluation.

At the second step, three companies from different branches were asked to work with the stakeholder tool evaluating a XR implementation project they are working on within their companies. The participants were first informed and trained on how to use the tool. Afterwards, they were able to use the tool on their own and test it. The evaluation focused primarily on the ease of use, practicality in the industry and comprehensiveness of the functions. The results of the evaluation were discussed individually with the companies. Practical suggestions for improvement were collected and subsequently integrated into the concept.

## 4.4 Derivation of Final Results

This chapter deals with the aggregation of the results from the evaluation steps. Feedback mentioned at the user group meeting was integrated during the final improvement phase. One example of an adaptation by the feedbacks was that the stakeholders in the matrix were anonymized (combination of numbers and letters) instead of listed names to prevent conflict potential in the organization. The same applies to the proposed measures in connection with target group-oriented communication and participation discussed with the chosen companies of the second evaluation step.

The result of this phase is a practical concept to reduce change resistant. This concept includes a company-specific stakeholder analysis accompanied by a communication and participation concept, whereby fears and resistance decreases, and technology acceptance increases. The results are shown in detail in the next chapter using a case study example.

## 5 RESULTS

The described methodological approach is realized in the year 2022 as one of the main results of the funded research project. As the project is still going on till end of 2023, this paper can only provide exemplary results and no actual data from one of the project partners. Presenting a real practical example will be part of a separate publication expected till end of the year.

## 5.1 Stakeholder Analysis Tool

As first step, the stakeholder needs to be classified either as internal or external stakeholder and added to the tool. As use case example in this respect, the category "XR Key User" is created, which represents an internal stakeholder (Fig. 4).
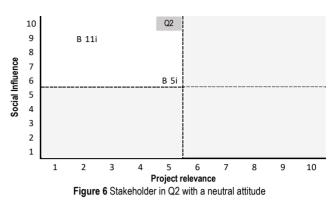


**Figure 4** Userform: Add Stakeholder Category

This is followed by allocating the stakeholder to a real instance. In this step, contact information of the stakeholder is recorded and an evaluation is given regarding the three dimensions project relevance, influence, and attitude towards the upcoming implementation of XR (Fig. 5).



**Figure 5** Userform: Evaluate Stakeholder

The result of the stakeholder analysis is a stakeholder matrix that shows the stakeholders relevant to the project according to their assessment (Fig. 2). The position of the stakeholders in the matrix forms the starting point for a target group-addressed application of the communication and participation concept.

As a second example a stakeholder with a high social influence, a low project relevance and a neutral attitude is assumed (B 5i in Fig. 6).



**Figure 6** Stakeholder in Q2 with a neutral attitude

In this case, these dimension characteristics represent the works council at the beginning of the change process. Since the works council has a neutral attitude towards XR in general, it also has a low relevance to the project. However, if an employee seeks support because the XR-application is not data protection-compliant, the attitude and thus also the project relevance can change to the negative side during the change. If the stakeholder analysis is only carried out in the beginning of the change, potential implementation barriers would remain unseen and can increase resistance. This issue underlines the significance of the regular use of a stakeholder analysis.

## 5.2 Information, Communication and Participation Concept

The collected and classified stakeholders now need to be addressed with individual measures using an information, communication and participation concept. In total 12 norm strategies have been derived based on combining the three dimensions.

| ID | Actions of information, communication, and participation |
|---|---|
| General actions | |
| IN-01 | Electronic circulars (e-mails, newsletters, ...) |
| IN-02 | Notices (Blackboard, bulletin board, posters, posters, ...) |
| IN-03 | Intranet (posts on the intranet, posts in forums, ...) |
| DI-04 | Events |
| Special actions | |
| EX-05 | Helpdesk (for assistance with the XR application) |

**Figure 7** Excerpt of norm strategy Q2 with a neutral attitude

At the beginning of the concept a general overview is given, in which the measures are structured according to the *Participation Building Kit*. As shown in the second case, the stakeholder's position is in quadrant Q2, and the stakeholder has a neutral attitude. This quadrant represents stakeholders with low project relevance and high social influence. Based on the positioning, the detailed description of the norm strategies is opened, which provides information about which levels of the *Participation Building Kit* can be used to serve this stakeholder group properly (Fig. 7). In addition, based on

the kit, the abbreviations for the measures were also chosen. The first two letters in combination with a number form the shortcut for a clearly assignable measure (e.g. IN for Information or DI for Discussion).

The detailed examination of the norm strategies provides recommendations as to which measures are suitable for efficient information, communication, or participation because of their positioning in the stakeholder matrix. This clarifies '*How*' these stakeholders need to be served. But, the implementation of these measures is not described in detail, because of the individual requirements of the company using the tool. Nevertheless, within the catalogue of measures, further literature on the proposed measure is cited to facilitate realization. The detailed consideration of the norm strategies granulates the "*What*" by adding the categories "*Description*", "*Goal*", "*Frequency*" and "*Measures*".

In general, the recommendations for action are differentiated into "*General actions*" and "*Special actions*". General measures represent activities to which all employees of the company are usually invited. Special measures are defined as media that are explicitly recommended for the implementation of XR. Following the measures of Fig. 7, the following Fig. 8 shows how this further information is provided to the companies.

| ID | Type | Actions | Further literature of the realization |
|----|------|---------|--------------------------------------|
| IN | Information | One-sided information transmission, which does not expect any reaction from the receiving party. | |
| IN-01 | Information | 1. Electronic circulars (e-mails, newsletters, posts in various internal company channels, protocol mailing, …) | Newsletter:<br>• The Content Marketing Handbook – Step by Step to Innovative Marketing[1]<br>• Newsletter[2]<br>E-Mail- und E-Newsletter-Campaigns[3]<br>Minutes: writing conversation minutes: guide or checklist[4] |
| IN-02 | Information | 2. Notice board (blackboard, bulletin board, team board, posters, …) | Posters: design a scientific poster[5] |
| IN-03 | Information | 3. Intranet (posts on the intranet, | Intranet: The intranet challenge – between information dissemination, discussion culture and knowledge manage- |

**Figure 8** Excerpt of the catalogue for actions

At this point it is crucial to mention once more the necessary framework conditions for a successful support of the tool. A one-time implementation as well as a one-time setting of measures is not sufficient to guarantee efficient information, communication, and participation for the stakeholders. Rather, this tool must be applied continuously. Furthermore, the measurement of results is essential, because only this way can verify the impact of the measures taken.

## 6 DISCUSSION AND CONCLUSION

The developed tool fills the previously mentioned gap in the literature. Now industrial companies have the possibility to track record of their relevant stakeholders within a change process in general and particularly in a XR change process. The aim is to prioritize them according to project relevance, social influence, and attitude and to set appropriate measures. On the one hand, the stakeholder matrix provides an overview of relevant stakeholders within the planned change process. On the other hand, the extensive and detailed catalogue of measures gives responsible people ideas how to increase the acceptance of the stakeholders and enables the people in charge without background knowledge in the areas of communication and participation to acquire the necessary know-how through self-study. In this way, the developed

approach represents a comprehensive tool for designing and implementing XR projects in the future to minimize resistance and to identify challenges at an early stage. This systematic approach ensures that all stakeholders are involved, and that the effectiveness of the measures can be evaluated.

Despite this, the developed tool is not a cure-all for assuring a positive change, but rather provides a proprietary support tool to systematically support the process of achieving a successful change. A successful change also requires considering the company-wide strategy and the associated overall orientation of the company. This is because XR implementations require both anchoring in the strategy and the commitment of management to create and provide the required resources. It is therefore advisable to use the stakeholder tool in combination with an XR strategy in order to assure not only a systematic, but also a holistic approach that aligns the XR strategy with the company's strategy and contributes to the achievement of its goals.

Furthermore, it should be mentioned here in the sense of the critical attitude towards new technologies - XR is not primarily a technology that is intended to replace human workplaces, but rather functions as an assistance technology to make working activities easier, to achieve more diversity (e. g. supporting people with disabilities) and improving the overall productivity. At the end of the day, how the technology is used and the extent to which it interferes in the workplace of employees depends, of course, on the decisions of management.

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# Optimisation of Parameters for Metal Part Cutting on a CNC Plasma Cutting Machine

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**Abstract:** This paper refers to the topic of determining the kerf value and axis accuracy of a CNC plasma cutter for the cutting of 2, 4 and 6 mm thick plates of construction steel, aluminum and stainless steel. After the thorough description of the researched materials, a detailed experiment plan was created in the Design-Expert software package. After cutting the test samples the data were measured. Upon completion of the cutting, all test samples were measured, and the data regarding their dimensional deviations on x and y-axis and bore diameter deviations was tabularly shown and analysed with the Design – Expert software. Statistical analysis of the measured data was made so that the optimal kerf values and the equations which describe dimensional deviations for each material and thickness could be made, based on the dimensional deviation of the test samples. Along with the kerf values, analysis has also given insight in the accuracy of the x and y-axis of the machine. Finally, an algorithm for optimizing multiple criteria was utilized to determine the ideal kerf value for each material and thickness. The objective was to identify the precise kerf value that results in the highest possible accuracy for the dimensions of the workpiece in both the x and y directions, as well as for the bore diameter.

**Keywords:** dimensional accuracy; CNC plasma cutter; kerf; process optimisation

## 1 INTRODUCTION

The feasibility and quality of plasma cutting are determined by numerous parameters, with the most important ones being [1,2]: plasma arc power, cutting speed, choice of plasma gas, choice of secondary gas (if used), nozzle-to-workpiece distance, kerf width and angle of cut. Plasma arc power is derived from the power supply typically ranging between 200 VDC and 400 VDC (depending on operator settings), although these values can be lower than 200 VDC or higher than 400 VDC. The operator determines the amount of electric current required for cutting, so for thinner materials, they may require less electric current from the power source, whereas for cutting thicker materials, they may require more electric current [3]. Power sources vary greatly in terms of the power and current strength they can use to create a plasma arc. For example, there are smaller power supplies with 6.5 kW power, intended for cutting softer steels and thinner aluminum (up to about 15 mm) with a current of 10 to 45 A, but there are also larger power supplies with power greater than 66.5 kW that can cut stainless steel with a thickness of 75 mm with a current of up to 300 A [4].

The primary objective of any processing method is to attain optimal quality of the final product, while maintaining maximum productivity. In the context of plasma cutting, it is crucial to consider multiple factors, such as achieving the highest possible lifespan of consumables (i.e., electrodes and nozzles), minimizing the quantity of slag on the workpiece, reducing post-processing of the cut specimen, minimizing the achievable kerf width, and ensuring dimensional and geometric precision of the cut specimen [5]. The cutting speed directly impacts these factors, as the adjustment of the cutting speed alters the kerf width, amount of slag, lifespan of consumables, and other related parameters. Power supply manufacturers typically provide recommended current, voltage, and cutting speed values for each specific model of power supply, based on the material being cut and its thickness. However, operators may adjust these values based on their own experiences, considering electrode and nozzle wear, ambient humidity and temperature during cutting,

surface conditions of the material being cut (e.g., presence of impurities and/or corrosion), among others.



a)



b)

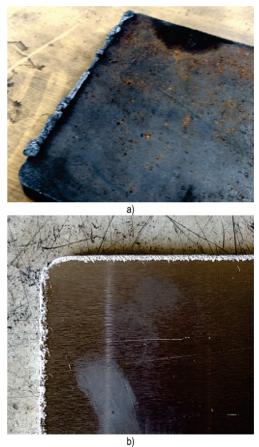**Figure 1** Common issues during machining process using suboptimal settings: a) The accumulation of slag on the underside of the cut specimen due to insufficient cutting speed, b) Slag on the upper side of the workpiece due to excessive cutting speed.

When conducting plasma cutting, it is recommended to process at the maximum possible speed, while ensuring that the final quality of the cut specimen is not compromised.

Reduction in cutting speed results in increased slag on the underside of the workpiece (Fig. 1a), leading to greater need for post-processing of the cut specimen, and potentially causing plasma arc deflection, which accelerates the erosion of electrodes and nozzles [6]. Additionally, excessive cutting speed may prevent successful cutting, as the material is incompletely melted and removed from the cutting zone, as seen in Fig. 1b.

The kerf refers to the geometry of the cut on a material and has its characteristic dimensions - width and angle. The width and angle of the kerf are correlated with other parameters, and their values are influenced by the cutting power (used current), cutting speed, type and thickness of the material, distance between the nozzle and the workpiece, and the gas used. The angle of the kerf is most easily observed in plasma cutting with air. As shown in Fig. 2, the width of the kerf at the top of the workpiece is greater than at the bottom, indicating that the cut is made at an angle [7].
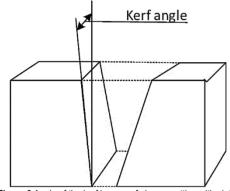


Figure 2 Angle of the kerf in case of plasma cutting with air [7]

Additional factors that can cause unfavourable kerf widths and angles include worn-out machine parts, possible protrusions or indentations on the workpiece that the height control system does not register quickly enough, the use of the wrong gas distributor, or non-compliance of the torch with respect to the workpiece. Essentially, low height and/or too slow cutting speed cause a negative kerf angle, while too high height and/or cutting speed cause a positive angle. Therefore, if a negative kerf angle occurs on the cut specimen, a potential solution to correct the cut quality is to increase the height or cutting speed, while decreasing the height or speed can be used when a positive kerf angle is present.
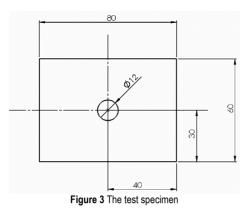
When it comes to the kerf width and angle, it is essential to find a compromise between quantity and quality, meaning it is necessary to find a cutting speed value that satisfies productivity criteria, but still achieves satisfactory cut quality and an acceptable kerf angle. It should be noted that at significantly higher cutting speeds than recommended, regardless of the demands on the quality of the cut specimen, the kerf angle might increase to the extent that the cut edges on the bottom of the workpiece come too close together and thereby got fused [7]. The literature provides many diagrams in which the amount of the kerf angle is calculated depending on the cutting speed specific workpiece material and

thickness [1, 8-10]. The objective of this experiment, notwithstanding all the previously mentioned factors, was to identify the optimal or nearly optimal process setup to attain satisfactory dimensional precision of the workpiece focusing on parameter that deals with kerf.

## 2 DESIGN OF EXPERIMENT

The primary goal of the experiment is to determine the optimal values of the kerf parameter for different materials and thicknesses, based on the measurements of rectangular test samples cut by plasma arc, assuming that the cutting speed, current strength, and voltage are constant for each material and its thickness. The secondary goal of this experiment is to determine the accuracy of the x and y axes of the machine. The measurements are used to test whether the cut along the x-axis has greater accuracy than the cut along the y-axis, which can help operators in the company orient the cut specimens, so that the sides of the workpieces that have stricter accuracy requirements are positioned along the more accurate axis of the machine. Improved machine accuracy results in reduced time spent on welding and assembly, as well as decreased consumption of additional materials during welding.

The experiment was conducted on CNC plasma cutting machine is primarily used for cutting structural steel, aluminum and stainless steel up to a thickness of 10 mm, although it has the capability to cut thicker materials. The machine's construction consists of a table made by the Chinese manufacturer HectMac in a welded design that can accommodate sheet materials with maximum dimensions of 1500 × 4000 mm, and a console that provides movement along the x-axis, i.e. along the length of the table provided by HIWIN manufacturer. On the console, there is also a pair of guides, each with a slider, for movement along the x and y axis. The torch as well as the power supply are produced by Hypertherm. Before starting the process of cutting, the CNC operator must adjust the required amount of electric current and plasma gas flow (in this case air) on the power supply and define the cutting speed, value of kerf, voltage value, time delay, and initial nozzle height when piercing the material on the machine control unit. Some CNC control units work in combination with software packages that have libraries storing kerf values for each processed material and its thickness, but the specific machine control unit does not have this option, so it is necessary to manually enter the value of kerf before running the program. The wrong value of the kerf can lead to poor workpiece quality.

To determine value of kerf, experiment with test samples which are cut from various materials of different thicknesses was conducted. The test specimens are rectangular plates with dimensions of 80 × 60 mm and a central bore with a diameter of 12 mm, shown in Fig. 3. The specimens are of the same dimensions for each material and thickness used in the experiment, but their orientation differs, thereby determining the accuracy of the x and y axes of the machine, which is also the secondary goal of the experiment.

**Figure 3** The test specimen

The three-level full factorial design with replications were chosen to analyse the effects and conduct optimisation (Tab. 1). The parameter of the kerf was varied over 3 level which are 0.25, 0.425 and 0.6 mm. The materials that are being used for the purposes of this experiment are structural steel marked S235JR, aluminum marked AlMg3, and stainless steel marked X5CrNiMo17-12-2. Testing is carried out for each material in three thicknesses: 2, 4, and 6 mm, and nine test samples are cut from each thickness, for 81 experiments. The response variables are obtained as deviation from the nominal dimension along the $x$ and $y$-axis, as well as deviation from the nominal diameter of the bore.

**Table 1** Experimental setup

| Factor | Name | Units | Minimum | Centre | Maximum |
|---|---|---|---|---|---|
| A: | KERF | mm | 0,25 | 0,425 | 0,6 |
| B: | Thickness | mm | 2 | 4 | 6 |
| C: | Material | - | Con. steel | Stainless steel | Aluminum |
| Response | Label | Units | | | |
| Y1 | $\Delta x$ | mm | | | |
| Y2 | $\Delta y$ | mm | | | |
| Y3 | $\Delta \Phi$ | mm | | | |

## 3 ANALYSIS OF THE RESULTS

After cutting all the test specimens, a final grinding process is carried out on the upper and lower sides using an angle grinder, in order to remove slag from the plates without altering their geometry and dimensions of length and width. The cut and ground test specimens are then measured with a vernier caliper to a precision of 0.02 mm for their outer dimensions (length and width, i.e. outer dimensions along the $x$ and $y$-axes) and bore width along the x and y axes.

The results of the experiment are presented in Tab. 2.

