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Measurement and Modelling of the Thermal Response of the Resistance Temperature Sensors

Tomislav Barić, Hrvoje Glavaš, Laura Kuretić, Mirko Karakašić*

Abstract: Knowledge of the dynamic properties of thermometers is of particular importance for successful automation of process management in real time. The dynamic behaviour, i.e. the thermal response of the thermometers, is primarily determined by the thermal time constants of the thermo sensor and the protective housing in which it is located (thermo immersion probe, thermowell). In this paper, we presented a simple, but for a large number of applications acceptably accurate method of determining the thermal time constants of the temperature sensor. The procedure for determining the thermal time constants of a thermometer is shown on the example of a thermometer with a resistance temperature sensor. The paper presents the thermal model of the resistance temperature sensor and the protective housing of the sensor. By suddenly immersing the immersion probe in a container with heated water, the temperature response was recorded. Based on the presented thermal model, the thermal time constants of the temperature sensor and the protective case were determined.

Keywords: measurement; modelling; resistance temperature sensor; thermal response

1 INTRODUCTION

In all applications of measuring instruments it is necessary to know well the static parameters of instruments. For example: measuring range, accuracy, reading accuracy, offset, hysteresis, resolution, etc. However, in certain applications it is equally important to know the static and dynamic parameters of the instruments [1, 2]. One of such applications of measuring instruments is real-time thermal measurements of certain processes in industry. In this paper, the importance of knowing the dynamic parameters of thermometers based on platinum resistance temperature detector (RTDs) is described in detail [3]. The physical principle on which platinum resistance thermometers are based is described in the paper. Also, the typical structure of platinum resistance thermometers is described. In some cases, the corresponding dynamic parameters of the thermometers with RTDs can be found from the instrument manufacturer's datasheets. When this is not the case, it is necessary to carry out measurements in order to determine the dynamic parameters of platinum resistance thermometers. Therefore, in this paper a simple, but for many applications satisfactorily accurate procedure for determining the dynamic parameters of platinum resistance thermometers is described. The paper also presents a theory and thermal model by which the phenomenon of thermal inertia can be explained. At the same time, with the presented theory and thermal model, the influence of certain physical quantities on the dynamic response of platinum resistance thermometers can be explained. Although this paper is exclusively focused on platinum resistance thermometers, the presented methodology for determining dynamic thermal parameters is also applicable to other types of thermometers.

2 RESISTANCE TEMPERATURE SENSORS AND THERMOMETERS

RTDs are types of sensors with a very simple structure whose resistance changes as its temperature changes [3]. The

change in sensor resistance can be described by a general expression [3]:

$$R(T) = R_0 \cdot (1 + \alpha_1 T + \alpha_2 T^2 + \dots + \alpha_n T^n), \quad (1)$$

where R_0 is the resistance at the reference temperature (typically at 0 °C), $\alpha_1, \alpha_2, \dots, \alpha_n$ are temperature coefficients of resistance. Metal type and sensor resistance at 0 °C are marked as follows: PT1000 means a platinum sensor that has a resistance of 1000 Ohms at 0 °C. By injecting a known current through the sensor, the voltage drop on the sensor is proportional to the resistance of the sensor. This voltage is amplified using an amplifier, and this amplified voltage corresponds to the temperature of the sensor in a certain scale. An example of the structure of a thermometer with a resistance temperature sensor is shown in the block diagram in Fig. 1 [4].

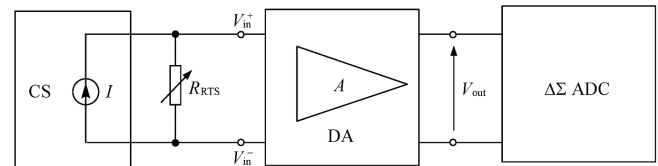


Figure 1 Block diagram of the structure of a thermometer with a resistance temperature sensor

A precise, temperature-stabilized current source (CS) injects a known current (I) into the resistance temperature sensor represented by a temperature-variable resistance (R_{RTS}). The voltage drop at the resistance temperature sensor is taken to the input of a differential amplifier (DA) that has a differential gain of A . At the output of the differential amplifier (DA) there is an amplified voltage $V_{out} = A \cdot (V_{in}^+ - V_{in}^-)$, which is taken to the input of the delta-sigma analog-to-digital converter ($\Delta\Sigma$ ADC). From the output of the delta-sigma analog-to-digital converter, the

signal can be sent to the display or/and for further processing by a personal computer (PC).

3 PROBLEM DESCRIPTION

The phenomenon of thermal inertia of the immersion probe and PT1000 sensor and the influence of these thermal inertias on the dynamic temperature response of the thermometer as a whole system can be explained by a simple thermal model based on Kirchhoff's thermal circuit (Fig. 2 [3]). The immersion probe consists of a cylindrical pipe ($\varnothing 3$ mm) in which a PT1000 sensor is placed at the end of the pipe (Fig. 2a [3]). Around the other end of the cylindrical tube is an ergonomically designed plastic handle with flexible conductors that are connected to a measuring device.

Due to the thermal inertia of the immersion probe and PT1000 sensor, the temperature of the sensor cannot be changed instantly. The sensor temperature changes as a thermal transient.

When the ambient temperature changes, which is described at the model level by a voltage source, the thermal

transient of the temperature change of the metal cylindrical tube first begins. After a certain time (deadtime, time delay), the thermal transient of the temperature change of the sensor begins. The entire transient of the temperature change of the sensor can be described as a second-order transient. This will cause an additional error in the reading of the instrument. That is, along with the static error, there will also be a dynamic error (Fig. 3 [3, 5, 6]).

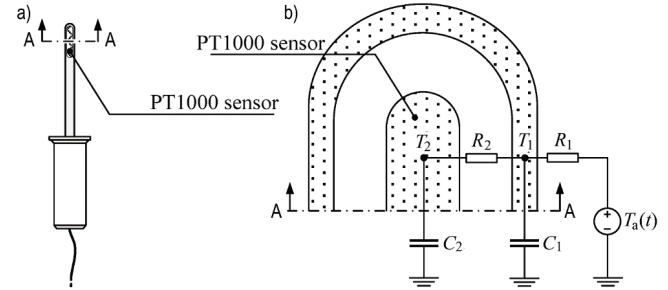


Figure 2 a) Simplified representation of the structure of the thermo probe and PT1000 sensor, b) enlarged detail of the top of the probe and the corresponding Kirchhoff thermal circuit

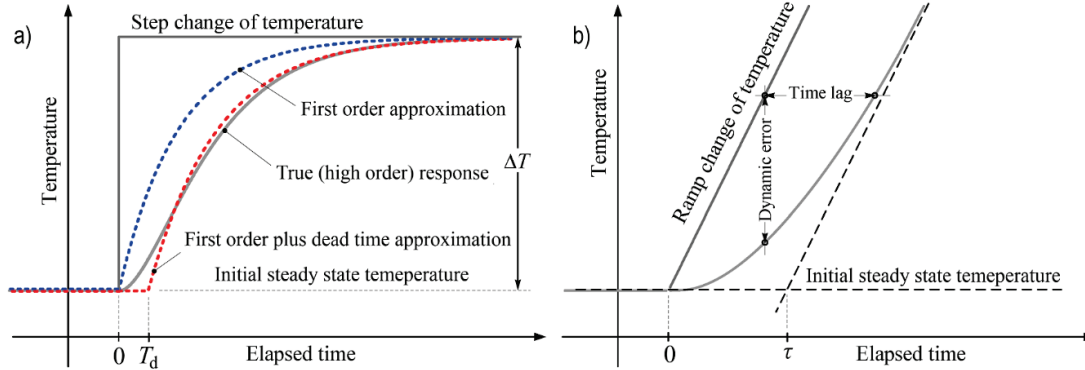


Figure 3 Temperature response (instrument reading) of PT1000 thermometer: a) to a sudden change (step change) in the measured temperature and two common approximations of the response, and b) to a linear change (ramp change) in the measured temperature, definition of dynamic error and time lag.