**Table 2** Results of the experiment

| | Orientation | A: Kerf (mm) | B: Thickness (mm) | C: Material | $\Delta x$ (mm) | $\Delta y$ (mm) | $\Delta \Phi$ (mm) |
|---|---|---|---|---|---|---|---|
| 1 | X-y | 0.25 | 2 | Aluminum | -0.16 | -0.38 | 1.24 |
| 2 | X-y | 0.425 | 6 | Con. steel | 0.64 | 0.52 | 0.09 |
| 3 | X-y | 0.6 | 6 | Aluminum | 0.48 | 0.04 | -0.57 |
| 4 | X-y | 0.425 | 4 | Aluminum | 0.12 | 0 | 0.66 |
| 5 | X-y | 0.6 | 4 | Con. steel | 0.56 | 0.28 | -0.24 |
| 6 | X-y | 0.25 | 2 | Stainless steel | 0.12 | -0.44 | 0.83 |
| 7 | X-y | 0.25 | 4 | Con. steel | -0.32 | -0.38 | 0.4 |
| 8 | X-y | 0.6 | 2 | Aluminum | 0.64 | 0.34 | 0.56 |
| 9 | X-y | 0.425 | 2 | Con. steel | 0.42 | 0.34 | 0.63 |
| 10 | X-y | 0.25 | 6 | Aluminum | -0.68 | 0.68 | 0.2 |
| 11 | X-y | 0.6 | 2 | Stainless steel | 1.14 | 0.4 | 0.1 |
| 12 | X-y | 0.6 | 6 | Stainless steel | -0.34 | -0.76 | -0.69 |
| 13 | X-y | 0.425 | 4 | Steel | -0.1 | -0.06 | 0.01 |
| 14 | X-y | 0.25 | 6 | Stainless steel | -0.12 | -0.82 | 0 |
| 15 | y-X | 0.425 | 4 | Stainless steel | -0.28 | -0.04 | 0.09 |
| 16 | y-X | 0.425 | 2 | Stainless steel | 0.44 | 0.82 | 0.71 |
| 17 | y-X | 0.6 | 6 | Steel | 0.56 | 0 | -0.6 |
| 18 | y-X | 0.425 | 2 | Aluminum | 0.44 | -0.28 | 0.82 |
| 19 | y-X | 0.6 | 4 | Aluminum | 0.34 | 0.74 | 0.08 |
| 20 | y-X | 0.6 | 2 | Con. steel | 0.6 | 0.68 | 0.27 |
| 21 | y-X | 0.25 | 6 | Con. steel | -0.56 | -0.38 | 0.01 |
| 22 | y-X | 0.425 | 6 | Stainless steel | -0.8 | -0.28 | -0.41 |
| 23 | y-X | 0.25 | 4 | Stainless steel | -0.08 | -0.5 | 0.46 |
| 24 | y-X | 0.6 | 4 | Stainless steel | -0.14 | 0.36 | -0.18 |
| 25 | y-X | 0.25 | 4 | Aluminum | 0 | 0.76 | 0.93 |
| 26 | y-X | 0.425 | 6 | Aluminum | -0.28 | 0.2 | -0.11 |
| 27 | y-X | 0.25 | 2 | Con. steel | 0.18 | -0.34 | 0.93 |
| 28 | y-X | 0.25 | 2 | Con. steel | -0.1 | 0.02 | 0.9 |
| 29 | y-X | 0.6 | 2 | Con. steel | 0.78 | 0.66 | 0.23 |
| 30 | y-X | 0.25 | 6 | Con. steel | -0.24 | -0.68 | 0.06 |
| 31 | y-X | 0.6 | 6 | Con. steel | 0.12 | 0.06 | -0.62 |
| 32 | X-y | 0.425 | 2 | Con. steel | 0.46 | 0 | 0.65 |
| 33 | X-y | 0.25 | 4 | Con. steel | -0.54 | -0.68 | 0.39 |
| 34 | X-y | 0.6 | 4 | Con. steel | 0.56 | -0.04 | -0.2 |
| 35 | X-y | 0.425 | 6 | Con. steel | 0.08 | 0.1 | -0.11 |
| 36 | X-y | 0.425 | 4 | Con. steel | 0 | -0.08 | 0.15 |
| 37 | X-y | 0.25 | 2 | Stainless steel | 0.18 | -0.12 | 0.97 |
| 38 | X-y | 0.6 | 2 | Stainless steel | 0.94 | 0.64 | 0.12 |
| 39 | X-y | 0.25 | 6 | Stainless steel | -0.98 | -0.86 | -0.1 |
| 40 | X-y | 0.6 | 6 | Stainless steel | 0.02 | -0.32 | -0.72 |
| 41 | y-X | 0.425 | 2 | Stainless steel | 0.18 | -0.18 | 0.38 |
| 42 | y-X | 0.25 | 4 | Stainless steel | -0.7 | -0.3 | 0.52 |
| 43 | y-X | 0.6 | 4 | Stainless steel | 0.26 | 0.08 | -0.26 |
| 44 | y-X | 0.425 | 6 | Stainless steel | -0.28 | 0.34 | -0.68 |
| 45 | y-X | 0.425 | 4 | Stainless steel | -0.64 | -0.18 | 0.05 |
| 46 | X-y | 0.25 | 2 | Aluminum | 0.02 | -0.22 | 1.09 |
| 47 | X-y | 0.6 | 2 | Aluminum | 0.68 | 0.18 | 0.61 |
| 48 | X-y | 0.25 | 6 | Aluminum | -0.28 | 0.26 | 0.34 |
| 49 | X-y | 0.6 | 6 | Aluminum | 0.3 | 1.52 | -0.3 |
| 50 | y-X | 0.425 | 2 | Aluminum | 0.6 | 0.06 | 0.81 |
| 51 | y-X | 0.25 | 4 | Aluminum | -0.56 | -0.52 | 0.8 |
| 52 | y-X | 0.6 | 4 | Aluminum | 0.4 | 1 | 0.14 |
| 53 | y-X | 0.425 | 6 | Aluminum | -0.04 | -0.44 | 0.11 |
| 54 | X-y | 0.425 | 4 | Aluminum | -0.26 | -0.22 | 0.15 |
| 55 | y-X | 0.25 | 2 | Con. steel | 0 | -0.14 | 1.01 |
| 56 | y-X | 0.6 | 2 | Con. steel | 0.34 | 0.48 | 0.2 |
| 57 | y-X | 0.25 | 6 | Con. steel | -0.1 | -0.68 | 0.11 |
| 58 | y-X | 0.6 | 6 | Con. steel | 0.36 | 0.04 | -0.58 |
| 59 | X-y | 0.425 | 2 | Con. steel | 0.38 | 0.1 | 0.65 |
| 60 | X-y | 0.25 | 4 | Con. steel | -0.44 | -0.32 | 0.55 |
| 61 | X-y | 0.6 | 4 | Con. steel | 0.24 | 0.48 | -0.18 |
| 62 | X-y | 0.425 | 6 | Con. steel | -0.04 | 0.54 | -0.18 |
| 63 | X-y | 0.425 | 4 | Con. steel | 0.08 | 0.2 | 0.04 |
| 64 | X-y | 0.25 | 2 | Stainless steel | -0.08 | 0.16 | 0.98 |
| 65 | X-y | 0.6 | 2 | Stainless steel | 0.66 | 0.96 | 0.23 |
| 66 | X-y | 0.25 | 6 | Stainless steel | -0.44 | -0.96 | -0.25 |
| 67 | X-y | 0.6 | 6 | Stainless steel | 0 | 0.22 | -0.94 |
| 68 | y-X | 0.425 | 2 | Stainless steel | 0.14 | -0.02 | 0.65 |
| 69 | y-X | 0.25 | 4 | Stainless steel | -0.38 | -0.32 | 0.44 |
| 70 | y-X | 0.6 | 4 | Stainless steel | 0.06 | 0.08 | -0.02 |
| 71 | y-X | 0.425 | 6 | Stainless steel | | | |

| | Orientation | A: Kerf (mm) | B: Thickness (mm) | C: Material | Δx (mm) | Δy (mm) | ΔΦ (mm) |
|---|---|---|---|---|---|---|---|
| 72 | y-X | 0.425 | 4 | Stainless steel | -0.34 | -0.04 | 0.19 |
| 73 | X-y | 0.25 | 2 | Aluminum | -0.14 | -0.26 | 1.23 |
| 74 | X-y | 0.6 | 2 | Aluminum | 0.52 | 0.38 | 0.55 |
| 75 | X-y | 0.25 | 6 | Aluminum | -0.34 | -0.3 | 0.32 |
| 76 | X-y | 0.6 | 6 | Aluminum | 0.32 | 0.12 | -0.54 |
| 77 | y-X | 0.425 | 2 | Aluminum | 0.32 | 0.06 | 0.95 |
| 78 | y-X | 0.25 | 4 | Aluminum | -0.34 | -0.28 | 0.71 |
| 79 | y-X | 0.6 | 4 | Aluminum | 0.18 | 0.66 | 0.18 |
| 80 | y-X | 0.425 | 6 | Aluminum | | | |
| 81 | X-y | 0.425 | 4 | Aluminum | 0.02 | 0.04 | 0.74 |

Statistical analysis was performed using the Design-Expert software package, by which three-dimensional response surfaces based on regression analysis of the measured values was generated. The aforementioned response surfaces provide a visual representation of the relationship between the input factors and the dependent variables.

Data analysis was performed for each of the cut materials, across the three dependent variables deviation along the x-axis of the machine, deviation along the y-axis of the machine, and average deviation of the bore diameter.

### 3.1 Analysis of the Deviation along *x*-Axis

In the first case, deviations along the *x*-axis of the machine ($\Delta x$) were observed, and the results of the analysis are presented for structural steel, aluminum, and for stainless steel in the Fig. 4.

As shown in Fig. 4, the range of values for the dependent variable $\Delta x$ in structural steel varied from approximately -0.45 mm to 0.6 mm, with the minimum value occurring for theoretical thicknesses between 4 and 5 mm and a kerf value of 0.25 mm, and the maximum value occurring for a thickness of 2 mm and a kerf value of 0.6 mm. Structural steels with a thickness of 6 and 4 mm exhibited both negative and positive values of $\Delta x$, depending on the kerf value input, while the values of $\Delta x$ for structural steel with a thickness of 2 mm were predominantly positive. Notably, greater oscillations were observed in the experimental conditions for a thickness of 6 mm and a kerf value of 0.425 mm.

The response surface for aluminum shows some similarities to the plot for structural steel. The minimum value of $\Delta x$ is approximately –0.45 mm, occurring at a material thickness of around 5 mm and a kerf value of 0.25 mm, while the maximum value of $\Delta x$ is about 0.6 mm, occurring for a material thickness of 2 mm and a kerf value of 0.6 mm. One notable distinction from the plot for structural steel is that the largest oscillations in measurements were observed for aluminum with a thickness of 4 mm and a kerf value of 0.25 mm.

The observed results for stainless steel are notably different. The minimum value of $\Delta x$ is –0.75 mm, occurring at a material thickness of 6 mm and a kerf value of 0.25 mm, while the maximum value of $\Delta x$ is approximately 0.65 mm, occurring for a material thickness of 2 mm and a kerf value

of 0.6 mm. The response surface for stainless steel exhibits a steeper slope compared to the previous response surfaces, as well as larger oscillations between the maximum and minimum values of the dependent variable $\Delta x$.
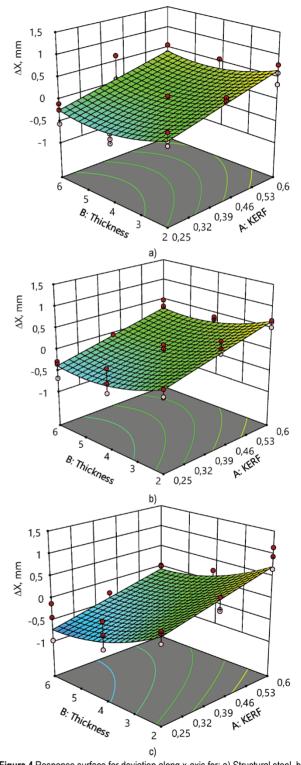


**Figure 4** Response surface for deviation along x-axis for: a) Structural steel, b) Aluminum, c) Stainless steel
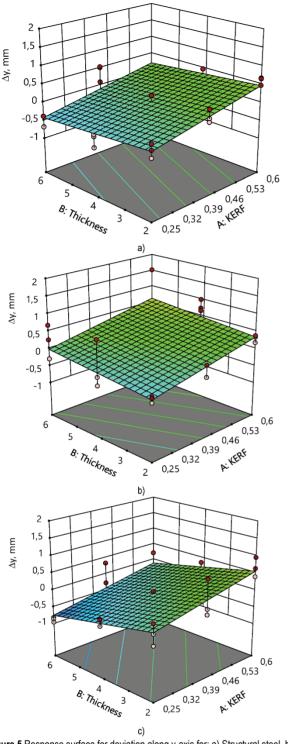
**Figure 5** Response surface for deviation along y-axis for: a) Structural steel, b) Aluminum, c) Stainless steel

## 3.2 Analysis of the Deviation along y-Axis

In the second case, deviations along the *y*-axis of the machine ($\Delta y$) were observed, and variation between individual experimental conditions were also studied. The analysis results are presented for the structural steel, aluminum, and for stainless steel in Fig. 5. The variation between the upper and lower values of $\Delta y$ for structural steel,

and aluminum as well, are significantly smaller compared to those observed along the x-axis. Additionally, the inclination of the three-dimensional surface is lower, and a certain linearity is noticeable between the data obtained through regression analysis.

The variation between measured deviations for the y-axis are significantly higher for stainless steel compared to aluminum or structural steel, as is the case for the *x*-axis of the machine. Despite the larger deviations compared to other materials, the y-axis of the machine once again shows smaller overall deviations compared to the *x*-axis, even for stainless steel. That is certainly interesting fact which points out that the machine precision is slightly better along y-axis.

## 3.3 Analysis of the deviation of bore diameter

After analysing the deviations of individual machine axes, the deviations of bore diameter ($\Delta \Phi$) are examined. When making the bore on the test specimen, both axes must participate simultaneously so that the plasma arc can make a circular movement. Therefore, the inaccuracy of both machine axes affects the final deviation of the diameter. The nominal value of the bore diameter is 12 mm, measured along the *x* and *y* axes, and the average deviation was calculated based on the individual diameter deviations on each axis. The mentioned deviations for structural steel, aluminum, and stainless steel is presented in Fig. 6.

In case of structural steel, the response surface graph shows opposite characteristics of deviations in comparison to the deviations along the *x* or *y* axis. The values of the kerf for structural steel with thicknesses of 2 and 6 mm, which provide relatively good accuracy of the external dimensions of the test sample, have largest effect on deviations in the diameter dimension. The response surface for aluminum has similar shape but with even more emphasized extreme deviations for a material thickness of 2 mm. Like previous diagrams in case of stainless steel it has the highest extreme negative deviation. What is specific about the diameter deviation in case of stainless steel is that variations between some specific values are significantly smaller than deviations in *x* and *y* axis.

## 3.4 Optimisation

Based on analysed data, the multicriteria optimisation algorithm was applied in order to find the optimal value of the kerf value for each material and thickness. The goal is to find specific kerf value that gives the maximum overall accuracy of the workpiece dimensions in the *x* and *y* axes and the bore diameter as well. More precisely, the goal is to find the kerf values with minimal value of the absolute deviations of $\Delta x$, $\Delta y$ and $\Delta \Phi$ for all observed workpiece materials and their thicknesses. The target value of $\Delta x$ and $\Delta y$ was set to 0 while the target value of $\Delta \Phi$ is set to minimal. The $\Delta \Phi$ is set to minimal due to fact that if diameter is smaller than nominal, it is possible to perform rework thus if the diameter is larger than nominal it could be costly and even impossible to do correction.
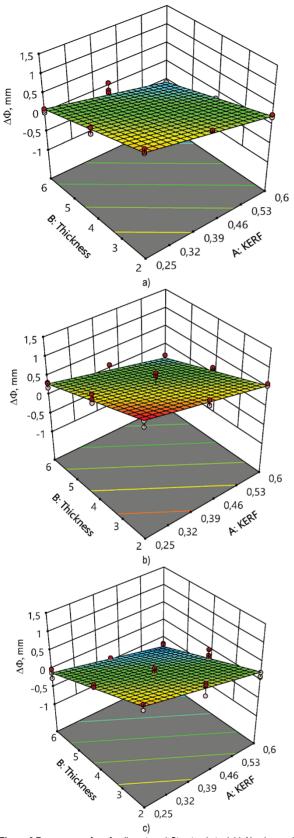
**Figure 6** Response surface for diameter: a) Structural steel, b) Aluminum, c) Stainless steel

Tab. 3 shows the values of the variable factor that give optimal or near optimal solution. It can be observed that for

certain thicknesses and materials, multiple solutions are considered as optimal, meaning that several different values of the variable factor can give slightly larger deviations in one dimension and slightly smaller deviations in another dimension.

**Table 3** Optimal solutions for minimal overall dimensional deviation

| Material | Thickness (mm) | Kerf (mm) | $\Delta x$ (mm) | $\Delta y$ (mm) | $\Delta \Phi$ (mm) |
|---|---|---|---|---|---|
| Con. steel | 2 | 0.382 | 0.251 | 0.075 | 0.660 |
| Con. steel | 2 | 0.379 | 0.247 | 0.071 | 0.665 |
| Con. steel | 2 | 0.386 | 0.259 | 0.083 | 0.652 |
| Con. steel | 4 | 0.420 | 0.000 | 0.019 | 0.180 |
| Con. steel | 6 | 0.479 | 0.184 | 0.000 | -0.340 |
| Aluminum | 2 | 0.494 | 0.470 | 0.153 | 0.767 |
| Aluminum | 4 | 0.454 | 0.000 | 0.220 | 0.377 |
| Aluminum | 6 | 0.452 | 0.000 | 0.357 | -0.088 |
| Stainless steel | 2 | 0.372 | 0.294 | 0.146 | 0.689 |
| Stainless steel | 2 | 0.369 | 0.290 | 0.142 | 0.693 |
| Stainless steel | 2 | 0.374 | 0.298 | 0.150 | 0.685 |
| Stainless steel | 4 | 0.531 | 0.000 | 0.101 | -0.133 |
| Stainless steel | 6 | 0.600 | -0.067 | -0.112 | -0.777 |

It is possible to determine the optimal size of the variable factor by considering specific constraints and requirements. These constraints and requirements may have different priorities depending on the situation. For instance, the dimensional precision of the bore can be prioritized over the linear dimensions during the optimization process.

As previously stated, higher machine accuracy reduces the time required for final machining of cut specimens and welding positions during assembly. In addition to time, increasing machine accuracy also saves additional material during final machining and welding. Finally, because of the optimisation of the available machines time and material savings contribute to reducing of costs and increasing production efficiency without a significant money investment.

## 4 CONCLUSION

After completing the statistical analysis of results, multiple significant features were discovered in the specific CNC plasma machine. Initially, it was observed that the y-axis of the machine had significantly lower average deviations, which were related to the machine's design. The console that enables movement along the y-axis contains two parallel guides, both made from one piece, while movement along the x-axis is enabled by one pair of guides, each composed of multiple pieces. Deviations in bore dimensions were significantly larger than deviations in external dimensions of cut specimens, which is an obvious result of the combined action of both axes during bore cutting and the accumulation of their individual inaccuracies. Structural and stainless steel showed the best accuracy for a thickness of 4 mm, while aluminum had the best results for a thickness of 6 mm. Optimal cutting depths were determined for the thicknesses being cut, and equations were derived to predict deviations if cutting thicknesses outside the experimental range is required. All observed features can help the operator in planning the machining process, i.e., entering the cutting

depth into the computer unit and positioning the cut specimens according to dimensional accuracy requirements.

A logical continuation of this research would be to cut materials of thicknesses outside the experimental range and compare the mathematically calculated deviations with the actual ones. Additional opportunities for timesavings and increased accuracy of the machine were identified during the experiment, such as:

- Machine levelling
- Replacing the mesh structure of the table on which the workpieces are placed to reduce the possible waviness
- Updating the software package on the control computer unit to include a cutting depth library, which would eliminate the need for manual input before running the program.

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# Remaining Socially Responsible in the Age of Smart Sustainable Production

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**Abstract:** This paper explores the transformations necessary in the field of social responsibility and social accountability employed by manufacturing companies as they transition to a model of smart and sustainable production. A focus group of managers in production companies has been interviewed concerning the challenges and support they derive for their environmental and community approaches, as the firms deploy advanced Industry 4.0 tools such as the internet of things, digital twins and virtual reality to upgrade their manufacturing systems and processes. The results are presented and discussed based on a set of ranked objective indicators, and proposals for a future implementation scenario are advanced.

**Keywords:** smart production; social responsibility; sustainable production

## 1 INTRODUCTION AND CONTEXT

Being a manufacturing company in this day and age, especially in Europe, is a challenging activity that can use up considerable resources just for surviving, let alone for being truly competitive. The European Union subscribes to a philosophy of twin transitions - green and digital [1], which is implemented over the complex background of social, economic, geopolitical, and medical emergencies. As the production sector transitions to a smart and sustainable model of operation, it is sometimes difficult to keep the proper focus on the social obligations that arise related to developing, designing, manufacturing, distributing and proper end-of-life treatment of consumer or industrial goods.

From establishing trust with the local community, and behaving in an ethical manner, to recognizing worker rights and ensuring their safety, to supporting worthy causes, the firms in this domain must not forget that although the present is characterized mostly by the technological transformations associated with Industry 4.0 and beyond (e.g., adoption of artificial intelligence or quantum computing), the human side of their impact is defining for their future success [2]. Both small and medium sized companies, and large businesses, must all be able to act with integrity and transmit the correct image of their efforts and results across many publicly scrutinized channels to large scale and globalized audiences.

The existing literature on this topic in the past 3 years has revealed some promising results, such as the need to establish strong holistic strategic innovation frameworks [3] and the decisive role of public reporting of performances [4]. Also, a considerable number of issues that are not yet properly addressed, such as the enabling factors for setting up successful co-production ventures [5] and the development of means to ensure long term operation of sustainable complex supply chains [6]. The consensus seems to be related to the need of manufacturing companies to develop innovative ways to tackle modern competitiveness and a modern social approach at the time [7]. However, from the point of view of costs, there are still a large number of unknown factors that can influence the feasibility of such a demarche [8, 9].

## 2 METHDOLOGY AND TECHNIQUES

The research approach utilized for the current undertaking is based on 4 steps (Fig. 1), including:
- a stage of literature review and identification of the state of the art based on existing article databases,
- an interview process with a questionnaire-based part and an open discussion,
- the ranking of indicators for the social responsibility approach derived from the interviews, using the Analytical Hierarchy Process (AHP) applied through the Qualica QFD program and
- a final discussion based on the correlation of the indicator and the most common smart sustainable production technologies also resulting from the questionnaire, implemented with the help of the Cause & Effect matrix from Qualica QFD.

The group of managers that was interviewed included 9 representatives from the following industries: metal fabrications (3 companies), automotive components (2 companies), furniture manufacturing (3 companies) and industrial goods (1 company). All of these can be considered part of the manufacturing sector in Transylvania, Romania.
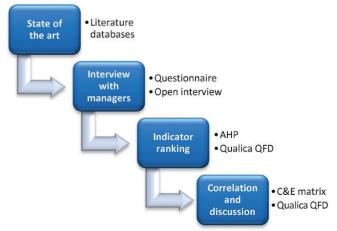


**Figure 1** Research methodology employed and applied techniques

The starting questionnaire used for interviews and discussions was intended as a preliminary investigation and contained the following questions (the first four were multiple selection questions and the last one was an open question to collect proposals):

- What type of Industry 4.0 technologies have you implemented: IoT, AI, Digital Twins, Big Data, Robotics, VR/AR?
- How do these support your environmental approach in monitoring, reporting, product re-design, process reengineering, auditing?
- How do these support your social community involvement in the lifecycle management of products, the circularity approach, social accountability, and CSR projects?
- What challenges you encountered / What trade-offs have you made: reuse budgets, discontinued products / processes, relocate / outsource the business, train / hire additional people, employ specialized consultancy?
- Can you formulate some relevant indicators to assess the impact of the technologies upon the social (and environmental) footprint of the company?

After the consultations with industry, a number of 5 indicators have been selected and ranked with the help of the AHP template in Qualica QFD (Fig. 2). The consistency index of the pairwise comparison has been checked with the help of an additional calculator [10] and found to be 6.4 %, below the acceptable 10 % limit. The results are presented both the in the order they were entered and the ranked order after the application of the process (Fig. 3), with the standard normalization of the software at the 5X level being almost unnecessary.



**Figure 2** Analytical Hierarchy Process applied to the identified performance indicators

## 3 RESULTS AND DISCUSSION

In the final stage of the study, the ranked indicators have been correlated with the 6 main technologies used by manufacturing companies as part of the smart and sustainable production paradigm, discussed with the interviewees from industry. The scale used includes three levels of relationship, from weak to strong and the importance of the 5 criteria is imported from the previous ranking. Also, the first indicator has been considered critical for the operating safety of the transformed production system, while the second indicator has been marked as critical for the proper functioning of the technology framework (Fig. 4).

As it can be observed, the technologies receive a calculated importance score that permits for the establishment of a proper strategic and operational approach for companies that seek the competitive benefits of Industry 4.0 without losing their socially responsible behaviour. By far, the highest score, 29,5 %, is obtained by Big Data Analytics that is supports the processing and interpretation of

all data from product and process sensors. It is considered mandatory for monitoring and improving the production system and in tracking and optimizing products performance. Important and desirable functions like enhancing product circularity, minimizing waste, tracking reliability, estimating impact upon user and so on, can be highly amplified by using proper techniques and tools for data analysis. The second place in terms of importance (of 21 % in this context) is occupied by artificial intelligence, which is a very promising technology and could be factored in decision making for product and process improvement, in public reporting and communication and in delivering the social value expected by the communities a firm interacts with through upgraded interactivity. However, we must take into account that this technology's image is now impacted by the booming interested sparked by ChatGPT, so it might be a good idea to revisit its usefulness for manufacturing companies after a certain amount of time has passed.



**Figure 3** Original order and sorted normalized results obtained from Qualica QFD

On the third and fourth places, with similar scores, we can find Internet of Things and Digital Twins which form the backbone on which data analytics can run. Both of these technologies are at a high level of maturity, with many solutions available on the market. Moreover, the complex nature of production systems and processes and the discrete identify of manufactured products are particularly suitable to being assessed with the help of smart sensors and acted upon through digital twins solutions. The remaining two approaches, robotics and VR/AR are already part of many manufacturing systems, for increased productivity and better training and maintenance, but their use for retaining socially responsible and socially accountable behaviours is not that significant.



**Figure 4** Cause & Effect Matrix relating socially relevant indicators to smart technologies in Qualica QFD

It is interesting to note that due to the correlations established by the research team based on information from industry, 3 of the technologies can be considered mandatory to achieve system safety and 4 are necessary to achieve its proposed function. Based on these, we must infer that 5 of the analyzed elements are obligatory for success (i.e. VR/AR must be included in the transformation).

## 4 CONCLUSIONS

Remaining socially responsible while undergoing significant transformations towards digitalization and smart production is a difficult goal for manufacturing companies. The study presented in this paper uses a systematic methodology within the confines of a limited focus group of managers involved in the activity of production firms, to determine the most relevant technologies associated with Industry 4.0 that are supportive in implementing social and environmental initiatives. Based on the findings, a customized strategy can be recommended in this case, including the following chronological steps:

1) Implement Big Data Analytics platforms and software, starting from existing production and product data and anticipating the exponential increase of data volume once the smart sensors are installed and connected through Internet of Things communication protocols. Based on the results, start making high reward improvements to the manufacturing system and the current product lifecycle approach.

2) Develop an integrated Digital Twin approach that makes use of a general Internet of Things approach employing low-cost high-autonomy sensors for the production equipment, the relevant supply chain interfaces and the products themselves, when achieving a certain level of complexity. Use the sensor data to enhance all environmental performance indicators, as well as to deliver a healthier and more cohesive work environment and community integration of the company. Use the digital twin of the production system to perform a massive amount of synchronous and asynchronous small reward improvements throughout the system.

3) Develop and use VR/AR applications, specific to the issues of the company, to supplement existing organizational operations, connect with external partners, suppliers and stakeholders to perform collaborative problem solving. Extend the use of the

application to increase the range of capabilities of the manufactured products. Integrate both types of applications with the digital twin and the data analytics platforms to create synergies.

4) Assess the potential of artificial intelligence solutions to bring additional value to the social responsibility projects of the firm by providing better interfaces with the community, detect and correct improper reporting and disseminate the contributions of the firm to the local community and general society.

In conclusion, we can surmise that by properly addressing both competitiveness and social impact issues with the help of up-to-date technologies, manufacturers in various industries can increase their chances of surviving on the market. In the next step of the research, we intend to introduce a full-scale questionnaire, that includes hypothesis testing and control questions, and to complement the manager interviews with actual production shadowing and validation based on key process indicators.

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# Estimating Costs and Benefits of Preventive Ergonomic Measures

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**Abstract:** Ergonomics is becoming increasingly relevant in industrial enterprises, as confirmed by the majority of Industry 5.0 experts who place emphasis on the development of social environments and employee care. This is gradually being integrated into legislation stipulating the obligation to provide employees with adequate working conditions. In the context of introducing necessary ergonomic measures in the workplace, we identify the dependence of these measures on the physical load of workers and the impact on the employer's financial burden. To determine the impact, a Cost-Benefit Analysis is used to evaluate not only the financial costs but also to assess social benefits and increased utility for the target groups. The verification of ergonomic optimisation of the workplace in terms of costs and impact on workers' health is conducted in a case study in a specific industrial enterprise. Finally, the positive impact of ergonomic optimisation on the physical load of workers is specified.

**Keywords:** CBA; ergonomics; financial costs; physical load

## 1 INTRODUCTION

Cost-benefit analysis (further referred to as CBA) is used to evaluate investment projects, strategic decisions, project plans, as well as individual tasks. It serves both to evaluate the financial costs of the project and the income flowing directly to the founder, but also to financially evaluate all the social benefits (e.g. tourism development) that the project will bring, whether for locals, city or state. The cost-benefit analysis therefore provides an opportunity to assess how advantageous the investment will be for public projects. That is, for projects where the goal is not to maximize profits, i.e. financial return, but to increase the benefit of target groups - social benefit. This assessment of the profitability of the investment can be made by converting indirect benefits into financial amounts. [1, 2]

CBA consists of several elements:

- Effects resulting from the investment - all impacts on target groups that the implementation of the project brings. These impacts can be financial and non-financial and are positive, negative or neutral.
- Costs - these are all negative impacts on the examined entities / target groups, i.e. negative effects resulting from the investment.
- Benefits - these are all positive impacts on the examined subjects / target groups, positive effects resulting from the investment.
- Beneficiaries - this is an entity / target group that is affected by both positive and negative impacts resulting from the investment.
- Criteria indicators - these are several standard indicators that are an important factor for deciding whether a project is meaningful or not. According to their values, projects can be compared with each other. [1]

On the other hand, ergonomics is an interdisciplinary field based on several scientific disciplines such as physiology, psychology of work, anthropometry, biomechanics, or safety, hygiene and philosophy of work. Ergonomics can then be defined as a scientific discipline that deals with the relationship between man, the work equipment (work tools, machines, tools and other work aids) and the work environment within the work process [3]. It is important to ensure that the three components are interlinked, as they affect the performance and quality of workers' work. The aim of ergonomics is to adapt the workplace and create such working conditions that:

- do not cause disproportionate workload,
- meet the requirements of human health and safety,
- minimize the effects of negative influences,
- optimize the mental and physical load,
- ensure personal development at maximum efficiency. [6, 7]

It is evident from the above stated points that the work environment should be designed (or adapted) to meet the needs and physical capabilities of a person: The person cannot adapt to a task, the task and environment should be adapted to the person. [5, 6]

### 1.1 Health Risks

Inadequate adaptation of the working environment to ergonomic requirements can negatively impact workers' performance, work quality, and most importantly, their health [4].

One common health issue associated with work is musculoskeletal disorders, which affect the joints and other tissues, particularly in the neck, back, shoulders, and upper limbs. These disorders can arise from factors such as excessive mechanical load, inappropriate postures, or improper handling of loads, all of which can be attributed to poor workplace ergonomics. Musculoskeletal disorders can range from minor pain to severe health problems and may qualify as occupational diseases. The development of these disorders is often gradual and influenced by a combination of physical and biomechanical, organizational, psychosocial, and sociodemographic risk factors [8].

By creating suitable workplace conditions, such as addressing unnatural and static postures or repetitive

movements, many of these risk factors can be significantly reduced. The declining health of workers can lead to increased doctor visits, long-term treatment needs, work absences, or even a forced career change. These issues not only affect the workers themselves but also impact the overall functioning of the company.

## 1.2 Ergonomic Rationalization

When trying to create a workplace that follows ergonomic guidelines, several elements should be taken into account, in particular the following:
- nature of work activity,
- the position of the worker when performing work,
- organization of work at the workplace,
- workplace equipment and to what extent the workplace will be used,
- possible mobility of the workplace,
- time required for the workplace activity,
- hygienic and safety regulations according to legislation and according to the given company,
- and other no less important aspects such as compliance with the rules set by the company for a specific workplace. [9]

Evaluating work equipment involves applying ergonomic criteria to strike a balance between a person's capabilities and the requirements of the equipment in given environment. From a workplace perspective, this includes considering the working space, dimensions, working plane height, and the impact on the worker's body dimensions and lower limbs. Additionally, the working environment's lighting, visual conditions, psychosocial aspects, and acoustic conditions are also crucial. From the worker's viewpoint, attention is focused on physical exertion, handling loads, suitable working positions that promote physiological comfort and frequent changes and preventing long-term unilateral overloading [6].

Numerous sources highlight the positive effects of adhering to ergonomic standards in the workplace. The objectives of ergonomic practices can be summarized as follows: arranging workplaces and processes to meet health, safety, and comfort requirements; maintaining workers' health and permanent work capacity; preventing worker overload; ensuring increased employee satisfaction; and improving the economy through ergonomic workplace design [10, 11].

The introduction of ergonomic methods is suitable both in production and non-production processes. Ergonomic rationalization of the workplace (meaning improved working environment and ergonomic conditions) can bring many benefits, such as:
- improvement of work well-being,
- reduction of worker fatigue,
- increase in the concentration of employees,
- reduction of scrap,
- increasing the prestige of the company,
- increase in employee satisfaction,

- decrease in potential occupational diseases or accidents at work,
- reduction of costs for employees who have to deal with problems associated with unsuitable ergonomics in the company (HR, HSE, etc.),
- potential increase in worker productivity,
- financial savings,
- work safety,
- increase of work efficiency.

Indirectly, the improved environment should also be reflected in a declining rate of fluctuation. Workplace rationalization is typically part of an ergonomic project, often following an ergonomic audit. The audit assesses various areas, including compliance with legal requirements, employee perception (through surveys), and specific parameters of the operation or workplace (e.g., physical load, noise, vibration, visual load) [12].

Rationalization of the workplace in terms of ergonomics can be done in many ways. The basic ones include reorganization of the workplace, the acquisition of special products or ergonomic equipment. Simple workplace modifications, which are often necessary, but can also be highly beneficial, include:
- adjusting the appropriate height of the desk and chair,
- placing frequently used objects in the optimum working plane,
- reducing reach distances,
- the acquisition of appropriate equipment to facilitate material handling,
- establishing standards for work activities and displaying them clearly in the workplace,
- provision of the necessary personal protective equipment,
- adjustment of lighting,
- change in the storage of material. [13]

As a part of a simple reorganization of the workplace, one of the main goals is, as mentioned above, to shorten the reach zones, which will achieve not only the elimination of unacceptable or conditionally acceptable working positions of the trunk or arms, but also reducing the time needed to complete the work task (assemble the product, produce a part etc.). Time savings can be calculated using methods like MOST or MTM, which determine standard task times. For instance, reducing the reach distance from 60 cm to 20 cm can save approximately 0.7 seconds, or even more if the distance exceeds 60 cm. While these timesavings may seem small individually, they accumulate significantly over the entire production cycle.