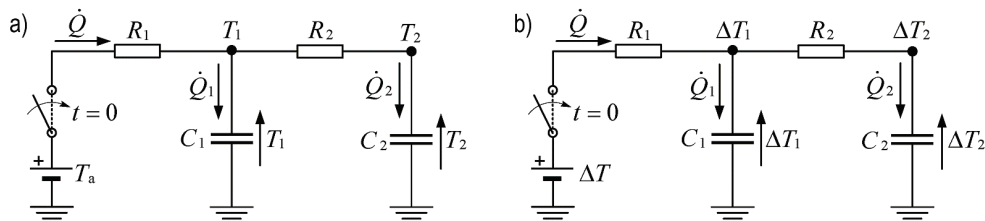


Figure 4 Equivalent Kirchhoff thermal circuits of the probe and the sensor

4 THERMAL MODEL

For further modelling and consideration, the Kirchhoff thermal circuit can be separated from the geometry as shown in Fig. 4.

The circuit elements of the thermal circuit shown in Fig. 4 have the following meanings. R_1 - represents thermal resistance of the probe due to convection of heat from the environment into the probe. R_2 - represents the thermal resistance to heat transfer between the probe and the temperature sensor due to heat convection. C_1 and C_2 represent the thermal capacitance of the thermal mass of the probe and sensor. The event of probe immersion into a liquid

substance with a temperature different from the temperature of the probe is modelled with the switch "S". Furthermore, T_a represents the ambient temperature, T_1 represents the temperature of the immersion probe housing, and T_2 represents the temperature of the sensor. Acknowledging the fact that when determining the transfer function, all initial conditions are set to zero, the equivalent thermal scheme that models the temperature transient can be presented as shown in Fig. 4b. The difference compared to the previous scheme (Fig. 4a) is that instead of absolute temperature values, over temperatures are used.

The above will simplify the further mathematical procedure. The resulting expressions will describe the change

in overtemperature, and they are related to the absolute temperature by an expression:

$$T_2(t) = T_a + \Delta T_2(t). \quad (2)$$

Based on the scheme shown in Fig. 4, after $t \geq 0$, the temperature transient is described by a system of equations:

$$\Delta T - \dot{Q} \cdot R_1 - \Delta T_1 = 0, \quad (3)$$

$$\Delta T_1 - \dot{Q}_2 \cdot R_2 - \Delta T_2 = 0, \quad (4)$$

$$\dot{Q} = \dot{Q}_1 + \dot{Q}_2. \quad (5)$$

Changes in the internal energy of the heat masses of the probe (\dot{Q}_1) and sensor (\dot{Q}_2) is determined by the expressions:

$$\dot{Q}_1 = C_1 \cdot \frac{d(\Delta T_1)}{dt}, \quad (6)$$

$$\dot{Q}_2 = C_2 \cdot \frac{d(\Delta T_2)}{dt}. \quad (7)$$

Since it is objective to assume $\dot{Q}_1 \gg \dot{Q}_2$, then from Eq. (5) follows $\dot{Q} \approx \dot{Q}_1$. Considering the above, the system of Eqs. (3) - (7) which describes the temperature transient is simplified to the form:

$$\Delta T - R_1 C_1 \cdot \frac{d(\Delta T_1)}{dt} - \Delta T_1 = 0, \quad (8)$$

$$\Delta T_1 - R_2 C_2 \cdot \frac{d(\Delta T_2)}{dt} - \Delta T_2 = 0. \quad (9)$$

By introducing substitutions $\tau_1 = R_1 C_1$ and $\tau_2 = R_2 C_2$ that have the physical meaning of the thermal time constants of the probe and sensor and applying the Laplace transform while setting the initial conditions to zero, the transfer function is obtained:

$$H(s) = \frac{\Delta T_2(s)}{\Delta T(s)} = \frac{1}{(1 + \tau_1 \cdot s) \cdot (1 + \tau_2 \cdot s)}. \quad (10)$$

Using the obtained transfer function, the temperature response can be determined for any excitation waveform:

$$\Delta T_2(s) = \Delta T(s) \cdot H(s). \quad (11)$$

For a sudden, sharp change in excitation, which corresponds to the momentary immersion of the probe in a liquid substance with an overtemperature ΔT , the excitation is described by a step function:

$$\Delta T(t) = \Delta T \cdot u(t) = \begin{cases} 0, & 0 < t, \\ \Delta T, & t \geq 0. \end{cases} \quad (12)$$

Where $u(t)$ is the Heaviside step (so-called unit) function [7]. Taking the Laplace transform of the previous expression gives:

$$\Delta T(s) = \frac{\Delta T}{s}. \quad (13)$$

Combining the Eqs. (10) - (13) gives an expression for the Laplace transform for the response i.e. sensor overtemperature:

$$\Delta T_2(s) = \Delta T \cdot \frac{1}{s \cdot (1 + \tau_1 \cdot s) \cdot (1 + \tau_2 \cdot s)}. \quad (14)$$

Applying the inverse Laplace transform [7] to the previous expression gives:

$$\Delta T_2(t) = \Delta T \cdot \left[1 + \left(\frac{\tau_1}{\tau_2 - \tau_1} \cdot e^{-\frac{t}{\tau_1}} - \frac{\tau_2}{\tau_2 - \tau_1} \cdot e^{-\frac{t}{\tau_2}} \right) \right]. \quad (15)$$

Substituting Eq. (15) into Eq. (2) gives:

$$T_2(t) = T_a + \Delta T \cdot \left[1 + \left(\frac{\tau_1}{\tau_2 - \tau_1} \cdot e^{-\frac{t}{\tau_1}} - \frac{\tau_2}{\tau_2 - \tau_1} \cdot e^{-\frac{t}{\tau_2}} \right) \right]. \quad (16)$$

Eq. (16) is an exact expression that describes the transient phenomenon of temperature change of the temperature sensor and enclosures around it. However, this expression is not practical for determining temperature time constants. At the same time, the influence of the time constants on the waveform of the temperature change is not intuitive. For this reason, it is more convenient to find a simpler and satisfactorily accurate function that describes the change in the sensor's temperature. Two approximations are typically used for this purpose. Both approximations refer to the system that is overdamped, i.e. without oscillations, such as the system analysed in this article.

If the description of the system is not critical, then a very rough approximation can be applied. That is, a second-order system can be approximated by a first-order system (FO) [2]:

$$T_2(t) \approx T_a + \Delta T \cdot \left(1 - e^{-\frac{t}{\tau'}} \right), \quad (17)$$

where τ' is equivalent thermal time constant.

If greater accuracy is required, the approximation of the second-order transfer function with the first-order transfer function plus dead time (FOPDT) can be applied. According to the approximation proposed by Sigurd Skogestad [8], a second order system that is overdamped, i.e. without oscillation, can be approximated as a first order system plus dead time (time delay) [8]:

$$\frac{1}{(1 + \tau_1 \cdot s) \cdot (1 + \tau_2 \cdot s)} \approx \frac{e^{-t_d \cdot s}}{s \cdot \tau + 1}, \quad (18)$$

Where are the time constant τ and dead time (time delay) t_d specified by expressions [8]:

$$\tau = \tau_2 + 0.5 \cdot \tau_1, \quad (19)$$

$$t_d = 0.5 \cdot \tau_1. \quad (20)$$

This method is applicable as long as the time constants differ by a factor greater than 1.5 [8]. Inserting Eq. (18) into the Eq. (11) gives:

$$\Delta T_2(s) = \Delta T \cdot \frac{1}{s \cdot (1 + \tau_1 \cdot s) \cdot (1 + \tau_2 \cdot s)} \approx \Delta T \cdot \frac{1}{s} \cdot \frac{e^{-t_d \cdot s}}{s \cdot \tau + 1}. \quad (21)$$

Applying the inverse Laplace transform [7] to the previous expression gives an expression for the overtemperature in the time domain:

$$\Delta T_2(t) = \Delta T \cdot \left(1 - e^{-\frac{(t-t_d)}{\tau}} \right) \cdot u(t-t_d). \quad (22)$$

Where $u(t-t_d)$ is the delayed Heaviside step function [7]. Combining Eq. (2) with Eq. (22) gives:

$$T_2(t) = T_a + \Delta T \cdot \left(1 - e^{-\frac{(t-t_d)}{\tau}} \right) \cdot u(t-t_d). \quad (23)$$

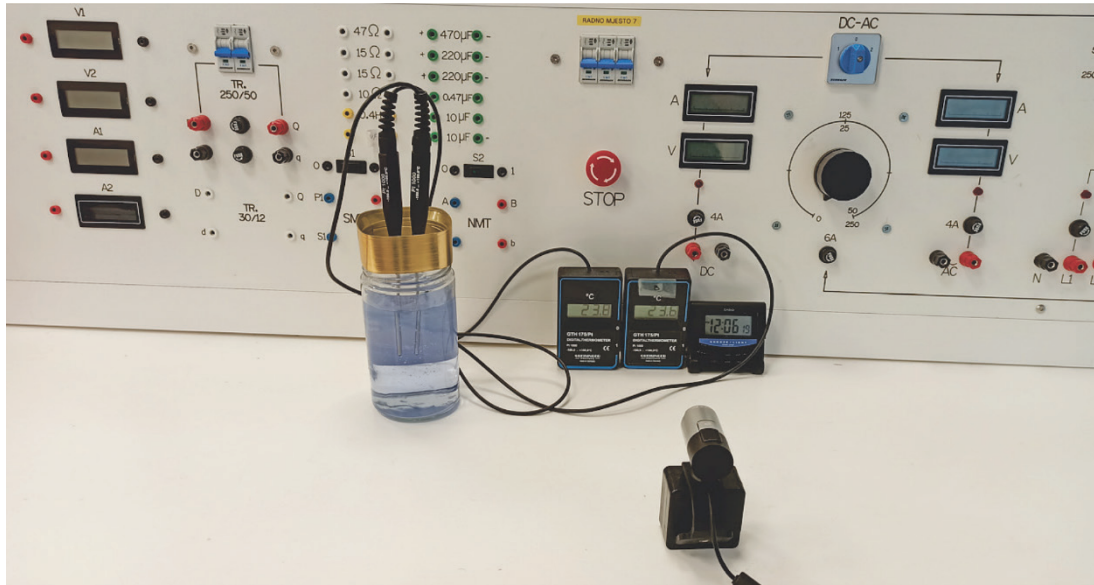


Figure 5 Photo of the measuring setup. Thermometer with resistance temperature sensor, container with heated water and camera for recording transient phenomena.

5 MEASUREMENT RESULTS AND DISCUSSION

The measurement of the temperature response was carried out for a sudden change (step change) in temperature. This was achieved by immersion probes being suddenly immersed in pre-heated water. In order for the recorded graphs to be smooth, two thermometers were used simultaneously (Fig. 5 [9]). The measurements were carried out using GTH 175 PT1000 thermometers with RTDs [10]. The measured values were recorded with a web camera and transferred from the video to an excel file for further processing. Model-based parameters were determined using the Mathcad 14 program [11]. For this purpose, the method of least squares was applied [7]. The obtained parameter values correspond to those that minimize the error between the model function and the measured values (Tab. 1). Temperature responses of the thermometer for different overtemperatures are shown in Fig. 6 [9].

According to the data in Tab. 1, certain trends are noticeable. By increasing the overtemperature ΔT , the time delay decreases t_d , also the time constant τ_1 , which is related to it by the expression, $\tau_1 = 2t_d$ decreases, the time constant τ

decreases, and the thermal time constant τ_2 remains constant. The obtained results are consistent with the theoretical prediction.

Table 1 Table title aligned centre

ΔT (K)	4.15	8.65	11.10	15.25	20.38
t_d (s)	0.526	0.431	0.332	0.306	0.228
τ (s)	1.848	1.763	1.675	1.599	1.532
$\tau_1 = 2t_d$	1.052	0.862	0.665	0.612	0.457
$\tau_2 = \tau - \tau_1/2$	1.322	1.332	1.342	1.293	1.304

*The average value of the thermal time constant τ_2 is $\bar{\tau}_2 = 1.3186 \text{ s} \approx 1.3 \text{ s}$

According to the theory of heat transfer [12], an increase in overtemperature causes an increase in the heat convection coefficient. By increasing the convection coefficient, the thermal resistance caused by heat convection R_1 is decreasing [12]. Given that C_1 has a constant value for metals (immersion probe), and taking into account that the thermal time constant is determined by the product of the thermal resistance and the thermal capacity C_1 , i.e. $\tau_1 = R_1 C_1$, the time constant τ_1 decreases as the resistance R_1 decreases, the thermal time constant τ_2 remains constant because it is determined by the product $\tau_2 = R_2 C_2$ in which both values are

constant. Namely, the thermal resistance R_2 due to heat conduction is constant, as well as the thermal capacity of the sensor C_2 .

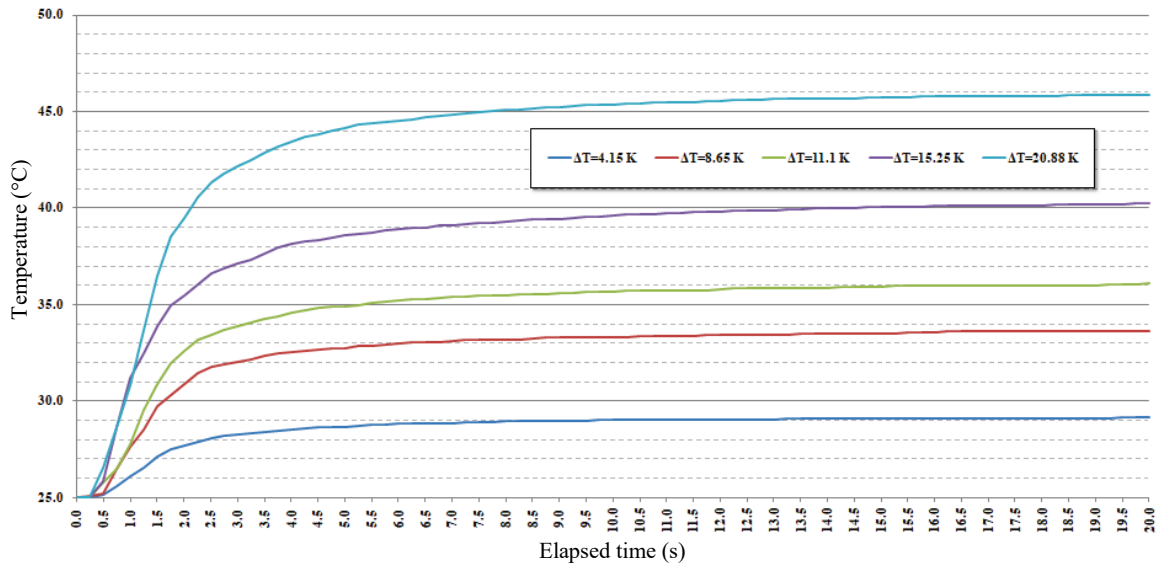


Figure 6 Temperature responses (instrument readings) of PT1000 thermometer to a sudden change (step change) in the measured temperature