However, in case of timesavings, it is necessary to take the possible increase in the production standard in the workplace into account as well, which can have an increasing effect on local muscle load. Local muscle load is the most suitable indicator of the most common occupational diseases in the Czech Republic. From the point of view of Czech legislation, the maximum number of hand and forearm movements that a worker can perform during an average 8-hour shift is determined. This limit is given by the Czech

government regulation No. 361/2007 Coll. The numbers of movements refer to the measured % Fmax. However, a maximum of 27,600 movements can be performed by a worker. [14]

Ergonomic rationalization also comes with financial costs. In general, the costs associated with rationalization can be divided into investment and operating. Investment costs are one-time costs for the project. Operating costs are those costs that are directly related to the workplace - scrap, production costs, compliance with safety, waste. Through ergonomic rationalization, we try to reduce operating costs, but therefore we have to make the initial investment. The CBA method is used to decide whether an investment is acceptable, as company stakeholders need to assess the return of investment [11].

## 2 METHODOLOGY

Proposed CBA Processing procedure consist of the following steps:
- Description of the nature of the project.
- Creation of a financial plan from the perspective of the investor or sponsor.
- Definition of the beneficiaries of an ergonomics project in an industrial enterprise.
- Definition of the maximum of all benefits and benefits over the life cycle of the investment.
- Classification of benefits into quantifiable and non-quantifiable.
- Conversion of quantifiable benefits and costs into cash flows.
- Interpreting the results, assessment of the results and decision on the acceptability of the investment and evaluation of the financeability and sustainability.

Having a clearly defined plan for the project is crucial for further evaluation process. For this reason, the first step of the methodology is further defined by the following points:
- Definition of all stakeholders and their distribution (e.g. households, enterprises, municipality, state, ...).
- Describing the zero and investment option projects and their difference.
- Identifying the maximum of all benefits and costs for all project life stages, breaking them down into quantifiable (valued) and non-quantifiable (non-valued).

To convert quantifiable benefits and costs into cash flows automatic calculator was created. This calculator allows us to enter variables applicable to the specific company and work position. These variables include:
- number of working days,
- number of shifts,
- time pool of work,
- length of safety breaks,
- cost per employee per hour,
- number of workers per position,
- tact per piece,
- revenue from sales per piece,

- cost of ergonomic rationalisation (purchase of fixtures, ergonomic tables, etc.),
- reduction of reach zones,
- savings in work movements,
- number of rejects,
- amount of waste,
- cost of medical examinations,
- costs associated with multiple jobs in other departments (e.g. HR, HSE, foreman).

At the same time, the risks and costs of occupational accidents and illnesses should also be taken into account. In the Czech Republic, according to the Labour Code, the employer is obliged to compensate the employee for damage or non-pecuniary damage caused by an occupational accident or occupational disease, if such damage or damage was caused to the employee:
- in the case of an accident at work during the performance of work tasks or in direct connection with it,
- in the case of an occupational disease, if the employee last worked for the employer under the conditions under which the occupational disease normally arises before it was discovered. [15]

The employer shall be obliged to compensate the employee for the related damage or non-pecuniary damage, even if he has complied with all his obligations under the relevant legislation, unless he waives the obligation to compensate for the damage or non-pecuniary damage in completely or in part. The employer may only waive its obligation to compensate for damage or non-pecuniary damage provided that the damage or non-pecuniary damage was caused either by a culpable breach of the law by the employee or solely as a result of the employee's drunkenness or abuse of other addictive substances.

The Labour Code further provides that an employee is entitled to claim the following types of compensation in the event of the employer's liability for an occupational accident or disease:
- compensation for loss of earnings during the period of incapacity for work,
- compensation for loss of earnings after the end of the incapacity for work,
- compensation for pain and suffering, (reasonable medical expenses) and compensation for damages in kind, if any. [15]

In addition to the Labour code, the details are also further specified by Government Regulation No. 276/2015 Coll. Compensation for loss of earnings during the period of incapacity for work shall be payable to the employee in the amount of the difference between the average earnings before the damage (caused by the work-related accident or occupational disease) and the full amount of the wage or salary compensation received during the period of incapacity for work.

Compensation for loss of earnings after the end of incapacity for work or on recognition of disability shall be due to the employee for difference between the average

earnings before the damage and the earnings after the work injury or occupational disease (plus any disability pension - if any - received for that reason). However, compensation for loss of earnings after the end of temporary incapacity for work shall not be payable until the employee reaches the age of 65 or retirement age, if higher, or until the date on which the old-age pension is awarded.

In the event that an employee is dismissed from employment, because of occupational illness, the employer is obliged, among the things mentioned above, to pay him or her a bonus equal to 12 months' average gross salary received in the course of employment. [15, 16]

## 3 CASE STUDY

An ergonomic rationalisation of the workplace in an unnamed industrial company was carried out. The company, in which this case study was performed, is located in Pilsen region in the Czech Republic. It specializes in the production of intelligent automated storage solutions that are tailored to customer requirements. The case study was focused on the position of warehouse reception area. Within the project brief, the use of robots or cobots was ruled out by the company itself and therefore not considered further in the study.

The following activities are carried out at the workplace by employees in the position of warehouse reception area. As part of their work, the workers receive goods, recheck them, repalletise them and sort them into pallets to be used later. The worker handles the administration of the shipments on the PC, prints the labels, which she then applies to the pallets to be shipped. She then takes the pallets ready for dispatch to their destination on a pallet truck. She also sorts the received shipments. The worker manually transfers each shipment from the pallet to the workbench, unpacks and then rearranges the KLT boxes as required and manually places them on the sliding line.



**Figure 1** Original workplace state [author]

The work is performed standing with moving around the work area. Personal protective equipment includes work boots, gloves, safety glasses and reflective vest. The maximum weight of the manually handled load is 17 kg. A visualisation of the workplace is shown in the figure below.

The work activity was examined and evaluated in this case study, is performed by female workers in three-shift operation. The female workers work in 8-hour shifts. They have a 30-minute lunch break and two 10-minute safety break for rest and relaxation. The ergonomic study was carried out on all female workers employed in the position, aged 33 to 45 years, average weight 63 kg, average height 172 cm. After workplace rationalization was performed, the workplace was analyzed for the female population, 5th, 50th and 95th percentile of the German population.

The initial state of the workplace was, in accordance with the Czech legislation, classified into the third work category based on:
- measured local muscle strain,
- the occurrence of conditionally acceptable and unacceptable working positions for more than the maximum permitted time during a shift.

This classification forces the company management to introduce safety breaks after 2 hours for 10 minutes, which is a regulation that is set by Czech legislation and must be observed. In case of non-compliance, the company faces heavy fines.

Based on the initial ergonomic analysis, several problems were identified:
- inappropriate handling plane,
- large number of working movements,
- the occurrence of excessive muscle forces when handling heavy KLT boxes,
- frequent bending of the trunk and unacceptable working position of the upper limbs.

Handling heavy loads and frequent trunk flexion can increase the risk of musculoskeletal problems in various parts of the body, including the lower back, shoulders, neck, and arms. These activities can lead to acute injuries such as strains, sprains, and muscle spasms, as well as chronic conditions such as degenerative disc disease, herniated discs, and spinal stenosis. In particular, frequent trunk flexion (bending forward at the waist) can increase pressure on the lower back, leading to strains and sprains in the muscles and ligaments of the lumbar spine. It can also compress the intervertebral discs, causing disc herniation and nerve compression, which can result in pain, numbness, and weakness in the lower extremities.

Therefore, it is important to use proper lifting techniques and ergonomic principles to minimize the risk of injury when handling heavy loads and bending frequently. Additionally, regular exercise and stretching can help strengthen the muscles and improve flexibility, reducing the likelihood of musculoskeletal problems.

As part of the rationalisation of the workplace, adjustments were made which allowed the workplace to be reassessed and reclassified as second work category. These were relatively simple modifications to the workplace that included:
- height-adjustable electric trolleys,

- height-adjustable tables for working in the ideal working plane,
- other equipment such as precision scales for weighing materials to eliminate the number of upper limb movements when manually counting parts.

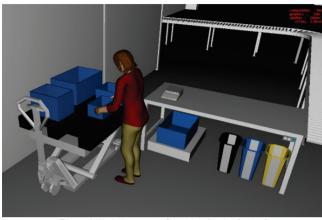You can see a visualisation of the new state in the image below.



**Figure 2** Workplace state after rationalisation [author]

Workplace rationalization was performed on one-work stations and the total cost of the rationalisation was set at 2,000 euros. On the other hand, the change of classification from the third to the second work category has led to multiple savings and benefits. The savings and benefits identified in this particular case study are listed and explained below together with their beneficiaries:

## 3.1 Time Savings

In this case, timesavings are achieved in three categories:
- Due to the original classification into the third work category, the mandatory safety breaks were previously respected (specifically 10-minute safety breaks after every 2 hours of work). After being classified as a second work category, these breaks are no longer needed, which accumulates to timesavings of 20 minutes per worker per 8-hour shift. In this case, considering the three-shift mode of operation, the total savings per day equal to 60 minutes. When considering 252 working days in the year and average cost per employee per hour of 21 euros, these time savings equal to savings of 5 292 euros. In this case, the main beneficiary is the enterprise itself (or its owner) as the daily production standard grows.
- One of the elements of rationalisation was shortening of the reach zones. In particular, the part of the work process, where the worker has to bend to pick up the part from the pallet on the ground was revised – parts are now located at the height of the working plane using height-adjustable electric trolleys. This eliminates the need to bend down to pick up individual pieces, which also reduces trunk flexion during the work shift. This time saving is calculated using the MOST system (Maynard operation sequence technique):

A) Consumption of time when removing a part from a pallet placed on the ground is shown in the table below.

**Table 1** MOST calculation for original workplace state

| General relocation | | Index | Time (s) | Description |
|---|---|---|---|---|
| Actions at a ceratin distance | A | 1 | 0,36 | within reach |
| Body movement | B | 6 | 2,16 | bend down and straighten up |
| Gaining control | G | 1 | 0,36 | grab |
| Actions at a ceratin distance | A | 1 | 0,36 | within reach |
| Body movement | B | 0 | 0 | no movement |
| Placement | P | 1 | 0,36 | let go |
| Total time consumption (s) | | | 3,6 | |

B) Consumption of time when removing a part located at the height of the working plane is shown in the table below.

**Table 2** MOST calculation for workplace state after rationalisation

| General relocation | | Index | Time (s) | Description |
|---|---|---|---|---|
| Actions at a ceratin distance | A | 1 | 0,36 | within reach |
| Body movement | B | 0 | 0 | no movement |
| Gaining control | G | 1 | 0,36 | grab |
| Actions at a ceratin distance | A | 1 | 0,36 | within reach |
| Body movement | B | 0 | 0 | no movement |
| Placement | P | 1 | 0,36 | let go |
| Total time consumption (s) | | | 1,44 | |

As the calculation shows, 2.16 s was saved per one piece. This causes an increase in the flow of incoming components and can be associated with a smoother production flow. During the average 8-hour shift, the worker is supposed to process 300 pieces. When considering, three shifts per day, this equals to daily time saving of 32,4 minutes. When considering 252 working days in the year and average cost per employee per hour of 21 euros, these time savings equal to savings of 2 857 euros. In this case, the main beneficiaries are both the enterprises (again, as the daily production standard grows) and the workers (as the occurrence of unsuitable working positions is reduced).
- Another way of saving time was through the acquisition of accurate measuring scales, which not only eliminated work movements, but also increased the efficiency of individual workers. At the same time, the accuracy of loading was increased. In this case, the main beneficiaries are both the enterprises (again, as the daily production standard grows) and the workers, as inappropriate and unnecessary finger and forearm movements have been eliminated.

## 3.2 Health Benefits

Ergonomics rationalization is a process of optimizing the workplace design and organization to promote comfort, safety, and productivity [10]. This approach considers the capabilities and limitations of human beings in their work environment and seeks to minimize the risk of injury, fatigue, and stress. In recent years, there has been growing recognition of the health benefits of ergonomics rationalization, as evidenced by numerous studies and initiatives aimed at promoting this approach. In the next

paragraphs, the various health benefits of ergonomics rationalization and its potential impact on the well-being of workers are listed.

- Reduced Risk of Musculoskeletal Disorders - one of the primary health benefits of ergonomics rationalization is the reduced risk of musculoskeletal disorders (MSDs). These are injuries or disorders affecting the muscles, tendons, ligaments, nerves, or joints due to repetitive or forceful movements, awkward postures, or other physical stresses. MSDs are a common cause of pain, discomfort, and disability among workers, and they can lead to lost productivity, increased healthcare costs, and reduced quality of life. Ergonomics rationalization can help prevent MSDs by optimizing the workplace design and organization to reduce physical stress and strain on the body. This may involve adjusting the height and angle of work surfaces, providing ergonomic chairs and tools, reducing the weight and size of objects, and minimizing the need for repetitive or forceful movements. By reducing the physical demands of work, ergonomics rationalization can help prevent MSDs and improve the overall health of workers.

- Improved Posture and Movement Patterns - another health benefit of ergonomics rationalization is the improved posture and movement patterns of workers. Poor posture and movement patterns can contribute to a range of musculoskeletal problems, as well as fatigue, stress, and reduced productivity. Ergonomics rationalization can help workers adopt better postures and movement patterns by providing ergonomic chairs, desks, and tools that promote neutral positions, as well as training and education on proper lifting, reaching, and other movements. By promoting better posture and movement patterns, ergonomics rationalization can help workers reduce the risk of injury and fatigue, as well as improve their comfort and efficiency at work. This, in turn, can lead to better health outcomes and improved productivity for both workers and employers.

- Reduced Fatigue and Stress - a third health benefit of ergonomics rationalization is the reduced fatigue and stress experienced by workers. Fatigue and stress can result from prolonged exposure to physical, mental, or emotional demands, and they can have a range of negative health effects, including reduced immune function, increased risk of chronic diseases, and impaired cognitive and emotional functioning.

Above-mentioned benefits are relevant for the overall concept of the methodology as well as for the case study described in this article.

### 3.3 Financial Cost Savings

The third work category includes work where the health limits are exceeded or the criteria for inclusion in this category are met. At the same time, biological exposure of natural persons is not reliably reduced by technical measures and the use of personal protective equipment is necessary for this purpose. The statistically higher incidence of occupational diseases is also an important criterion for classifying work in the third category.

As the incidence of occupational diseases is more frequent, there is also a need to check the health of workers more frequently, for which reason compulsory occupational medical examinations are ordered once every 2 years with a special examination for a risk factor, for example, in the case of a risk in local muscle stress, a measurement by electromyography must be carried out.

In the case of the third work category, basic safety conditions must be observed - this is either controlled rotation between workplaces. The controlled rotation must be recorded and archived for 10 years. It must be kept both on paper and electronically. This incurs the cost of recording employee attendance. In the event that rotation is not an option, safety breaks are ordered, these must be after 2 hours and for 5-10 minutes. The employer determines the length of safety breaks. However, during this time the enterprise loses the pieces produced and pays the workers during the "off" time, thus incurring a cost in the form of the employee's wage and lost profit due to the unproduced pieces.

In the case of the third category of work, the use of personal protective equipment is also necessary - it varies according to the type of risk of the workplace. Workers also need to be properly trained, this is usually the job of the HR or HSE (Health and Safety Executive).

The rationalisation of the workplace has brought us into the second working category, reducing the cost of occupational health checks and mandatory safety breaks. At the same time, the efficiency and effectiveness of the workforce has been increased and the potential for spinal or upper limb injuries and potential occupational disease has been eliminated. Elimination of occupational health checks equals to the average saving of 350 euros per year for the occupational checks themselves.

**Table 3** Supporting processes

| Employee position | Hours per year | Hourly costs (euros) | Saving (euros) |
|---|---|---|---|
| HR | 20 | 51 | 1020 |
| HSE | 25 | 42 | 1050 |
| Warehouse manager | 20 | 42 | 840 |
| Head of warehouse reception | 15 | 34 | 510 |

However, other departments of the company are also involved in the supporting processes, which can be much more complicated when the workplace is categorized in the third work category and health limits are exceeded. According to the information from the examined company, the workers involved include HSE, warehouse manager, HR and head of warehouse reception. These supporting processes include involvement in authorised measurements of physical load, administrative work regarding occupational health checks or dealing with employee fluctuation (e.g. HR searching for new employees, training of new employees, purchase of protective equipment or clothing). In the past years, there have also been multiple instances of work accidents. The company provided us with an estimate of hours each employee spends working on above-mentioned

activities or resolving the issues connected to them. The time consumption, hourly costs of employees and quantified savings are listed in the table below, in sum the saving come to 3420 euros.

According to the Labour Code, the employer is obliged to continuously search for hazardous factors and processes of the working environment and working conditions, to identify their causes and sources. This also involves regular measurement of physical load performed by external authorized laboratory based on the risk factor of exceeded physical load. Average cost for this measurement in the Czech Republic is set out at 1000 euros. The need for this measurement is eliminated by recategorization of the workplace into the second work category (due to the ergonomic rationalisation).

### 3.4 Summarized Savings

Based on a recalculation of the benefits and costs of ergonomics in the company, it was calculated that after the rationalisation, which would require initial investment of 2,000 euros, with the average wage of the female workers, around 11,000 euros would be saved per year (the savings are described in more detail in the previous sections).

## 4 DISCUSSION AND CONCLUSION

This article contains the research part, which is focused on defining the importance of following ergonomic principles within industrial enterprises and the possible negative consequences of not doing so. Further, it elaborates on the possibilities of evaluating the benefits of implementation of ergonomic measures through Cost Benefit Analysis.