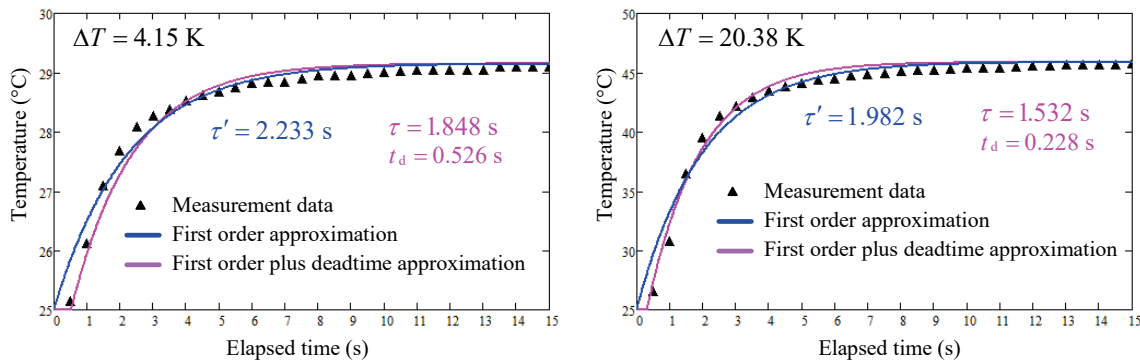


Figure 7 Measured temperature response of PT1000 thermometer to a sudden change in the measured temperature and response approximations

6 RECAPITULATION ANNOTATION

Automating the management of industrial processes in real time requires knowledge of the actual temperatures in real time. For this purpose, it is important to know the dynamic characteristics of thermometers. The paper presents a relatively simple, but for many applications acceptably accurate model by which electric thermometers can be modelled. Also, the paper presents one of the procedures that can be used for determining the parameters of such models. Although the selected example in the paper refers to a laboratory instrument, where the immersion probe has a relatively small diameter, and therefore a small thermal mass, i.e. time constant, the presented procedure is also applicable for industrial applications when thermowells are used. In that case, significantly longer time delays can be expected, i.e. the importance of their consideration is greater. Given that the fluid convection coefficient depends on the type of fluid and the temperature of the fluid, the following recommendations are given. We recommend that, if possible, the procedure for determining the dynamic parameters of the thermometer uses the fluid that is present at the place of installation of the

thermometer. We also recommend determining the dynamic parameters in the temperature range expected in the process where the thermometer will be installed.

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Soil Erosion Susceptibility Prediction Using GIS-Based Multicriteria Analysis and Worldview-3 Satellite Images

Ante Šiljeg, Mladen Jurišić, Ivan Marić, Fran Domazetović, Dorijan Radočaj*

Abstract: Soil erosion has been identified as a major threat to existing soil deposits, which negatively affects ecosystem sustainability, agricultural production and clean water supply. This study covered the eastern part of Kaštela Bay with the aim of developing a model of susceptibility to soil erosion by applying the GIS-based multicriteria analysis, based on nine determinant criteria categorized by the Jenks method in five classes. The largest representation of soil erosion susceptibility was detected on the slopes of the Kozjak and Mosor massifs. According to the calculated weighting coefficients using the analytic hierarchy process (AHP), the slope was the most impactful criterion with 29.9 % importance. It was followed by hydrological criteria of topographic wetness index, standardized precipitation index and LS-factor, with 13.1 % importance each. After the development of the model, zones of very high and high susceptibility to soil erosion were delineated, with a combined coverage of 33.34 % of the study area. These areas were identified as a potential threat from the future occurrence of negative effects of soil erosion, which should be addressed in the future by land policy managers and government managers.

Keywords: analytic hierarchy process (AHP); digital elevation model; GAMA method; GIS-based multicriteria analysis; soil erosion

1 INTRODUCTION

Soil erosion is a process of gradual degradation and denudation of surface soil layers, which globally causes long-term reductions in agricultural productivity and significant financial losses [1]. It has been identified as a major threat to existing soil deposits, which negatively affects ecosystem sustainability, agricultural production and clean water supply [2]. Although soil erosion is a natural process, rapid climate change (desertification, extreme rainfall, heat waves) and various anthropogenic pressures (deforestation, overgrazing, inappropriate agricultural practices and tillage) recently intensified and expanded the spatial scope of this process [1]. Historical sources from different parts of the world noted that soil erosion was present throughout almost the entire Holocene, and that climate change and anthropogenic effects gradually became the main propagators of this process. Land use has a significant impact on the geomorphological stability of the slope and the emergence of various slope processes. Improper land use, such as excessive deforestation or livestock valorization of a particular area, can significantly accelerate the natural process of soil erosion [3]. Resistance to wear processes is related to vegetation cover and the approach a particular location is utilized. Vegetation cover has a diminishing effect on the susceptibility of a particular terrain to soil erosion, as it reduces the erosive ability of surface runoff [4].

According to the average rate of soil loss, Croatia is among the most endangered countries of the European Union [2]. However, some parts of Croatia are significantly more vulnerable and endangered than the soil erosion process due to different micro-location characteristics, with very high values of the average loss rate. Particularly high values of the average rate of soil loss are present in the coastal area. The development of a model of susceptibility to soil erosion is the basis for planning measures to limit and adapt to further negative consequences of the soil erosion process. With the application of GIS-based multicriteria decision analysis

(GIS-MCDA), it is possible to develop a model of soil susceptibility to soil erosion according to appropriate predisposing criteria, such as slope, aspect, planar and profile curvature. Due to the pronounced influence of slope on the evolution of relief, it has a decisive role in the development of a model of susceptibility to soil erosion [4]. The terrain aspect can indirectly affect the intensity of soil erosion, determining the effects of climatic factors, such as sunshine duration, precipitation intensity, humidity, wind exposure and conditions the development of vegetation cover [4]. Terrain curvature affects the soil-water interaction during surface runoff, but also the rate of water runoff down the slope [5].

The aim of the research is to develop a model of susceptibility to soil erosion of the wider eastern part of Kaštela Bay through the application of GIS-MCDA and to identify areas of a potential threat from the future occurrence of negative effects of soil erosion.

2 MATERIALS AND METHODS

The study area covers a wider eastern part of the Kaštela Bay, which is historically among the most susceptible areas to soil erosion in Croatia (Fig. 1). The development of a model of susceptibility to soil erosion was carried out through the application of GIS-MCDA. Its application in soil erosion modeling consisted of six steps, three of which are automated using the GIS automated multicriteria analysis (GAMA) method [6]. GIS-MCDA analysis was performed based on nine determinant criteria and zones with different susceptibility to soil erosion were selected. The resulting zones were categorized by the Jenks natural breaks classification method in five classes, minimizing deviation of values within the class according to class mean (very low, low, medium, high and very high susceptibility).

Criteria extracted from the digital elevation model (DEM) were divided into primary and secondary morphometric parameters. As the input in GIS-MCDA, the

following primary morphometric parameters were singled out: slope, aspect, planar and profile curvature. The three secondary parameters representing hydrological effects were topographic wetness index, standardized precipitation index, specific watersheds, and one morphometric secondary parameter (LS-factor). Figs. 2 and 3 display selected primary and secondary criteria for GIS-MCDA susceptibility to soil erosion.

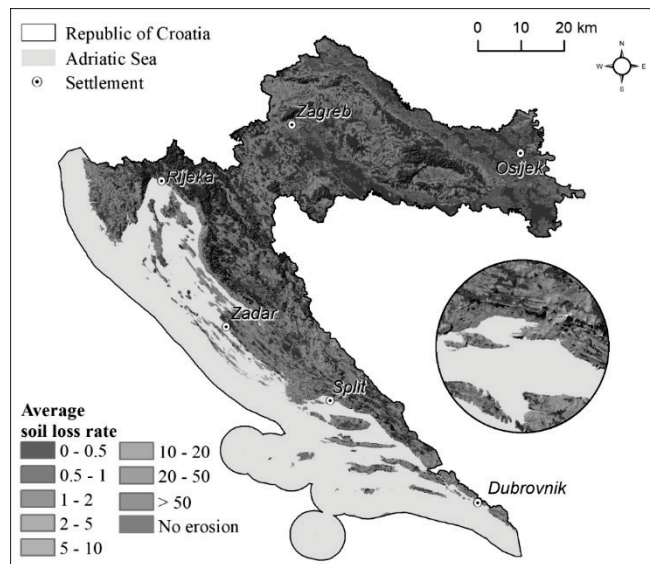


Figure 1 Study area with average annual soil loss rate in Croatia, based on data from Panagos et al. (2015) and ESDAC (2020)

The digital surface model (DSM) is created from the provided WV-3 stereo images in the OrthoEngine 2018 extension of the Geomatica 2018 software. DSM was created in the OrthoEngine extension is divided into selecting a mathematical model, adding orientation and control points needed for the orientation of stereo images, automatically adding of tie points, adjusting the model (bundle adjustment), making an epipolar image, automatically creating a DSM, and manual error filtering. Optical Satellite modeling based on assigned rational polynomial coefficients (RPC) and zero-order polynomial adjustment was selected as the most commonly used mathematical models for DSM creation from WV stereo images [7].

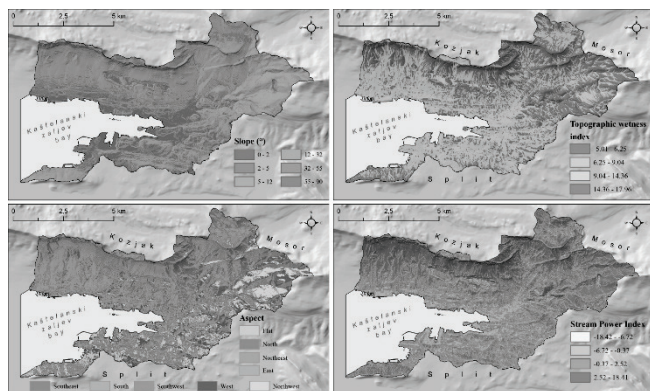


Figure 2 Selected primary criteria for GIS-MCDA susceptibility to soil erosion

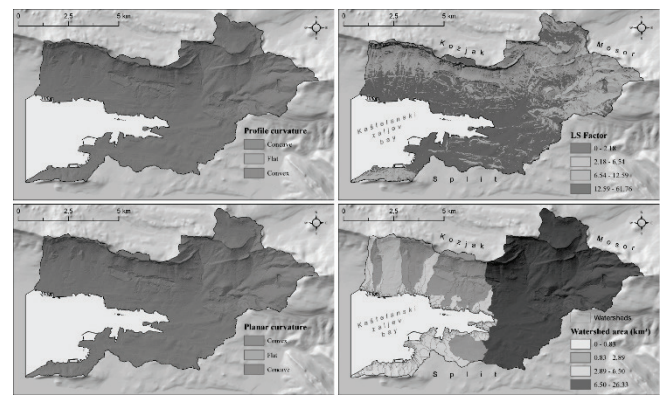


Figure 3 Selected secondary criteria for GIS-MCDA susceptibility to soil erosion

Field orientation points with precise coordinates for DSM georeferencing were collected on May 12, 2020 with *Stonex S10* real-time-kinematic (RTK) global navigation satellite system (GNSS) receiver, at 13 different locations distributed throughout the research area. The method of semi-global matching of DSM was used. Automatic DSM correction to digital terrain model (DTM) was performed by Geomatica 2018 software using the DSM2DTM algorithm, which allowed automatic DSM filtering according to defined user-defined parameters. After automatic conversion by manual filtering, all remaining errors which arose from the automatic filtration process were removed.

By standardizing the selected GIS-MCDA criteria, all input values are transformed to an equal numerical scale through a process of criteria standardization [8]. The used nine criteria were standardized on a numerical scale of 1–5 using the GAMA method, so that value of 1 was assigned to the least suitable class, while the value of 5 was assigned to the most suitable class per criterion. The Boolean criteria were assigned with binary values of 0 or 1. The analytic hierarchy process (AHP) was used for weight determination of input criteria, which allowed the subjectivity and consistency of weight coefficients to be verified through a consistency ratio (CR) [9]. The aggregation of standardized criteria values and their respective weighting coefficients was performed using the weighted linear combination.

3 RESULTS AND DISCUSSION

The susceptibility model to soil erosion was performed in six steps through the application of GIS-MCDA in ArcGIS software. Susceptibility to soil erosion according to the representation of individual classes is shown in Tab. 1. According to the results of the representation of individual classes of susceptibility to soil erosion in Tab. 1, it was observed that the Boolean criterion occupies the largest area. The Boolean criterion includes all permanent water surfaces as well as all urban and industrially built areas, in which due to anthropogenic modifications of the terrain, soil erosion cannot occur. These areas are excluded from the GIS-MCDA of soil erosion susceptibility as areas with no probability of soil erosion, with a weighting factor of zero. An overview of the AHP pairwise comparison matrix is shown in Tab. 2, and the calculated weighting coefficients are shown in Tab. 3.

Table 1 Representation of individual classes of susceptibility to soil erosion

Susceptibility class	Area (km ²)	Share (%)
Boolean	20.12	27.58
Very low	6.98	9.56
Low	9.94	13.62
Medium	11.61	15.91
High	14.98	20.52
Very high	9.35	12.81

Table 2 Pairwise comparison matrix of criteria within the AHP

Criterion	SLO	TWI	SPI	LSF	ASP	LULC	PROF	PLAN	WAT
SLO	1	3	3	3	3	4	6	6	9
TWI		1	1	1	2	2	3	3	6
SPI			1	1	2	2	3	3	6
LSF				1	2	2	3	3	6
ASP					1	3	5	5	6
LULC						1	3	3	6
PROF							1	1	3
PLAN								1	1
WAT									1

SLO: slope, ASP: aspect, PLAN: planar curvature, PROF: profile curvature, TWI: topographic wetness index, SPI: standardized precipitation index, WAT: specific watersheds, LSF: LS-factor

Table 3 Weighting coefficients representing the impact of individual criteria on soil erosion susceptibility calculated within the AHP

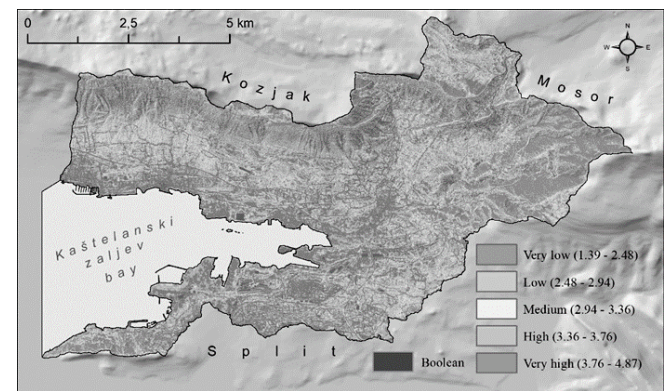
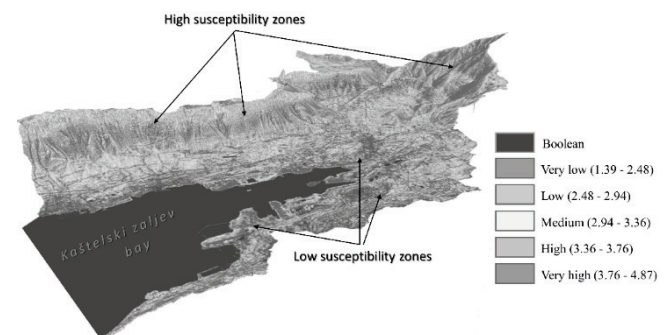
Criterion	Weighting coefficient	Share (%)
SLO	0.299	29.9
TWI	0.131	13.1
SPI	0.131	13.1
LSF	0.131	13.1
ASP	0.125	12.5
LULC	0.082	8.2
PROF	0.041	4.1
PLAN	0.041	4.1
WAT	0.019	1.9