The following conclusions can be drawn from the research carried out:
1) Workplace rationalisation has an impact on ergonomic design.
2) The ergonomic design of the workplace has an impact on the health of the worker.
3) The physical condition of the worker influences his mental state and therefore his performance.
4) The quality of work environment and working conditions affects employee turnover.
5) If ergonomic rules are not followed, there is a higher risk of workers suffering from musculoskeletal disorders or occupational diseases.
6) The relationship between the financial costs and benefits of ergonomic solutions has not been comprehensively addressed.

Following these statements, a methodology for evaluating the benefits of ergonomics using CBA was formulated and subsequently explained and quantified on a specific example of workplace rationalization.

This case study illustrates how the proposed methodology can be used to objectively assess the benefit of potential modification of the workplace aimed at improving working conditions (particularly in terms of ergonomics).

Having an independent and objective assessment is fundamental during any decision-making process, and the decision on future investment in workplace rationalisation is no exception. This approach allows a comparison between several possible options and defines benefits for individual beneficiaries / stakeholders.

Currently, the methodology is designed primarily to reflect the conditions set out in the Czech national legislation. The authors of this study see potential in extending the methodology for use in other countries within the European Union. This would require further research to identify common points but also differences in legislation regarding public health and limitations of working conditions in individual countries.

### Acknowledgements

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# Methods of Land Cover Classification Using Worldview-3 Satellite Images in Land Management

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**Abstract:** Modern geoinformation technologies, such as remote sensing satellite missions and classification methods, are becoming increasingly prominent in land cover classification. Due to the emergence of high spatial resolution missions with improved temporal and spectral resolutions, such as Worldview-3, this approach enabled new possibilities in land management. To provide an in-depth analysis of such possibilities, this study reviews methods of land cover classification using WorldView-3 satellite imagery. With 29 different spectral channels and a spatial resolution of 1.2 m, Worldview-3 multispectral satellite images represent the most modern currently publicly available commercial multispectral images. The classification of multispectral images is performed to facilitate the identification and recognition of objects in the images. Analyzed classification methods are: supervised (semi-automatic) classification methods, unsupervised (automatic) classification methods, and object-based classification methods. In order to increase the accuracy in land cover studies, it was determined as necessary to develop automatic methods that rely on a combination of controlled and uncontrolled classification methods. This approach enables the automatic determination of samples for conducting supervised classifications of interest for land management.

**Keywords:** high-resolution imagery; multispectral imagery; OBIA; remote sensing; segmentation; supervised classification

## 1 INTRODUCTION

Remote sensing is finding increasing application in various scientific fields, including agricultural land management [1]. The non-sustainable management leads to soil degradation and impaired sustainability as the products of human activities in the global ecosystem [2, 3]. It also disregards accidental or intentional release of unwanted chemicals, biological and physical material, or energy into the ecosystem. These products include elements that disrupt the normal functioning of the ecosystem. Global research estimates that 80% of contamination comes from land-based sources [4]. Terrestrial activities and sources of contamination remain major threats to the ecosystem as well [5]. The classic parameters which are affected include temperature, electro-conductivity, pH, and soil organic matter.

However, modern technologies such as remote sensing sensors used to map and monitor contamination (oil, solid waste, soil erosion, algae blooms) and to assess the environmental impact or predict contamination trends are also gaining prominence [6]. With the help of satellite images, the reflectance of various objects in the range of electromagnetic radiation that is not visible to humans became measurable [7]. The importance of satellite images that can be of different spatial, radiometric, spectral and temporal resolutions and therefore applicable for different purposes has been recognized worldwide, including in Croatia [8–10]. Satellite images of higher spatial resolutions, such as Worldview-3, reduce the possibility of overlapping spectral values among neighbouring pixels [11]. Furthermore, higher spatial resolutions represent a great potential for obtaining a large number of more detailed information [12]. Therefore, their use is very important because it is very difficult to directly identify the desired element by visual interpretation.

The aim of this paper is to review modern land cover classification methods using Worldview-3 satellite imagery as a basis for the decision-making in land management. The particular focus was given to the classification process and its potential automation, to improve the widespread availability of such methods in the future.

## 2 WORLDVIEW-3 (WV-3) MULTISPECTRAL SATELLITE MISSION

Depending on the pre-processing level and applied corrections, WV-3 satellite imagery are available in the following six basic product types: Basic 1B Imagery, Basic 1B Stereo Imagery, Standard 2A Imagery, OrthoReady OR2A Imagery, OrthoReady Stereo OR2A Stereo Imagery and Orthorectified imagery [8]. The display of differences in spectral properties between multispectral images over the same area before and after orthorectification is displayed in Fig. 1.



**Figure 1** Worldview-3 image before (A) and after (B) orthorectification

With a total of 29 different spectral channels (8 multispectral channels, 8 SWIR channels, 12 CAVIS channels, and 1 panchromatic channel) and a spatial resolution of 1.2 m, WV-3 multispectral satellite images are the most modern currently publicly available commercial multispectral images [13]. The spectral channels of the multispectral WV-3 satellite mission are shown in Tab. 1.

**Table 1** Spectral bands of a multispectral WV-3 satellite mission

| Spectral band | Areas of application |
|---|---|
| Coastal | Coastal research; shadow detection; differentiation of land and water surfaces |
| Blue | Coastal research; forest classification; differentiation of soil and vegetation; water surfaces |
| Green | Type of agricultural crops; bathymetry; seagrass detection |
| Yellow | $CO_2$ concentration; differentiation of iron ores; sediment analysis |
| Red | Vegetation classification and analysis; chlorophyll absorption |
| Red Edge | Health, age, and type of vegetation; seagrass and reefs; separation of land |
| Near-Infrared 1 | Study of biomass; plant stress; material differentiation; separation of water surfaces; soil moisture detection |
| Near-Infrared 2 | Study of biomass; plant stress; material differentiation |

Due to the reflection of various objects in the range of electromagnetic radiation that is not visible to humans, it is possible to identify the desired element by visual interpretation [14]. The reflection of electromagnetic waves depends on both chemical and physical soil properties [15]. Water and moisture content produces a low reflection in the visible part of the spectrum while near-infrared (NIR) area there is no reflection due to the absorption of clear water. High reflections in the red and NIR part of the spectrum indicate a high concentration of the substance in water [16].

## 3 METHODOLOGICAL FRAMEWORK FOR LAND COVER CLASSIFICATION

Classification is based on assigning pixel values to selected, pre-determined spectrally specific classes [17]. The classification of multispectral images is a process, which includes the verification of test samples depending on the classification algorithm used. The classification of multispectral images is carried out to facilitate the identification and recognition of objects in the images. The procedure and choice of classification are very important when calculating a classified raster [17]. The wrong choice of classification method or incorrectly defined training samples can lead to significant errors in the output model [18]. The simplest definition of classification would be to group certain parts of the image into spectral and then information classes afterward based on their similarities [19]. The basic element of a multispectral image and any raster data is a pixel. It is treated as a separate unit containing digital number (DN) values from several spectral bands. The DN number is recorded depending on the radiometric resolution of the satellite image. By comparing pixels with each other, it is possible to determine classes (groups) that are then linked to information categories that are of interest to users. Classes generally represent land cover. Land cover can consist of natural or artificial structures that cover a certain part of the Earth's surface, such as vegetation, water surface, buildings, forests and wetlands [20] (Fig. 2).

Since the images contain information in several parts of the electromagnetic spectrum beyond human visual perception, spectral information represented by pixel values

in different spectral ranges is used for classification [21]. The basic problem of image classification is to establish connections between spectral and information classes. The problem is complicated by the fact that within one information class there can be variability so that its pixels belong to different spectral classes. On the other hand, it is possible that pixels that have the same spectral values belong to different information classes.



**Figure 2** Display of the satellite image and land cover model of the same area

## 4 CLASSIFICATION METHODS

Classification methods can generally be grouped into supervised (semi-automatic) classification methods, unsupervised (automatic) classification methods, and object-based classification methods [22, 23]. The classification of land cover and land use is based on the different spectral responses of different materials. The fundamental principle of spectral classification is to distinguish between objects using variations in reflectance or emission properties that are dependent on wavelength. However, spectral classification encounter difficulties and lower accuracy in regions where many land cover types have similar reflectance patterns, resulting in a spectral confusion.

### 4.1 Supervised Classification Methods

The supervised classification method represent the classification of a specific scene/image based on user-defined samples. These are used to define land cover classes, and class determination is done on the spectral characteristics of each sample. The best-known conventional algorithms of supervised classification are maximum-likelihood and minimum distance. In the supervised classification, samples of known identity are taken for the classification of pixels of unknown identity, by the placement of unclassified pixels in one of the information classes [24]. Labeled samples, which

are composed of a large number of pixels, sample the spectral characteristics of information categories. It is recommended that the marked areas should contain at least 100 pixels for each class [25]. The advantages of supervised classification are that the operator has control over the selected information categories provided for a particular location. The primary components of the supervised classification are represented in Fig. 3.
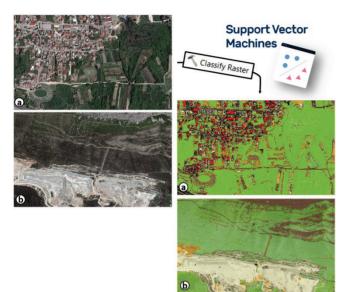


**Figure 3** Thematically classified data set with land cover classes for: a) agricultural land in urban areas, b) agricultural land in rural areas

The most notable drawback of supervised classification is that the operator defines the classification structure of the data itself [26]. These classes do not have to match natural classes. Secondly, the samples selected by the operator may be an inaccurate representation of those conditions that take place within the rest of the image. The next disadvantage includes the work itself that the analyst must do to complete the analysis. Selecting data for samples alone can take an extraordinary amount of time. The remaining significant flaw of the supervised classification describes the limitation of man as a classifier. Given that the operator defines the information categories, there is a great possibility that the category that should have been present is omitted because of the operator's false subjective assessment [27].

## 4.2 Unsupervised Classification Methods

The unsupervised classification method automatically classifies the scene based on the statistical grouping of spectral features and characteristics [17]. It is based on grouping pixels so that their spectral values meet some criterion of homogeneity [28]. For some algorithms, this criterion can be set in advance by specifying the allowable variability of pixel values, while for some algorithms only the desired number of categories is specified. Starting from the given parameters, the classification algorithm finds the natural structure in the data set. The result of classification is a set of spectral classes that then need to be paired with information classes. The user only needs to define the

number of classes to be created. Various grouping algorithms are used to determine the statistical data group. Pixels are grouped together depending on their spectral similarity. The computer then analyses each group and categorizes them separately into appropriate classes. If the analyst determines that the image is classified into 10 different classes, the algorithm will create the proposed 10 classes according to the spectral similarity of the pixels. The most well-known algorithms are K-means and ISODATA [29]. Fig. 4 shows an example of noise that occurs when performing an unsupervised classification on a part of a multispectral image.
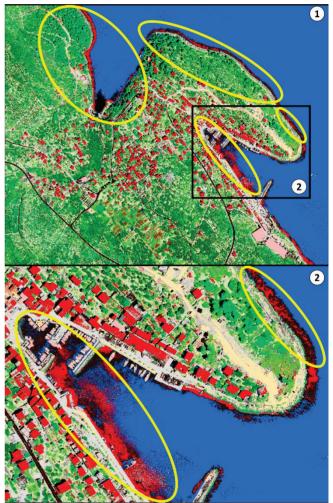


**Figure 4** Noise in the classification result after the unsupervised classification for: 1) predominantly rural areas, 2) predominantly urban areas
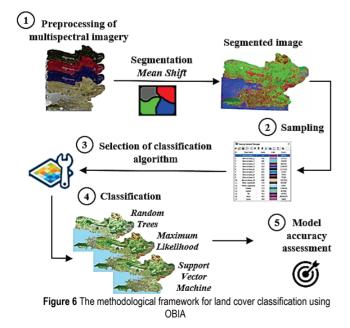
The advantages of unsupervised classification are automation, easier work of analysts, reduced space for human error, and no need for a thorough knowledge of the image being processed [30]. In unsupervised classification, most processes are automated and the influence of analysts on the classification process itself is minimized. The shortcomings and limitations of unsupervised classification are mostly due to the reliance on "natural" grouping and the difficulty of categorizing them into information classes according to study focus [31]. The supervised and unsupervised methods are

based on the spectral analysis of each pixel in the study area, neglecting the spatial and contextual information of the surrounding pixels. The specific property of pixel-based approaches on high-resolution images is producing a "salt-and-pepper" effect (Fig. 5), which contributes to inaccurate classification.



**Figure 5** The "salt-and-pepper" effect in the pixel-based classification process

### 4.3 Object-oriented Classification Methods

In order to eliminate these problems, object-oriented classification procedures have been developed to analyze spatial and spectral properties in a segmentation process. The typical methodology of the object-oriented classification approach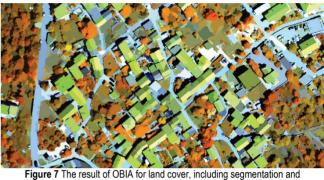 is presented in Fig. 6. In general, several classification methods should be evaluated during the study to evaluate the most accurate one, as their effectiveness typically depends on the properties of input data. By integrating these segments in the iterative learning algorithms, the main aim was to achieve more accurate results than pixel-based methods. OBIA is a method that creates objects of different shapes and sizes, while methods based on pixel classification generate square pixels [32].



**Figure 6** The methodological framework for land cover classification using OBIA

In summary, there are two basic components to OBIA: the first component is based on segmentation and the second

is based on classification (Fig. 7). The object-oriented feature extraction process involves a work process that covers three main functional areas: image segmentation, generation of analytical data on segmented parts, and classification [33]. It can be said that OBIA is a process identical to the supervised and unsupervised classification, with a segment or superpixel being classified, instead of individual pixels. Each segment or superpixel is characterized by a specific spatial and spectral set of values that ultimately determine which class it belongs to [34]. Segmentation groups pixels with similar spectral characteristics that are located in close proximity to one segment.



**Figure 7** The result of OBIA for land cover, including segmentation and classification

The Mean Shift approach to segmentation uses a moving square matrix when calculating the average value of pixels that can be a part of the particular segment [35]. As the moving grid of squares moves over multispectral images, pixel values are calculated iteratively to check the suitability of each segment. The result is a grouping of pixel images into segments characterized by spectral similarity of reflection. The output of the Mean Shift tool is a 3-channel, 8-bit resolution segmented image. Spectral detail is a parameter that sets the level of importance given to the spectral differences in the multispectral image [30]. In geographic information system (GIS) it varies from 1 to 20. Higher values mean that in the segmentation process great importance is given to spectral differences between pixels. In other words, higher values are used when some features on a multispectral model have similar spectral characteristics, but these should be classified into separate classes. Smaller values create spectral smooth outputs. For example, higher values allow differentiation between different trees, while lower values represent everything as one class. Spatial detail is a parameter that determines the importance of proximity between features in a multispectral model [30]. Valid values in GIS also range from 1 to 20. A higher value is appropriate for a scene where small compact features should be singled out, while lower values create a spatially smooth result. For example, if high-value buildings and roads are set up in an urban area scene, they can be classified as special classes (greater spatial detail). On the other hand, if smaller values of the urban scene are selected in the same scene, it will be classified as a single class with less spatial detail. The minimum segment unit is a parameter expressed in pixels. It merges segments smaller than this size with its most suitable

adjacent segment. Band indexes are a parameter related to the selection of one or more bands to be used in segmenting a multispectral image. The bands in which the differences between the features are most noticeable are selected. The size of the objects created by image segmentation depends on the details of the desired land cover model and the input data. After segmentation, there is a classification of isolated objects. They are classified based on object-specific statistical parameters. Finally, taking into account the spatial and spectral characteristics of the multispectral image, it is very important which of the above three classifications is used to obtain the most accurate and time-optimal results [35].

## 5 CONCLUSIONS

Remote sensing methods and techniques using WorldView-3 satellite imagery allow application in environmental protection with very high precision. Depending on the type of land cover classification, it is necessary to choose satellite images of appropriate spatial and temporal resolution. The advantage of supervised classification is that the operator has control over the selected menu of information categories provided for a particular area, and allows the classification to be performed using multitemporal data. The shortcomings of supervised classification certainly include the human factor that is prone to error. Unsupervised classification is automated, facilitates the work of analysts, reduces the space for human error, and does not require a thorough knowledge of the image being processed. The shortcomings of unsupervised classification stem mostly from the difficulty of categorizing classes into information categories that accurately represent land cover. In order to increase the accuracy in land cover analyses, it is necessary to develop automatic methods that rely on a combination of supervised and unsupervised classification methods that enable automatic determination of samples for conducting supervised classifications.

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# Influence of Natural Zeolites on the Thermal Decomposition of Multi-layered Plastic Waste

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**Abstract:** The pyrolysis process drove scientific attention lately, as it represents the basis for the production of second generation of synthetic fuels and other chemicals. The process takes place in inert atmosphere, and liquids, gases, and small number of solid particles represent main reaction products. Pyrolysis can be thermal or catalytic. Thermal pyrolysis requires very high temperatures, and products do not have high quality, while addition of catalysts reduces the reaction time, there is a better conversion rate, and lower operation temperature. In this paper, multi-layered plastic waste is used as raw material for thermogravimetric analysis (TGA). The composition of used plastic waste was previously determined based on the analysis of a large number of samples from fraction of mechanically non-recyclable plastic waste collected from waste treatment facilities in Croatia. Two natural zeolites with the most promising catalysts properties were selected for the reaction. Thermogravimetric analysis was used to understand the pyrolysis process of multi-layered plastic waste and to determine the thermochemical behavior and kinetics. Kinetic analysis was performed using the isoconversional Kissinger-Akahira-Sunose method. The aim of this paper was to investigate how selected natural zeolite catalysts influence the kinetics of the pyrolysis process of multi-layered plastic waste.