SLO: slope, ASP: aspect, PLAN: planar curvature, PROF: profile curvature, TWI: topographic wetness index, SPI: standardized precipitation index, WAT: specific watersheds, LSF: LS-factor

According to the results in Tab. 3, the largest percentage is occupied by terrain slope, which according to Wilson and Gallant [10] directly affects the intensity of various denudation processes. Due to the pronounced influence of slope on the evolution of relief, the slope criterion has a decisive role in the development of a susceptibility model to soil erosion [4]. The second factor that had the greatest impact on soil erosion susceptibility was the aspect, as it indirectly affects soil erosion intensity and determines the susceptibility to climatic factors [11]. Among the lower impacts, the profile and planar curvature of the slope were observed, since on convex slopes the surface runoff slows down and the transport capacity weakens. Specific watersheds had the least impact on soil erosion. The consistency of pairwise comparison matrix in AHP was checked through a CR of 0.046. Based on the developed model of susceptibility to soil erosion of the wider eastern part of the Kaštela Bay (Fig. 4), zones of a potential threat from the future occurrence of negative effects of soil erosion have been identified.

As displayed in the developed susceptibility model within the wider eastern part of Kaštela Bay, very high and

high zones of susceptibility prevail, covering 33.34 % of the total study area. Their dominant concentration was detected on the slopes of the Kozjak and Mosor massifs. On these slopes, water runoff occurs from a larger area, where in some locations there may be a gradual formation of more pronounced surface runoff and soil erosion. This is in line with the observations of Valentin et al. [3], where the velocity and erosive force of runoff increased according to the increase in slope. This area is also affected by the recent intensive urbanization, but also by agricultural valorization and exploitation of mineral raw materials for cement production, such as exploitation field "St. Juraj - St. Kajo" [12]. These anthropogenic factors affect the acceleration of the natural intensity of soil erosion, contributing to an increase in susceptibility to the emergence of new erosion zones [13]. Low and very low susceptibility to soil erosion are also present on bare slopes in the peak zone of Kozjak and Mosor, where the configuration of the relief prevents the formation of more prominent surface runoff. Zones of very low susceptibility cover a total of 6.98 km² (9.56% of the total area), while zones of low susceptibility cover 9.94 km², or 13.62% of the total area of the study area. The coastal area is generally a flat and densely populated area, where susceptibility to soil erosion is very low. A large part of this area is covered by anthropogenic substrates like concrete or asphalt, which prevent soil erosion. The zone of medium susceptibility to soil erosion covers 15.91% of the total area of the research area, which mainly refers to the transition area between the flat coastal area and the steeper slopes of Kozjak and Mosor.

**Figure 4** Susceptibility model to soil erosion of the wider eastern part of the Kaštela Bay**Figure 5** Three-dimensional representation of the soil erosion susceptibility model

Based on the 3D representation of the developed susceptibility model to soil erosion (Fig. 5), it can be further confirmed that most of the zones of greatest susceptibility to soil erosion are located on the slopes of Kozjak and Mosor. In addition, it is evident that the zones of least susceptibility to soil erosion are located mainly in the area of flat coastal areas. This points out to the possibility of improper land use, caused by anthropogenic activities of deforestation or livestock valorization, which can significantly accelerate the natural process of soil erosion. Conversely, the importance of digital soil mapping for other biochemical and physical properties [14] and infiltration modelling [15] arouse, aiding land policy managers in more sustainable management.

4 CONCLUSIONS

Based on the developed susceptibility model to soil erosion using GIS-MCDA of the wider eastern part of Kaštela Bay, potential zones of threat from the future occurrence of negative effects of soil erosion have been successfully identified. The slope had the largest impact on soil erosion and occupied the largest area of the study area, while the specific watersheds had the smallest impact. The developed model of susceptibility within the investigated area is primarily affected by zones of very high and high susceptibility to soil erosion, which together covers 33.34 %. By making a 3D representation of the susceptibility to soil erosion, it was determined that most of the zones with the greatest susceptibility to soil erosion are located on the slopes of Kozjak and Mosor. Zones of the least susceptibility to soil erosion were observed mainly in the area of flat coastal areas, which should be addressed in the future by land policy managers and government managers. These findings not only contribute to a comprehensive understanding of soil erosion dynamics in the region but also provide valuable information for effective land management and conservation strategies to mitigate the impending environmental challenges associated with soil erosion.

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The Impact of Human Resource Planning on Strategic Goals of Companies

Akram Hemmati*, Hossein Adab

Abstract: Today's world, especially the world of companies, is undergoing significant and continuous changes and transformations. All dimensions of companies, from internal to external environments, from human to non-human factors, are rapidly transitioning from one state to another. In today's competitive world, one of the important tools for creating transformation, ensuring the survival of a company, and achieving desired goals and missions is the human element. This research aims to examine the impact of human resource planning on the strategic goals of the company (case study: Exon Group). The research population includes all employees of Exon Group in Tehran, totalling 360 individuals. Structural equation modelling was used to test the hypotheses, and the software used in this study includes SPSS version 22 and Smart PLS version 2. The research findings indicate that human resource planning has a significant impact on the strategic goals of the company.

Keywords: human resource planning; strategic goals of the company

1 INTRODUCTION

Human resources are considered the key to achieving the company's goals in every organization and provide new ideas for innovation and prosperity in production. Human resources enhance the performance of the company and play a fundamental role in creating continuous competitive advantage and increasing productivity. In a time when human resources are valued and considered the most strategic resource of companies, and when other company resources and even advanced technologies are deemed incapable without the presence of knowledgeable human resources, companies face numerous challenges in attracting and retaining competent employees with various skills and expertise [1].

Human resource management in project-based organizations is a relatively unfamiliar subject that can serve as the foundation for organizational success and competitive advantage. Axon Group, as a contractor in the field of construction and technical and mechanical installations, is not exempt from this rule and requires the implementation of a human resource management approach that supports this unique structure. Human resource management in this company is approached as a multifaceted perspective [2].

It encompasses the set of processes required for the effective utilization of the personnel involved in project execution, including supervisors, workers, executives, experts, and labourers. Given the increased competition in the job market, rising costs of human resources, and the dynamics and complexity of changes, the lack of proper efficiency in human resources can lead to significant costs and project failures [3].

Therefore, investigating this issue is essential. In light of the aforementioned points, the objective of this research is to examine the impact of human resource planning on the strategic objectives of the company (case study: Axon Group)

2 THEORETICAL FOUNDATIONS AND A REVIEW OF BACKGROUND LITERATURE

Literature and research background: In the competition of the 21st century, where traditional competitive mechanisms are less effective, companies are constantly searching for newer resources of competitive advantage, and one of the most crucial resources is human resource management. In agile organizations, human resources are the primary source of productivity. Today, human resource units within organizations have gained special importance. These units play the most strategic roles within the organization. Strategic human resource management refers to all activities that effectively influence individuals' behaviour in designing and implementing the organization's strategic needs [4, 5].

In the field of the subject of this article, various research has been conducted, including the following: Javanmardi and Hamkaran (2019) investigated "Explaining the ISM method for determining strategic objectives and increasing the performance of strategic management for organizations to achieve agility." The results showed that managers can accurately determine their strategic objectives and define the path and method of achieving them using this information. Hopefully, the results of this study will prove beneficial. Mohammadi (2018) examined "The relationship between employees' individual goals and the achievement of strategic objectives in Isfahan Iron Melting Company." The results of descriptive and inferential data analysis based on the Pearson correlation coefficient and regression showed a relationship between employees' individual goals and the achievement of strategic objectives in the organization [6].

The researchers and colleagues (2017) examined the "Human Resource Planning Process." Their findings indicated that considering the role and importance of human resources in organizational development and success, human resource planning can play an effective role in achieving efficient and desirable human resource utilized [7].

Dabaron and Venderila (2019) investigated the "Evaluation of the Impact of Human Resource Planning Programs on Strategic Objectives of Companies: Organizational Outlook". The results showed that human

resource planning, including workforce planning and succession planning, yielded better results in achieving strategic objectives of the company. Succession planning, employee programs, and talent management strategies enhanced the efficiency of the company. Job analysis and design had no significant impact on achieving strategic objectives of the organization. [8, 9]

Akhar and colleagues (2017) examined "Knowledge Management and Human Resource Planning Systems: Complementary or Contradictory?" The results showed that human resource planning had no positive effect on operational performance but had a precedence over knowledge management. Additionally, the results demonstrated that knowledge management had a positive impact on operational performance, acting as a mediator between the relationships of human resource planning and operational performance. Finally, path analysis revealed a positive relationship between operational performance and financial performance. [10]

Pedro Rovio (2017) explored "Organizational Resource Planning and the Value of Customer Relationship Management". The results indicated that human resource planning systems were a valuable asset for business value, but it was found that the impact of customer relationship management systems on business value was not significant. The integration of systems as an intermediary between human resource planning and customer relationship management was not prominently visible, but it had a positive and noticeable impact on business value. [11]

3 RESEARCH METHODOLOGY

The present research aims to investigate the "Impact of Human Resource Planning on Strategic Objectives of the Company (Case Study: Axon Group)". Therefore, the research methodology employed is practical.

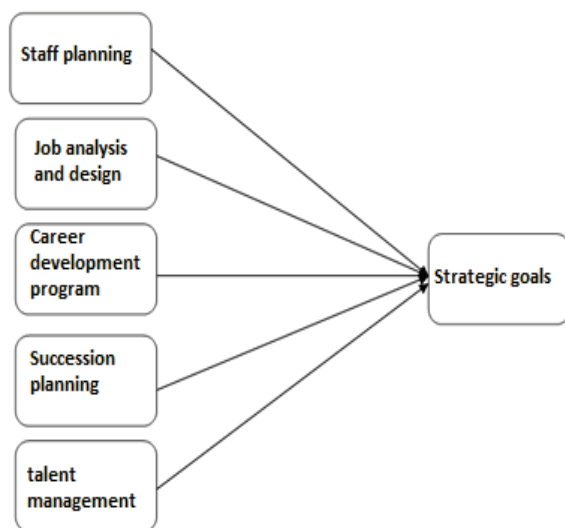


Figure 1 Conceptual Model of the Research

The main objective of this research is to examine the impact of human resource planning on the strategic

objectives of the company. Based on this objective, the following hypotheses have been considered:

- Human resource planning has a significant impact on the strategic objectives of the company.
- Workforce planning has a significant impact on the strategic objectives of the company.
- Job analysis and design have a significant impact on the strategic objectives of the company.
- Career development programs have a significant impact on the strategic objectives of the company.
- Succession planning has a significant impact on the strategic objectives of the company.
- Talent management has a significant impact on the strategic objectives of the company.

These hypotheses will be tested using appropriate data analysis techniques and statistical tools. The research methodology will involve collecting relevant data, conducting interviews or surveys, and analysing the gathered information to draw meaningful conclusions.

4 RESULTS AND ANALYSIS

This article utilizes descriptive and inferential statistical analysis to analyse questionnaire data. Descriptive statistics include frequency tables, means, standard deviations, and variances. For inferential statistics, a structural equation modelling (SEM) approach is used to test hypotheses. The software used for data analysis includes SPSS version 22 and SmartPLS version 2 [12].

In order to employ parametric statistical techniques, the distribution of variables should be normal, which is tested using the Kolmogorov-Smirnov test. Based on Tab. 1, which relates to the Kolmogorov-Smirnov test, it can be observed that the obtained significance level for each variable is higher than 0.05. As a result, the null hypothesis is accepted. Therefore, the research variables in the examined sample have a normal distribution. Hence, parametric methods can be used to investigate the research hypotheses.

H0: Research variables have a normal distribution.

H1: Research variables do not have a normal distribution.

Table 1 Kolmogorov-Smirnov test

Variables	Quantity	Significance Level
Strategic Objectives	186	0.645
Employee Planning	186	0.000
Analysis and Design	186	0.317
Job Development Program	186	0.148
Succession Planning	186	0.209
Talent Management	186	0.264

By using this approach, it is possible to determine the significance of the relationship between research variables. In this case, meaningful numbers will be those that fall outside the range (1.96 and -1.96). This means that if a value in the t-test falls between 1.96 and -1.96, it will be considered insignificant [13].

The results obtained from the application of inferential methods in the form of structural equation models are presented [14, 15].

Employee Planning has a significant impact on strategic objectives. Based on the research model with significant

numbers, it can be observed that the t-statistic between the variable Employee Planning and strategic objectives is equal to 2.480. Since this value falls outside the range [1.96 and -1.96], this hypothesis is confirmed [16].