**Keywords:** multi-layered plastic waste; pyrolysis; TGA; zeolites

## 1 INTRODUCTION

Since 1970s, the ratio of plastic production has been growing. According to the historic growth of plastic production, primary plastic is expected to reach 1 100 million tonnes by 2050. According to the UNEP statistic, about 36% of all produced plastic are applied in packaging sector (UNEP). In Europe, 40% of 55 Mt of plastics is produced only for packaging [1]. Multi-layered plastic is mostly used for food packaging, personal hygiene products (e.g., shampoo, conditioner) [2]. Multi-layered plastic food packaging makes up 17% of total plastic packaging film production. The thickness of multi-layered plastic food packaging differs from 30 µm to 1 mm. Also, the number of the layers varies between 3 and 20 [1]. Multi-layer plastic improves properties of packaging, like barrier performance, which leads to longer shelf-life. Multi-layers are made of materials with different physical and chemical properties. Polymers like polyethylene, polypropylene, polyethyleneterephthalate, and polylactic acid [3]. Multi-layered packaging also contains a thin layer of aluminum foil and different layers of lamination in paper and plastics that act like a barrier to light, moisture, oxygen, and $CO_2$. Also, multiple-layer plastics comprise other components, like chemical additives (fillers, plasticizers, flame-retardants, colorants, stabilizers, lubricants, foaming agents, and antistatic agents). Due to the complex structure, multi-layered plastic waste is very difficult to be processed at the large scale [4].

Every country has different waste management strategy, which influences the sorting and recyclability of plastic waste. Also, the food packaging contains high amounts of impurities, such as food residues. Typical sorting steps are not adjusted for high-quality sorting of flexible films, but near-infrared technology can detect different material layers. Therefore, new procedures for sorting are needed, in order to improve recyclability of multi-layered plastic food packaging [5]. Recovery of those materials is possible only if materials can be separated or in case that they can be processed together. However, both methods are considered impossible, since todays recycling plants aim to recycle only mono-materials, and different polymers or materials are unmixable. Therefore, multi-layered plastic is non-recyclable, and only thermal recovery or disposal are possible options [6].

### 1.1 Pyrolysis of Plastics

Pyrolysis is a thermo-chemical process that occurs in the inert atmosphere (with no oxygen present), whereby organic compounds are decomposing, generating gaseous and liquid products that are used as fuels and chemicals [7, 8]. It can be distinguished between thermal and catalytic pyrolysis [9]. Thermal pyrolysis requires high temperatures, between 350 and 900 °C, with liquids as the main reaction products [7]. Catalytic pyrolysis needs lower temperatures and the reaction time is shorter [10]. Catalysts enhance the hydrocarbon distribution [11]. Catalysts can be either homogeneous or heterogeneous. The most utilized catalyst from the first category is aluminum chloride [12]. Heterogeneous catalysts are more widely used for plastic pyrolysis. Some from this category are: $ZnO$, $MgO$, $CaCO_3$, $CaC_2$, $SiO_2$, $Al_2O_3$, $SiO_2$-$Al_2O_3$, ZSM-5 zeolite, red mud, and FCC [11, 13]. Generally, catalysts lower the activation energy, and accelerate the reaction rate [14].

Pyrolysis process of plastic waste is influenced by several factors: temperature, retention time, composition of feedstock, moisture, particle size, catalyst presence, type of the reactor, pressure, carrier gas, etc. All of these factors can affect quality, quantity and distribution of the pyrolysis products [15, 16]. Many studies on thermal and catalytic pyrolysis of plastics have been conducted lately. Polyolefin-based plastics are decomposed through a random chain scission mechanism in order to produce heterogeneous products (linear paraffin, olefin) [15]. Thermal pyrolysis generally leads to higher production of waxes in comparison to catalytic pyrolysis [11, 17-21]. Catalytic pyrolysis has more advantages compared to the thermal pyrolysis, because the energy consumption decreases, and a narrow range of hydrocarbons is produced [15, 22]. Only limited number of papers were published on the catalytic pyrolysis of multi-layered plastic waste [4, 23-27]. Those studies have mostly

concentrated on catalytic pyrolysis products and their characterization. Also, low number of studies has focused on reaction kinetics during catalytic pyrolysis of multi-layered plastic waste [1, 20, 28, 29].

## 1.2 Thermogravimetry as a Tool for Pyrolysis Studies

One of the most common approaches to pyrolysis process research, including catalytic pyrolysis as well, is thermogravimetric analysis [30]. Thermogravimetry or thermogravimetric analysis (TGA) is used for monitoring of a substance mass as a function of temperature or time. Sample is subjected to a controlled temperature and controlled atmosphere [31]. TGA is used for investigation of thermal stability, oxidative stability, composition. The weight gain/loss of the samples can be assigned to different factors. The gain of the weight means adsorption or oxidation, while weight loss describes the decomposition, desorption, dehydration, desolvation or volatilization [32]. In another technique, derivative thermogravimetry (DTG), the derivative of mass-change with respect to time is recorded in a function of time or temperature. Also, the derivative of the mass-change in regard to time can be recorded as a function of time or temperature. In both cases, as the result, the first derivative of the TGA diagram is obtained, which is in form of peaks, instead of a stepwise curve [33].

Many studies have been conducted on pyrolysis of plastic materials through TGA analysis [21, 34-40]. These studies are based mostly on the pyrolysis of a single type of plastic or co-pyrolysis of two or more different types of plastics, like LDPE, PP, PS, PET, and PP. Several studies focused on TGA with different carrier gasses like $N_2$, $CO_2$ or He [41, 42]. Only limited number of studies has investigated the TGA analysis of multi-layered plastic food packaging plastics [1, 20, 43]. In the work of Kremer et al. [1] the ZSM-5 catalyst modified with iron (III) oxide showed good results during the catalytic pyrolysis of multi-layered plastic waste, in a way of lowering activation energy of reaction, increasing of the acidity of the zeolites, and improving the reactivity of the catalyst's surface.

So, the aim of this study is to investigate the effect of natural zeolite in the pyrolysis of multi-layered plastic packaging waste. This was achieved by conducted thermogravimetric analysis and reaction mechanism (kinetic study) was done by using isoconversional Kissinger-Akahira-Sunose (KAS) method. Natural zeolites were chosen because they are available and affordable compared to the synthetic catalysts, and they have shown a great result in pyrolysis of plastic waste. Following papers gave a great insight in pyrolysis of plastics in the presence of natural zeolites [44-48].

## 2 MATERIALS AND METHODS
## 2.1 Materials

As previously explained, the multi-layered plastic food packaging is formed through layering of several thin plastic layers, accompanied with other materials like paper or/and aluminum. The composition of multi-layered plastic waste was previously determined based on the analysis of a large number of samples from the fraction of mechanically non-

recyclable plastic waste collected from waste treatment facilities in Croatia. The realistic multi-layered plastic food packaging had following composition: PE 71.17 %, EVOH 0.42 %, PP 9.70 %, PET 11.62%, PA 3.36 %, Cellulose 0.45%, and Aluminum 3.30 %.

## 2.2 Catalyst Characterization

Surface properties (surface area, prosity, acidity, cation exchange capacity) have strong influence on catalytic activity. The catalyst that has the highest cation exchange capacity also tends to show maximal convestion rate. Seven different natural catalysts from the wider region of the municipality of Celinac (Republic of Srpska, Bosnia and Herzegovina) were tested on specific surface area, capacity of cation exchange, Si-percentage, Al-percentage, pore volume, pore diameter. Among tested natural zeolites, third and seventh sample had the highest capacity of cationic exhange, and therefore these zeolites were chosen for the further process of pyrolysis of multiple-layered plastic waste packaging.

Natural zeolites were used in the experiments. Physico-chemical properties of natural zeolites were determined with following techniques: low-temperature nitrogen adsorption (LTNA), thermogravimetric analysis (TGA), differential thermogravimetric analysis (DTG), infrared spectroscopy with Fourier transformation (FTIR), scanning electron microscopy and energy dispersive X-ray analysis (SEM-EDS), and X-ray diffraction analyses (XRD). The cation exchange capacity was also determined. Textural properties of samples (specific surface area, mean pore diameter, pore volume, external specific area, micropore volume and micropore area) were determined from adsorption/desorption isotherms obtained by adsorption of gaseous nitrogen at temperature of liquid nitrogen (–196 °C), when He was used as a carrier gas. For the measurements, instrument Micrometrics ASAP-2000 was used. Specific surface was calculated with BET-equation, while pore volume and mean pore diameter were determined based on the adsorption branch of the isotherm according to the Barrett, Joyaner, Halenda (BJH) method. Examination of the morphological characteristics of the samples was done using scanning electron microscopy and energy dispersive X-ray analysis on JEOL-JSM-5300 device. Cation exchange capacity was determined by standard ammonium-acetat method, where the concentration of exchangeable cations ($Na^+$, $K^+$, $Ca^{2+}$, and $Mg^{2+}$) is determined by applying atomic absorption spectroscopy (AAS) Varian Spectra AA 55B. Following table (Tab. 1) contains the most important characteristics of the chosed natural zeolite for the pyrolytic run.

**Table 1** Characteristics of chosed natural zeolite with most promising properties for the pyrolysis

| Sample | Zeolite 3 | Zeolite 7 |
|---|---|---|
| Specific surface area ($m^2$/g) | 26.6 | 113.27 |
| Mean pore diameter (mm) | 15.97 | 10.99 |
| Pore volume ($cm^3$/g) | 0.081 | 0.20 |
| Si | 30.65 | 32.92 |
| Al | 6.09 | 7.32 |
| Cation exchange capacity (mmol/100 g) | 186.12 | 254.6 |

Natural zeolites with most promising catalyst properties were selected for the process, which means that two zeolites (zeolite 3 and zeolite 7) were choosen among the tested zeolites, because of the high cation exchange capacities. Surface area is an important factor for the application of natural zeolites as catalysts [49]. Therefore, zeolites 3 and 7 seem as the most perspective catalysts for the TGA run and further kinetic analysis.

As it can be seen from the Fig. 1, microscopic tests have shown that natural zeolite consists of a large number of plates, clearly defined shapes, many of them have a plate shape, which is characteristic for the crystal structure of clinoptilolite [50]. Following studies have used clinoptilite natural zeolites for pyrolysis of plastic waste [51, 52].
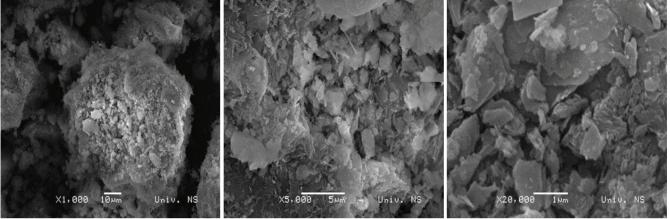


**Figure 1** SEM pictures of zeolite sample number 3

## 2.3 Analytical Equipment

Thermogravimetric analyzer Q500 (TA Instruments, DE, USA) performed the pyrolysis experiment. The experiments were done in inert atmosphere (nitrogen flow), at different heating rates (5, 10, 15, and 20 °C/min) ranging from 40 to 600 °C. The weight of the sample and catalyst loading was 10 mg.

## 2.4 Kinetic Study – Overview

In order to describe the principles and mechanisms of pyrolysis reaction, kinetic study needs to be done. The rates of conversion are proportional to the concentration of reacted material. Therefore, the conversion rate can be expressed on following way (Eq. (1)) [53]:

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \beta \frac{\mathrm{d}x}{\mathrm{d}T} = K(T)f \tag{1}$$

where $x$ is the reaction extent, i.e., degree of advance defined as (Eq. (2)) [53, 54]:

$$x = \frac{w_0 - w}{w_0 - w_\mathrm{f}} \tag{2}$$

$w$ is the weight of the sample at the given time $t$, while $w_0$ and $w_\mathrm{f}$ refer to values at the start and at the end of the weight loss process. $f(x)$ and $K(T)$ are functions of conversion and temperature [53]. $\beta$ is the linear heating rate (°C/min) [54]. $K(T)$ is the temperature dependence of the weight loss rate can be modeled by Arrhenius equation (Eq. (3)) [53]:

$$K(T) = A\exp\left(-\frac{E}{RT}\right) \tag{3}$$

$E$ stands for the activation energy, $A$ is the pre-exponential factor and $R$ is the gas constant [53].

When the Eq. (1) and Eq. (3) are combined, the reaction rate can be accessed in the following form (Eq. (4)) [53]:

$$\beta \frac{\mathrm{d}x}{\mathrm{d}T} = A\exp\left(-\frac{E}{RT}\right)f(x) \tag{4}$$

### 2.4.1 Kissinger-Akahira-Sunose Method – KAS Method

There are different methods for non-isothermal degradation kinetic study of thermodiagrams. Following five methods are mostly used for obtaining degradation mechanisms and kinetics of polymers: Coats-Redfern method, Coats-Redfern (modified) method, Flynn-Wall-Ozawa method, Kissinger-Akahira-Sunose method, and Friedman method [55]. The model-free approaches are built on the Arrhenius parameters, with no dependance on the reaction order. The model-free methods are also known as isoconversional, because the reaction rate is a function of the temperature, at constant extent of conversion. By isoconversional method, isothermal and non-isothermal pyrolysis can be analyzed [56]. Vyazovkin et al. [57] suggested the Kissinger-Akahira-Sunose method, because of its accuracy in estimation of energy activation values.

The previous equation (Eq. (4)) can be written on following way (Eq. (5)) [53, 58]:

$$\frac{\mathrm{d}x}{f(x)} = \frac{A}{\beta}\exp\left(-\frac{E}{RT}\right)\mathrm{d}T \qquad (5)$$

This equation integrated with the conditions $x = 0$ at $T = T_0$ gives following expression (Eq. (6)) [53, 58]:

$$g(x) = \int_0^x \frac{\mathrm{d}x}{f(x)} = \frac{A}{\beta}\int_0^T \exp\left(-\frac{E}{RT}\right)\mathrm{d}T \equiv \frac{AE}{\beta R}p\left(\frac{E}{RT}\right) \qquad (6)$$

This method assumes that $A$, $f(x)$, and $E$ are independent of $T$, and $A$ and $E$ are independent of $x$, then the Eq. (6) can be integrated to give the following logarithmic equation (Eq. (7)) [53, 58]:

$$\ln g(x) = \ln\left(\frac{AE}{R}\right) - \ln\beta + \ln p\left(\frac{E}{RT}\right) \qquad (7)$$

The KAS method also uses the Coats-Redfern approximation, according to which it applies (Eq. (8)) [53, 58]:

$$p\left(\frac{E}{RT}\right) \cong \frac{\exp\left(-\dfrac{E}{RT}\right)}{\left(\dfrac{E}{RT}\right)^2} \qquad (8)$$

When the Eq. (6) and Eq. (8) are combined, following expression is obtained (Eq. (9)) [53, 58]:

$$\ln\frac{\beta}{T^2} = \ln\frac{AR}{Eg(x)} - \frac{E}{RT}. \qquad (9)$$

## 3 RESULTS OF THERMOGRAVIMETRIC ANALYSIS AND KINETIC STUDY

### 3.1 Thermogravimetric Analysis

The thermogravimetric (TG) diagram is recorded at four different heating rates (5, 10, 15, and 20 °C/min) and the first-derivative TG curves (DTG) are shown in Fig. 2a and 2b.

Degradation of individual polymers occurs in following order PS < PET < PP < PE [59]. Only degradation of PS happens in the temperature range from 350 to 450 °C. Temperature degradation of pure PET is between 390 and 470 °C, while PP, LDPE, and HDPE degrade between 450 and 510 °C [19]. PP pyrolysis temperatures are lower than that of HDPE and LDPE because of the third carbon atom, which reduced the polymer stability [60]. From the Fig. 2a it can be seen that the thermal degradation occurs in two steps, in temperature range between 300 and 450 °C.

On the following Fig. 3a and 3b, the TGA and DTG diagrams of degradation of each component from the obtained plastic mix are shown.
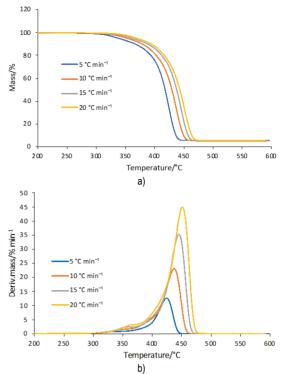


**Figure 2** a) TGA diagrams of mixed plastic and different heating rates (5, 10, 15, and 20 °C/min); b) DTG curves of mixed plastic and different heating rates (5, 10, 15, and 20 °C/min)
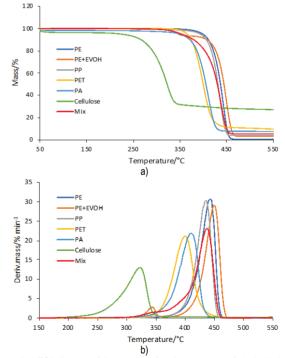


**Figure 3** a) TGA diagram of degradation of each component of obtained plastic mix; b) DTG curves of degradation of each component of obtained plastic mix

TGA curves refer to degradation of PE, PP, PET, PA, and cellulose in one stage, degradation of PE+EVOH, plastic mix, and plastic mix with natural zeolites in two stages.

TGA plots and DTG plots for plastic mix with chosen zeolites are shown in the Fig. 4a, and 4b, at heating rate of 10 °C/min.
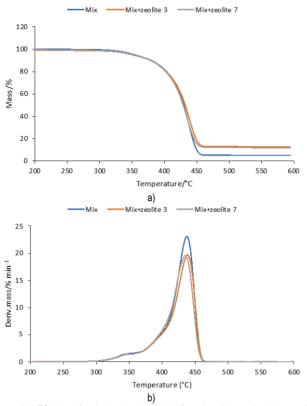


a)



b)

**Figure 4** a) TGA plots for plastic mix with zeolite 3, and zeolite 7, at heating rate 10 °C/min; b) DTG plots for plastic mix with zeolite 3, and 7, at heating rate 10 °C/min

**Table 2** Thermogravimetric parameters for plastic mix, by heating rate of 10 °C/min

| Sample | $T_{on}$/°C | $T_1$/°C | $R_1$/%min$^{-1}$ | $T_2$/°C | $R_2$/%min$^{-1}$ | $T_f$/°C | $M_f$/mass% |
|---|---|---|---|---|---|---|---|
| PE | 411.29 | | | 442.99 | 30.64 | 453.07 | 0.62 |
| PE+EVOH | 325.92 | 339.97 | 3.09 | 443.29 | 32.19 | 453.44 | 3.27 |
| PP | 400.88 | | | 427.86 | 33.78 | 438.92 | 3.90 |
| PET | 369.51 | | | 400.12 | 21.15 | 417.66 | 9.01 |
| PA | 375.83 | | | 410.71 | 21.91 | 424.90 | 7.51 |
| Paper | 270.05 | | | 322.95 | 13.01 | 336.39 | 23.44 |
| Mix | 330.57 | 342.00 | 1.41 | 437.44 | 23.13 | 449.63 | 5.20 |
| Mix+z3 | 324.83 | 341.11 | 1.29 | 438.45 | 19.75 | 451.32 | 12.84 |
| Mix+z3 | 328.39 | 343.63 | 1.36 | 435.42 | 19.56 | 448.29 | 11.83 |

The TGA plots of plastic mix with and without catalysts is realtively similar. The form and shape of DTG diagram of the sample in presence of catalysts are similar to the original sample, implying that there is a slight change in the reaction mechanism. This further indicated that the kinetic study of plastic mix with catalysts was not necessary. Tab. 2. shows thermogravimetric parameters for obtained plastic mix, by heating rate of 10 °C/min.

As it can be seen from the Tab. 2, mass loss for the plastic mix with zeolite 3 begins at temperature of 324.83 °C, and for the plastic mix with zeolite 7 at temperature of 328.39 °C. Maximum mass loss rate of the first peak for the plastic mix

with zeolite 3 was 1.29 % min$^{-1}$, and for the plastic mix with zeolite 7, 1.36 % min$^{-1}$. Beside temperature of the second peak, and mass loss at the second peak, Tab. 2. contains values of final temperature of degradation of plastic mix. By subtraction of $T_{on}$ from $T_f$, the decomposition temperature interval can be calculated.

Pore size and acidity are important factors for the catalytic cracking of polymers [7]. The obtained catalysts have low silicium to alumina ratio ($SiO_2/Al_2O_3$). Low $SiO_2/Al_2O_3$ ratio is related to the high acidity [52, 53] and lower mass loss rates. Only a negligible difference was obtained between mass loss rates of the original samples and the samples in the presence of catalysts. Coke formation could be another explanation for the lower mass loss rate. The utilization of a macroporous catalysts may reduce the coke formation. But, macroporous catalysts are not acidic, and do not have polymer active sites. Also, microporous catalysts could improve the catalytic reaction by producing more gases and lowering the liquid yield, but more qualitive than in the case with macroporous [22]. Additionally, natural zeolites have impurities in forms of Na, Mg, S, K, Ca, Ti, or Fe, which could influence the further reactions. However, industrial aplication of catalytic pyrolysis for recovering of plastic materials needs to be done with well-controlled catalysts in order to ensure coherent and repeatable products. So, natural catalysts might have undesirable impurities, quality, and composition for industrial utilization [54]. However, results of this study have shown that addition of catalyst slowed down the degradation process of our plastic mixture, so that the rate of polymer degradation is lower in comparison to the process with no catalysts. Study of Kremer et al. [20] showed good results by using Fe-ZSM catalyst for pyrolysis of multi-layered plastic waste.

## 3.2 Kinetic Study

Data and information on used kinetic study are provided in the subsection 2.4 and 2.4.1.

The Fig. 5 shows variation of activation energy in dependance of $x$ parameter.
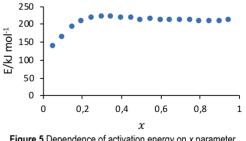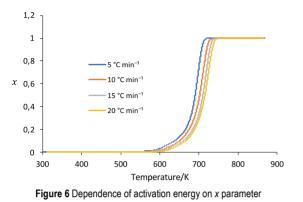


**Figure 5** Dependence of activation energy on $x$ parameter

The average activation energy amounted 204.37 kJ/mol, and minimal activation energy amounted 136.85 kJ/mol, while maximal activation energy was 219.10 kJ/mol. The dependance of activation energy from the x parameter provides information about complexity of the process – if it is linear, it occurs in one step, or if it is complex (when activation energy changes more than 30% related to the

average value of activation energy), the reaction occurs in at least two stages. Obtained results refer to two stage process, one from the beginning of the reaction until conversion rate is 0.25, and the second stage from the conversion rate of 0.25 until the end of reaction. Fig. 6. shows conversion cruves for different heating rates.



**Figure 6** Dependence of activation energy on $x$ parameter

The KAS plots of $\ln(\beta/T^2)$ versus $1/T$ ($K^{-1}$) for different values of conversion are shown in the Fig. 7.
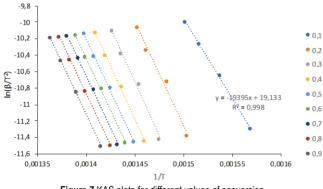


**Figure 7** KAS plots for different values of conversion

According to the Eq. (9), the activation energy is calculated from the slope of the line, and the pre-exponential factor $A$ from the segment on the $y$-axis, when the appropriate function $g(x)$ is used (Tab. 3).

**Table 3** Values of activation energy $E_a$ and values of $R^2$ corresponding to the linear fittings in the Fig. 7

| $x$ | $E_a$ | $R^2$ |
|---|---|---|
| 0.1 | 161.27 | 0.9980 |
| 0.2 | 207.56 | 0.9948 |
| 0.3 | 218.66 | 0.9923 |
| 0.4 | 215.89 | 0.9967 |
| 0.5 | 211.64 | 0.9977 |
| 0.6 | 211.46 | 0.9987 |
| 0.7 | 209.83 | 0.9993 |
| 0.8 | 208.41 | 0.9998 |
| 0.9 | 208.37 | 0.9998 |

The calculated values of the correlations coefficients ($R^2$) are corresponding to the linear fittings in the Fig. 7 and are between 0.9923 and 0.9998.

## 4 CONCLUSION

This work focused on the analysis of catalytic degradation of multi-layered plastic waste through thermogravimetric analysis in order to provide information and understand the mechanism of catalytic degradation of plastics. Because of their affordable price and availability, natural zeolites could be potentially used as catalysts for the plastic pyrolysis. Their great properties have already shown good results in previous investigations and experiments. Beside thermogravimetry, kinetic study (KAS method) was obtained aiming to understand influence of natural zeolites on the pyrolysis process of multi-layered plastic waste. However, thermogravimetric analysis showed that kinetic study of selected plastic mix in presence of catalysts was not needed, due to the similar form and shape of DTG diagram of the sample with catalyst and without catalyst. Also, thermogravimetry analysis showed that degradation rate of plastic mix with catalyst is actually lower than the degradation rate with no catalysts.

However, kinetic study was performed only on the plastic mix, without any catalysts. It was found out that non-isothermal decomposition of selected plastic waste occurred in two stages. The values of activation energy, calculated with the KAS method were between 136.85 and 219.10 kJ/mol. Results of this study showed that utilization of natural zeolites as catalysts slowed down the process of degradation of investigated plastic mixture, so that the rate of catalytic degradation of polymer was slower in comparison to the process with no catalysts. Therefore, this study concluded that application of other catalysts may be more efficient than the utilization of the selected natural zeolites.

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# Development of a Strategy Roadmap for the Widespread Implementation of Extended Reality

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**Abstract:** Digital transformation has led to a multitude of new technical solutions. This includes Extended Reality technologies: Hardware and software systems that enrich the real environment with information. The area of application extends to the entire value chain and thus offers great potential for companies. A systematic and holistic implementation strategy is necessary to exploit this optimally. XR solutions often remain prototypes mainly because of lack of knowledge management and missing understanding about the technology. In this respect, this article presents a tool for the systematic, holistic strategic consideration of XR from the vision to the planning of measures. The tool presented combines common methods such as the Strategy Map, the Transformation Map or the Balanced Scorecard. Thus, it does not only offer companies a strategic framework, but also includes concrete measures for a sustainable, successful implementation.

**Keywords:** Change Management; Extended Reality (XR); implementation; strategy; management

## 1 INTRODUCTION

The ongoing digital transformation is no longer a trend. In 2023 it describes the technological status quo. This forces companies to act and deal with new possibilities. A systematic approach is recommended to be successful in the long run. [1] It is important to define a path at the strategic level, to be able to shape it operationally.

Classical management theory agrees on that and emphasizes the value of high-quality strategic work. However, corporate success is not secured by the formulation of a general digitization strategy. It has to be split into sub-strategies according to specific operational areas. This also applies to the implementation of far-reaching technologies, as is the case for the introduction of new technical or digital (work) assistance technologies.

In this respect, the group of extended reality (XR) technologies including augmented, mixed and virtual reality is an important technology area in industry. [2] This research is underlined by current tech trend barometers. [3, 4] This has been further reinforced by the COVID-19 pandemic. [5] XR technology uses digital devices to enrich the real world with digital information. [6] A technology strand as a new work tool can often intervene in existing processes across the entire company and improve them. Fields of application and areas of use are complex and range from human resources to research and development, sales, and production. [7]

Potential applications also lead to a wide range of technical solutions regarding both hardware and software. This is breadth of possibilities must be systematized to achieve the optimal result for each company. The necessity of strategic consideration of XR integrations thus becomes clear. Nevertheless, companies currently still place little focus on this strategic consideration. Often, XR solutions are purchased for prototypical use cases and do not go beyond this status. Systematic and strategic embedding and active support of these applications can help to prevent these situations.

The paper takes up this initial situation and presents a strategy tool to enable a sustainable, successful and holistic implementation of XR technologies in companies. The tool

also includes the planning of measures and translates theoretical strategy into practical procedures. This interweaving of content and system represents value added in this field of research. The strategy tool was developed due to multi validated conceptional research by the authors translating different strategic approaches to the implementation of XR solutions in industry. In detail, the common methods Strategy Map, Transformation Map as well as Balanced Scorecard were combined and supplemented by the requirements of the industry. As for the contents, those aspects of the methods were used which were considered to be specifically relevant for the implementation of XR.

This research is part of a collective research project. It is nationally funded by the Austrian Research Foundation FFG. The practical validation was done with 20 partner companies in the project.

## 2 CHANGING TO EXTENDED REALITY

XR is one of the most relevant emerging technologies to come out of the fourth industrial revolution. [1-3] The focus is to enrich reality with information in different ways. Depending on the technology, data from different systems can be linked and displayed via a digital device in a location- and time-flexible manner. It is also possible to superimpose virtual information on reality in real time to enable remote support or remote training. Moreover, the technology enables working on and with virtual objects, such as a digitally modeled plant, a machine or individual components, which in turn opens up a wide range of possible applications. [6]

The use cases described show that XR is not a new, detached technology that performs individual steps of work in a similar way to a machine. Rather it is a work tool that changes the way activities such as assembly, training, maintenance or product development are carried out. [2] But not only previously mentioned processes are affected. By making information widely available, XR makes it possible to bring decision-relevant information to all areas of the company - from management to shopfloor. This enables decentralization of decisions and associated enrichment and enhancement of workplaces. [8] However, this also implies a

change in the behavior of employees [7], towards "Augmented Operators" [9], making employees' key elements of the implementation of XR. A high level of acceptance of the technology is necessary in order to achieve a sustainable and successful introduction. [10, 11]

Due to the multitude of potentials of XR for companies and the need for change that results from the use of XR for work processes, the broad implementation of XR is to be classified as a comprehensive change that should be accompanied by systematic change management.

In terms of change management, the clear formulation of a goal as well as the related design of the goal achievement represents a central element in order to achieve acceptance and cost efficiency during the implementation. [12] 70% of all change processes fail due to the lack of a clear goal and a systematic approach to change. [13, 14] Therefore good strategic planning, support and monitoring are essential for the success of the implementation. This clearly shows the need for strategic considerations during the rollout. [1]

## 3 KEY FACTOR STRATEGY

Without a well-defined plan, companies may struggle to integrate the technology effectively, leading to wasted resources and lost opportunities. A clear strategy should outline the goals and objectives of the XR implementation, identify the specific use cases of the technology, and specify technical requirements and infrastructure needed to support it. [1]

The implementation of a XR technology in companies usually takes the following path: a person who is interested in the topic starts testing the technology. Sometimes several projects run in parallel in different departments, which leads to ambitious but un-coordinated initiatives. [15] This hands-on approach makes sense for testing the possibilities of a technology. However, it also harbours the risk of technological "island solutions", if they emerge they do not result in a sustainable strategic implementation in the company.

A new technology opens up many opportunities for companies. However, to be able to put these opportunities into practice, it is necessary to rethink and transform the organizations themselves, their established processes and corporate culture. Therefore a successful long-term implementation of XR solutions corresponds with profound changes in companies and poses a multitude of challenges [16, 17].

Strategy also plays a crucial role in managing the risks associated with a new technological implementation. Although XR technology itself is not expensive, the implementation may involve time-consuming investigations and programming. It is not a technology that is built up in a short time and therefore needs long-term commitments. Therefore, a strategic approach is necessary to ensure the long-term viability of the technology. [1]

Based on this information the authors decided to use established strategy tools as the 'Balanced Scorecard', the 'Strategy Map' and the 'Transformation Map' to create a tool

chain to establish XR in a company sustainably. These tools are already known in the companies surveyed.

The **Balanced Scorecard** (BSC) is a strategic management tool that helps organizations to translate their vision and strategy into action. The BSC provides a framework to align organizational goals with performance measures and targets. This helps organizations to focus on the most critical drivers of success. The BSC includes four perspectives: financial, customer, internal business processes, and learning and growth. Each perspective includes specific objectives, measures, targets, and initiatives that help organizations track and manage their progress. [18]

The **Strategy Map** is a tool to visualize and communicate the strategic objectives of an organization and how they are linked to each other. The strategy map provides a clear and concise way to communicate complex strategies to stakeholders, including employees, investors, and customers. The strategy map includes a visual representation of the organization's goals, objectives, and measures, as well as the relationship between them [19, 20]. The strategy map is a valuable tool for the implementation of a technology as it helps organizations to communicate the value proposition of the new technology. [21]

The **Transformation Map** is a visual strategic mapping tool, similar to the 'Business Model Canvas'. It is used for all scales of initiatives and activity to map outputs to outcomes, outcomes to objectives and objectives to an overarching vision. In a transformation map, all actions required to reach the key objective within a context of change are listed. The transformation map provides a clear and concise way to visualize and manage the relationships between different systems and stakeholders involved in the implementation of a technology. [22]

## 4 METHODOLOGY

The main research goal was to develop a tool to not only develop a XR strategy, but also to guide a company through the entire implementation process. Therefore, it was necessary to combine established methods and adapt them to the circumstances and needs of companies to increase the possibility of usage in practice.

This objective results in a multi-stage research design:
1) Scientific substantiation
2) Surveying industrial practice
3) Development of a holistic strategy tool
4) Practical validation
5) Adaptation and finalization of the tool

Two areas of research were examined to provide a **scientific basis (1)** for the study. First, established models for deriving corporate strategies were reviewed. In this respect, it was essential that the models did not focus on individual aspects but take a holistic view of the company. Because of the research, the 'Transformation Map' and the 'Strategy Map' were considered particularly suitable. In combination, these provide the rough framework for the new tool. The more detailed elements were derived based on the 'Balanced

Scorecard'. It takes into account both hard facts and soft facts, which was considered essential for the introduction of XR.

The literature research was supplemented by a **survey of practitioners (2)**. To this end, a workshop was held by the partner companies involved in the project. The goal was to determine which tools are already established in the companies for strategy development and strategic planning and why. In combination with the results of the literature research, the **tool for strategy** development and support presented in this paper was **developed (3)**.

The prototype was subjected to **practical validation (4)** for quality assurance purposes. Three independent companies from different industries took part. They tested both the content of the tool and the implementation process for practicability, user-friendliness and understanding. The findings generated in this way were incorporated into the **final development of the strategy tool (5)** and contributed to quality improvement, particularly with regard to the practical usability of the tool.

The following chapter shows the design of the tool in detail.

## 5 RESULTS
### 5.1 Developed Strategy Tool

The strategy tool as shown in Fig. 1 is based on a structured approach under the assumption that strategies are developed focusing on the entrepreneurial vision, mission and targets. With the help of this tool and the methodology stored within, the target state can be efficiently defined and the way to achieve it can be designed.
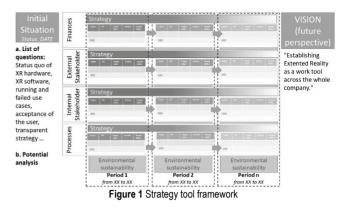
Based on the BSC model, perspectives were formulated. Based on these perspectives the implementation path was concretized. The following perspectives serve as sub-areas for this purpose:
1) Finance
2) External stakeholders (customers, suppliers...)
3) Internal stakeholders (key users)
4) Processes.

The classic strategy process, based on a strategic analysis of the initial situation, is based on data and insights of the past and/or current time. In today's world, in which companies have to deal with high volatility, uncertainty, complexity and ambiguity (VUCA) [23], this approach falls short. Consequently, the time horizon, which is supposed to represent the path from the initial situation to vision, is divided into periods. The color attenuation shows the decreasing level of detail of the planning over time.

In addition, the focus was placed on economic but above all ecological aspects, which must be taken into account. In this case XR applications play a fundamental role. This ecological view is placed above all perspectives in each period.

The tool developed by the systematic approach described is a VBA (visual basic application) Excel tool, which, as a systematic strategy process is divided into several phases. An Excel tool was chosen because all partner companies are familiar with Excel in a corporate context. Both user confidence and the high degree of familiarity have a positive effect on the use of the tool.



**Figure 1** Strategy tool framework

Methodologically, the tool consists of eight spreadsheets, five content related (written in Italic) and three supporting ones:
1) Introduction to the topic
2) Fill-in help and FAQ
3) *Initial situation*
4) *Vision*
5) *Sub-strategies*
6) Example of goals and dependencies
7) *Template Goals*
8) *Template dependencies*.

It starts with an **introduction (1)** to the topic to explain the general approach of the tool, the benefit of it and what it should be used for. The **Fill-in help (2)** explains which steps should be taken to work with the tool efficiently. Also, a **FAQ (2)** section was created mainly based on the information from the practical validation as described in chapter 5.2.

After that, the core of the tool starts. The first step in developing a strategy for the introduction of XR in the company is to discuss the **initial situation (3)**, with the help of the knowledge gained from an analysis of the current situation. As already mentioned, this takes place in the four perspectives finance, external stakeholders (customers, suppliers...), internal stakeholders (key users) and processes. Questions in the tool lead the editors to the answers being the basis for a holistic vision for the implementation of XR. Topics are about the actual status quo of XR including previous experiences with XR and existing competences. Furthermore, a potential analysis is suggested in this phase in order to find areas of application for XR within the company. This can be done either by means of expert interviews or by an on-site analysis in the company. As a result, the initial situation is described with the help of the knowledge gained from the as-is analysis.

Subsequently, a **vision (4)** for the introduction and definition of the desired benefits of XR applications in the company is created. This is done with three relevant questions:
1) What do you want to achieve with XR in your company?

2) Why do you want to implement XR in your company?
3) What role do you want XR to play in your company in the future?

The vision is a motivating, positively-formulated presentation of the goals to be achieved through the use of XR technologies. To this end, this vision sets a direction in which companies want to move and where they want to be in the future; using XR-technology.

Using the information now available, **sub-strategies (5)** are derived from the perspectives: Finance, External Stakeholders, Internal Stakeholders and Processes. This makes the overarching strategy more concrete and therefore tangible for the individual areas of action. In this case, it is essential that sub-strategies be clearly in line with the vision. These guidelines provide the framework for concrete action planning.

At this point, users are shown based on an **example (6)** how the planning of targets and actions should be carried out and how individual measures can be considered in terms of time and content. This is necessary to avoid delays in the implementation of the individual measures.

Based on the sub-strategies defined in advance, **goals (7)** are derived with associated key figures, measures and their statuses in the next step of the target definition, as shown in Fig. 2.

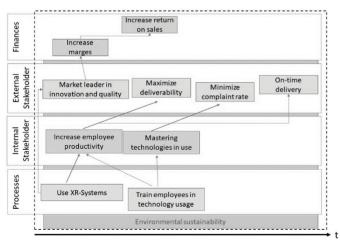**Figure 2** Detailed planning of goals, measures and responsibilities

**Figure 3** Example for the planning of dependencies

In order to make specified goals measurable and traceable, a key figure (KPI) is assigned to each defined goal. Subsequently, measures are defined to achieve these goals efficiently and effectively. These also serve to develop

recommendations for action. In addition, responsibilities are defined for each target value.

In the last spreadsheet of the strategy tool, the individual goals, which have been assigned a target value, as well as some additional strategically particularly relevant goals are **set in relation (8)** to each other. They must be planned dependent on time and content (8) as shown in Fig. 3. This is to avoid bottlenecks and delays in the achievement of measures.

The filling of the tool can be done with the support of consultants as well as by the company itself. Therefore, general information and a fill-in guide were placed within the tool that are found in the first two spreadsheets of the excel file.

### 5.2 Validation of the Tool

As described within the methodological framework in chapter 4, the tool has been practically validated with three companies in 2022. The companies were asked to give feedback on the following areas: Comprehensibility, usability, ease of use and practicability in application. In the first step of the validation, the companies familiarized themselves with the tool and submitted written feedback to the authors. This was important, since the aim was to develop a self-assessment tool. The second step was made up of personal feedback-meetings that took place with each validation partner to discuss the adaptions we proposed based on the feedback.

The employees involved in the validation were responsible for the implementation of XR solutions in the respective companies and already had experience in both XR and strategic planning.

Since the project will run until the end of 2023, the focus in this publication is on the description of the tool and not on current data from a project partner. A publication of a real example of a project partner will take place in a separate publication at the end of 2023.

However, the first feedback from the project partners was recorded to further improve the quality of the tool. The following table 1 shows the main feedback of the partners.

**Table 1** overview of the main validation feedback

| Validation partner | Feedback |
|---|---|
| Company 1 (metal industry) | • Add advice, who should fill in the tool<br>• Change vision to reflection<br>• Add current value<br>• Define level of detail to fill in the tool |
| Company 2 (technical services) | • Introduction to the topic clear<br>• Add navigation button to Q&A in every sheet<br>• Add button to duplicate periods automatically<br>• Add responsibilities to BSC attributes<br>• Add a practical example |
| Company 3 (transportation) | • Explain terms such as internal or external stakeholder<br>• Questions are clear<br>• Different parts of the tool require different people working with the tool |

The feedback mainly targeted the usability and ease of understanding of the tool itself. The choice and combination of strategic tools was mentioned positively. The Authors evaluated the results of validation and came up with some adaptions/supplements of the tool. Most of the comments led to questions now answered in the aforementioned FAQ section of the tool.

The first prototype contained only the recommendation on how to proceed, but not an exemplary presentation and the description of individual terms.

To guide companies, a suggestion was made on which functions in the company are useful for the development of the individual steps. For example, for step 1: "Analyze the initial situation" it is recommended that a change manager in conjunction should do this with decision-makers and employees of the target departments.

The FAQ now includes an explanation of the most important terms, such as the term "stakeholder". This is essential to achieve a uniformal understanding of the terminology used to work with the tool.

To increase the usability of the tool, a direct link to the FAQ spreadsheet is provided on each sheet of the strategy tool.

## 6 RECOMMENDATIONS

The literature emphasizes several times the importance of strategic planning in different business areas. Strategy provides the guidelines and defines the company's activities. It is therefore even more important to include company-wide changes in the overall corporate strategy and to accompany the respective change strategically. This also applies to the introduction of XR in the company.

Furthermore, the development of the tool presented in close cooperation with companies has shown that a strategy tool should ideally be directly linked to implementation planning and success control. This proximity in terms of content not only shows the direct link between strategy and operational activities, but also illustrates the importance of the planned change.

With regard to XR applications in particular, it has been shown that in practice there is often still no dedicated XR strategy. However, in view of the amount of potential and the far-reaching effects of the technology on work processes, strategic consideration and planning is recommended.

In addition to the positive feedback of the companies, the practical validation also resulted in limitations. For example, the tool is only fully useful if it is directly coupled with other existing strategic tools. This means that it is no longer seen as a separate stand-alone solution within the company but is integrated into existing processes and strategic considerations. Furthermore, it was found that although the companies rated the usefulness of the tool as high, its use often fails due to a lack of routine. Therefore, the authors developed their own training workshop for the tool and held seasons several times. This increased user motivation.

Overall, it can be stated that the tool presented helps to approach the introduction of XR as a work tool in a company in a holistic manner. However, if the company decides that before the implementation the respective XR use case should be an isolated solution, the tool is too extensive and not recommended.

The tool has already been used to provide support that is more intensive to several companies in their XR strategy development. The results of this are not yet finalized, but will be part of a follow-up publication.

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# Article Title Only in English (Style: Arial Narrow, Bold, 14pt)

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Ivan Horvat, Thomas Johnson, Marko Marić (Style: Arial Narrow, Normal, 10pt)

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## 1 INTRODUCTION (Article Design)
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Article title must clearly reflect the issues covered by the article (it should not contain more than 15 words).

Body of the text is divided into chapters and the chapters are divided into subchapters, if needed. Chapters are numbered with Arabic numerals (followed by a period). Subchapters, as a part of a chapter, are marked with two Arabic numerals i.e. 1.1, 1.2, 1.3, etc. Subchapters can be divided into even smaller units that are marked with three Arabic numerals i.e. 1.1.1, 1.1.2, etc. Further divisions are not to be made.

Titles of chapters are written in capital letters (uppercase) and are aligned in the centre. The titles of subchapters (and smaller units) are written in small letters (lowercase) and are aligned left. If the text in the title of the subchapter is longer than one line, no hanging indents.

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Typographical symbols (bullets), which are being used for marking an item in a list or for enumeration, are placed at a beginning of a line. There is a spacing of 10pt following the last item:

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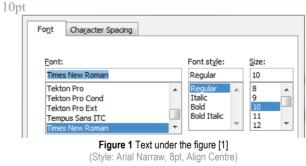1) Item 1
2) Item 2
3) Item 3

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**Figure 1** Text under the figure [1]
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The journal is printed in black ink and the figures have to be prepared accordingly so that bright tones are printed in a satisfactory manner and are readable. Figures are to be in colour for the purpose of digital format publishing. Figures in the article are numbered with Arabic numerals (followed by a period).

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**Table 1** Table title aligned centre
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|  | 1 | 2 | 3 | 4 | 5 | 6 |
|-----|-----|-----|-----|-----|-----|-----|
| ABC | ab | ab | ab | ab | ab | ab |
| DEF | cd | cd | cd | cd | cd | cd |
| GHI | ef | ef | ef | ef | ef | ef |

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Equations in the text are numbered with Arabic numerals inside the round brackets on the right side of the text. Inside the text they are referred to with equation number inside the round brackets i.e. ".... from Eq. (5) follows ...." (Create equations with MathType Equation Editor - some examples are given below).

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$$F_{\text{avg}}(t, t_0) = \frac{1}{t} \int_{t_0}^{t_0+t} F\big[q(\tau), p(\tau)\big]\, \mathrm{d}\tau, \tag{1}$$

$$\cos \alpha + \cos \beta = 2\cos \frac{\alpha + \beta}{2} \cdot \cos \frac{\alpha - \beta}{2}, \tag{2}$$

$$(\boldsymbol{AB})^{\mathrm{T}} = \boldsymbol{B}^{\mathrm{T}} \boldsymbol{A}^{\mathrm{T}}. \tag{3}$$

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Variables that are used in equations and also in the text or tables of the article are formatted as *italics* in the same font size as the text.
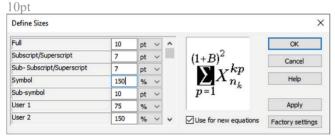
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**Figure 2** The texts under figures
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**Figure 3** The texts under figures
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**Original scientific papers** are articles that according to the reviewer and the editorial board contain original theoretical or practical results of research. These articles need to be written in such a way that based on the information given, the experiment can be repeated and the results described can be achieved together with the author's observations, theoretical statements or measurements.

**Preliminary communication** contains one or more pieces of new scientific information, but without details that allow recollection as in original scientific papers. Preliminary communication can give results of an experimental research, results of a shorter research or research in progress that is deemed useful for publishing.

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**Introduction** contains the depiction of the problem and an account of important results that come from the articles that are listed in the cited literature.

**Main section of the article** can be divided into several parts or chapters. Mathematical statements that obstruct the reading of the article should be avoided. Mathematical statements that cannot be avoided can be written as one or

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[4]    Amidzic, O., Riehle, H. J., & Elbert, T. (2006). Toward a psychophysiology of expertise: Focal magnetic gamma bursts as a signature of memory chunks and the aptitude of chess players. *Journal of Psychophysiology, 20*(4), 253-258. https://doi.org/10.1027/0269-8803.20.4.253
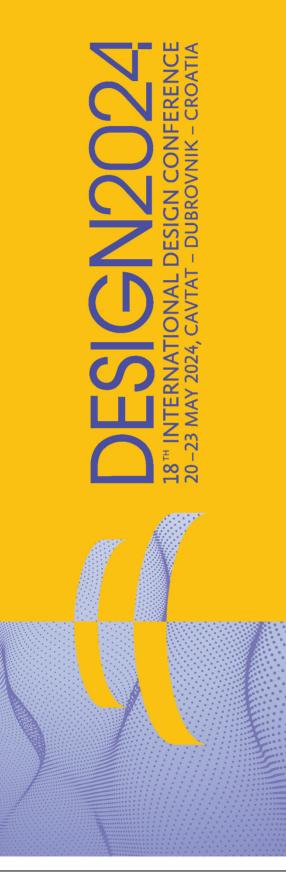[5]    Reitzes, D. C. & Mutran, E. J. (2004). The transition to retirement: Stages and factors that influence retirement adjustment. *International Journal of Aging and Human Development, 59*(1), 63-84. Retrieved from http://www.baywood.com/journals/PreviewJournals.asp?Id=0091-4150
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# DESIGN2024

## 18TH INTERNATIONAL DESIGN CONFERENCE
### 20–23 MAY 2024, CAVTAT – DUBROVNIK – CROATIA

## INVITATION

*By tradition, DESIGN Conference is a forum for discussion and further development of design knowledge from cognition and philosophy to methods and tools, from research theory to practice.*

The transition from known and comfortable to unknown and challenging is ubiquitous. It is challenging every aspect of our being. How can design research and practice respond to changes, influence wellness, ensure sustainable development, reimagine the future, rethink product design and development in new and emerging contexts?

How to improve design methodologies, tools, projects, and processes? How to develop products and services to make the world a healthier place? Which competencies, information, and communication technologies are needed? What is the impact on everyday design work? Which social and legal issues should be considered? How will we teach future designers, communicate ideas and share knowledge?

Applied, theoretical, and results-oriented papers from academia and industry, based on thorough analysis or argumentation, will be considered for the conference programme. The submitted papers should fit into one of the proposed conference topics. It is expected that these specific topics are extensive and nonexhaustive.

A list of example keywords is added to illustrate the core topics. It is required explicitly from all contributors to show how they contribute to the overall research within these areas. A detailed description of topics and instructions for online submission is available at www.designconference.org.

Programme chairs welcome the high-quality submissions covering substantial, original, and previously unpublished research.

Rigour academic research should provide designers with the next generation of methods and tools appropriate to the demands.

## PROGRAMME

*The DESIGN Conference provides an interactive environment where participants proactively create opportunities to share design knowledge and new cross-disciplinary research that leads to innovation.*

### PLENARY SESSIONS
The new ideas and visions will be presented by the keynote speakers.

### TOPIC-ORIENTED SESSIONS
Will host papers selected around common research questions in order to foster discussion.

### WORKSHOPS
DESIGN 2024 workshops will promote integration of different views, approaches and methods. Workshop coordinators could invite selected presentations and demonstrations in order to stimulate the debate as well as to propose any format of delivery that inspires interaction. The workshops will be organised on the 20th of May.

### PHD STUDENTS' FORUM
The forum will be a unique opportunity for younger researchers and PhD students to discuss their research questions and ideas with experienced researchers, practitioners and R&D managers in order to facilitate their research efforts.

### THE DESIGN DEBATE
The purpose of the design debate is to investigate in a forensic manner some key topics that affect the engineering design research community. Two opponents and the debate moderator will be distinguished key players in the community presenting evidence for or against a particular topic.

## REVIEWING POLICY

The papers will be accepted on the double-blind review basis made by the members of the Scientific Advisory Board.

The review criteria will be the novelty and level of contribution, validity of conclusions, industrial or application perspective and formal qualities of the contribution.

DESIGN Conference papers are published online with open access. All papers are indexed in SCOPUS and WOS - CPCI and referenced in CrossRef with DOI identifier.

# DESIGN 2024 TOPICS

**DESIGN THEORY AND RESEARCH METHODS**
Multidisciplinary research approaches
Design theories and models
Experimental design research
Design typology
New paths in design research

**DESIGN ORGANISATION, COLLABORATION AND MANAGEMENT**
Organisational processes for Industry 4.0
Product development models and agile management
Market and business implications
Co-design and collaboration
Design teams and communication
Open/social innovation

**DESIGN INFORMATION AND KNOWLEDGE**
Design representations of information and knowledge
Decision-making rationale and support
Knowledge-intensive design
Knowledge-based engineering
Emerging IT technologies

**DESIGN METHODS AND TOOLS**
Product families and modularisation
Prototyping methods and tools
CAx/PDM/PLM
Requirements and change management
Usage and integration of supportive technologies

**HUMAN BEHAVIOUR AND DESIGN CREATIVITY**
Human factors in design
Designer's attitudes and skills
Design thinking, cognition and problem-solving
Cognitive processes in design creativity
Supporting and assessment of design creativity
Bioinspired design

**DESIGN FOR SUSTAINABILITY**
Sustainability awareness
Design for social equity and cohesion
Design for the circular economy
Technology and sustainable society
Product-service systems
Sustainable transition

**DESIGN FOR HEALTHCARE**
Healthcare ecosystems
Healthcare design
Healthcare services
Use of advanced technologies in healthcare
Life sciences and design

**DESIGN FOR ADDITVE MANUFACTURING**
Design approaches for additive manufacturing
Design digitalisation approaches
Design optimisation frameworks
Generative design and topological optimisation
Architecting materials for additive manufacturing

**DESIGN FOR EXCELLENCE**
Design for product improvement and quality
Design for manufacturing and assembly
Design for packaging and ergonomics
Design for robustness and reliability
Design for maintainability

**ARTIFICIAL INTELLIGENCE AND DATA-DRIVEN DESIGN**
Artificial intelligence in product development
Data-driven design process
Knowledge discovery and data mining in design
AI for smart product-service systems
Digital twins
Autonomous vehicles and electromobility

**INDUSTRIAL DESIGN**
User-centred design
Aesthetics and visual impressions
Product semantics and perceptions
Visual and haptic interactions
User experience
Social relationships and emotional design

**SYSTEMS ENGINEERING AND DESIGN**
Architecting complex engineering systems
Simulation within complex systems
Model-based systems engineering (MBSE)
Complex cyber-physical systems design
Approaches to socio-technical systems design

**DESIGN EDUCATION**
Competency and skills development
Digital learning and ICT in education
Project-based learning
Adopting different teaching and learning environments
Lifelong and organisational learning

**ENGINEERING DESIGN PRACTICE**
Geometrical modelling and advanced CAx use cases
Advanced visualisation and virtualisation
Case studies of design methods application
Best design practices from industry

## IMPORTANT DATES

**1** Full paper submission deadline
**15 November 2023**

**2** Final acceptance of papers
**31 January 2024**

**3** Publish-ready papers
**23 February 2024**

**4** Final Conference programme
**April 2024**

**5** DESIGN 2024 Conference
**20-23 May 2024**

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