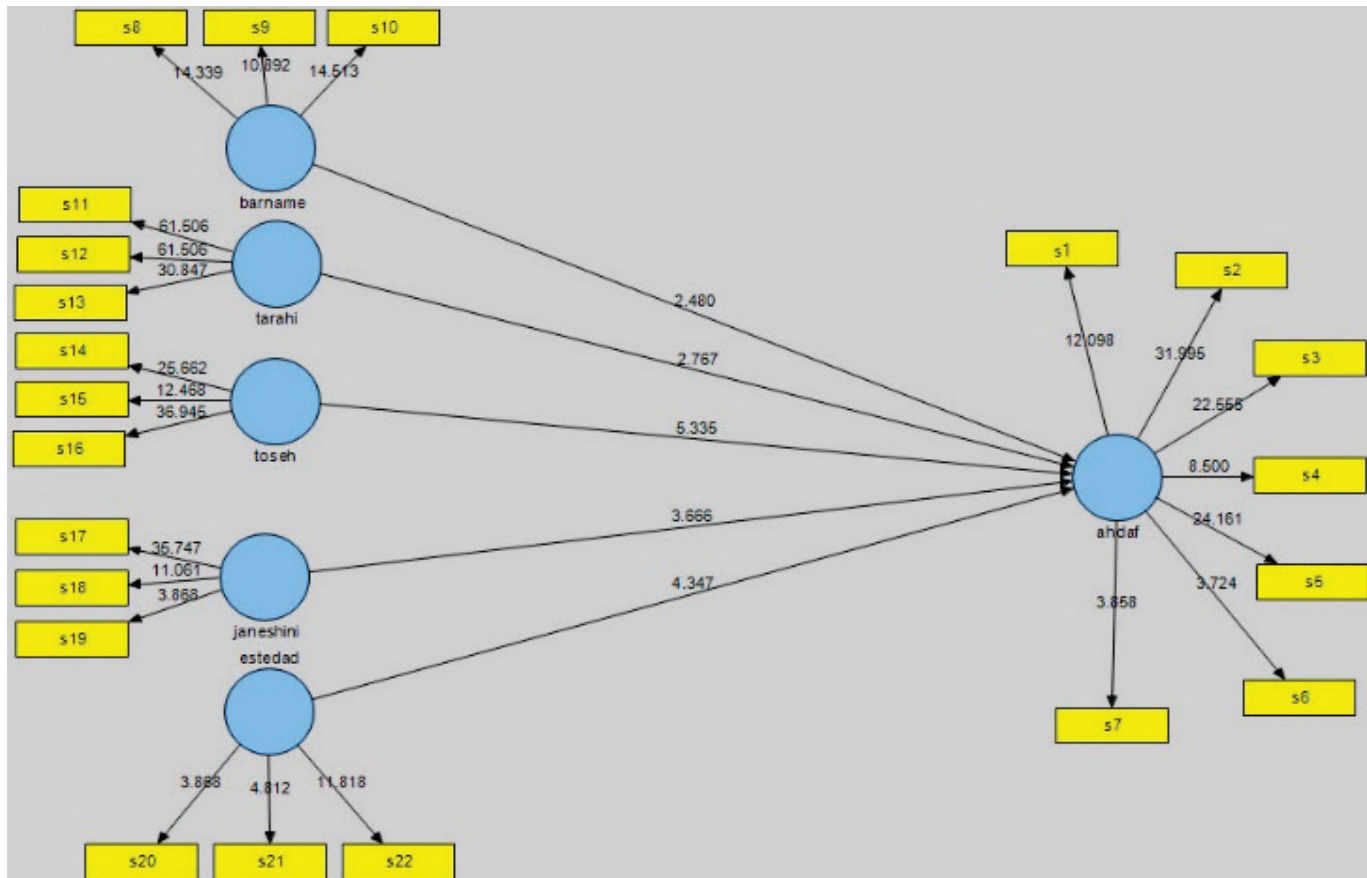


Figure 2 Research Model Test (Significant Numbers)

Job Analysis and Design has a significant impact on strategic objectives. Based on the research model with significant numbers, it can be observed that the t-statistic between the variable Job Analysis and Design and strategic objectives are equal to 2.767. Since this value falls outside the range [1.96 and -1.96], this hypothesis is confirmed [17].

Job Development Program has a significant impact on strategic objectives. Based on the research model with significant numbers, it can be observed that the t-statistic between the variable Job Development Program and strategic objectives is equal to 5.335. Since this value falls outside the range [1.96 and -1.96], this hypothesis is confirmed [18, 19].

Succession Planning has a significant impact on strategic objectives. Based on the research model with significant numbers, it can be observed that the t-statistic between the variable Succession Planning and strategic objectives is equal to 3.666. Since this value falls outside the range [1.96 and -1.96], this hypothesis is confirmed [20].

Talent Management has a significant impact on strategic objectives. Based on the research model with significant numbers, it can be observed that the t-statistic between the variable Talent Management and strategic objectives is equal

to 4.347. Since this value falls outside the range [1.96 and -1.96], this hypothesis is confirmed [21].

5 CONCLUSION

The hypothetical results of the present study are summarized below:

Hypothesis 1: Employee planning has a significant impact on the strategic goals of the company. Partial least squares analysis results showed that employee planning has a statistically significant impact on strategic goals with a path coefficient of 79.7%.

Hypothesis 2: Job analysis and design have a significant impact on the strategic goals of the company. Partial least squares analysis results showed that job analysis and design have a statistically significant impact on strategic goals with a path coefficient of 85.3%.

Hypothesis 3: Job development programs have a significant impact on the strategic goals of the company. Partial least squares analysis results showed that job development programs have a statistically significant impact on strategic goals with a path coefficient of 48.9%.

Hypothesis 4: Succession planning has a significant impact on the strategic goals of the company [22]. Partial least squares analysis results showed that succession planning has a statistically significant impact on strategic goals with a path coefficient of 74.7%.

Hypothesis 5: Talent management has a significant impact on the strategic goals of the company. Partial least squares analysis results showed that talent management has a statistically significant impact on strategic goals with a path coefficient of 42.4%. Based on the results obtained from the data analysis, the following actionable recommendations can be proposed [23]:

Having a business plan that defines the scope, advantages, resources, costs, risks, and time frame of the proposed strategies is crucial and mandatory. This will focus individuals on the benefits of the work. There should be a clear and explicit model to determine how the organization should operate behind the implementation efforts. Having a suitable business plan simplifies the work and affects the implementation of the project [24].

Recognizing individual differences (people have different characteristics, and they should not all be treated the same) [25].

Performance evaluation should focus on determining and measuring individuals' performance and the process of carrying out the work, rather than relying on personal attributes and qualities [26].

Employees and members of the organization should have clear goals, and the performance outcomes resulting from their actions towards those goals should be presented to them.

Pay attention to the importance of strategic planning in the organization, and the development of an appropriate strategy, employing organizational factors such as knowledge management and considering it in the planning process. Organizations need to understand how to utilize knowledge as a valuable and strategic resource for excellence and success [27].

Strategic human resource activities within long-term programs create the necessary platform and environment for the emergence, promotion, and encouragement of creative thinking among employees and managers.

To strengthen strategic human capital within the organization, experienced and retired individuals can be utilized as mentors, identify strategic positions within the organization, and improve this matter through continuous measurement of employees' competency levels and the use of programs.

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Classification of Garlic Varieties with Fluorescent Spectroscopy Using Machine Learning

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Abstract: Machine learning techniques can produce fast, accurate and objective results in the analysis of agricultural products. These artificial intelligence-based systems are frequently encountered in studies on agriculture in the literature. This study reveals the usability of machine learning algorithms in classification of garlic cultivars using fluorescent spectroscopic data. For this, six types of garlic were used: Razgradski-11, Razgradski-12, Razgradski-115, Plovdivski-120, Yambolski-99 and Topolovgradski. In the first stage, the parsing analysis made from the fluorescent spectroscopic data of the garlics was carried out with seven different machine learning. The classification results of these seven types of machine learning algorithms were obtained. In the second stage, the classification results were obtained by adjusting the hyperparameters of each Machine Learning (ML) algorithm in order to control the improvability of the classification accuracy rates. Finally, performance metrics such as Specificity, precision, MCC, F1-Score of the classification processes obtained in the two stages were compared. In general, it was observed that the classification performances increased with the hyperparameter adjustment performed in the second stage. In this study, classification results with ML showed that fluorescent spectroscopy data of garlic strongly represented garlic species and provided high performance classification accuracy of 99.93% with Neural Network (NN), one of the machine learning methods using these data.

Keywords: Fluorescence Spectroscopic Data; Garlic; Hyper Parameter Tuning; Machine Learning Algorithms; Performance Metrics

1 INTRODUCTION

Garlic (*Allium sativum* L.) is a cereal product rich in minerals, vitamins, protein, polysaccharides, calcium, potassium and oligosaccharides. [1]. It is a potentially medicinal agricultural product with curative, therapeutic, antibacterial and antimicrobial properties in terms of medicinal properties of humans for hundreds of years [2, 3]. In many countries, garlic is recommended to be consumed by doctors because of these properties that it has in pain relief, calming, digestive and respiratory system disorders and cardiovascular disorders [4]. More than 200 phytochemical compounds contained in garlic and essential oils obtained from garlic contribute to the vitality and health of humans [5]. It has been suggested that garlic essential oil has many potentials such as antioxidant, antimicrobial [6, 7], antibacterial [8], antiviral [9] and biological activity [5]. Garlic has been used as a natural disinfectant in poultry, to sterilize hatching eggs [10]. Due to these benefits, its production continues to increase in the world, especially in countries such as China and India. The quality of garlic may vary according to the region, climate conditions, growing environment and variety where it is grown [11]. Growing conditions can affect the chemical composition of garlic, which will affect its bioactive compound content and quality [12]. Allicin content, antioxidant capacity and total phenolic contents may be different in garlic varieties [11]. Therefore, it is important to distinguish garlic varieties in terms of cultivation and use. Classification and separation process in fluorescent spectroscopy data using machine learning methods will eliminate the difficulties that experts working in this field will experience in classifying these data [13].

Fluorescence spectrometry has recently become a widely preferred method for dealing with the authenticity and quality of various foodstuffs due to its selective and high sensitivity as well as relatively low cost [14, 15]. Fluorescent spectroscopy and hyperspectral fluorescence imaging consider two unique fingerprints to examine compounds in

foodstuffs [16]. Fluorescence spectroscopy can be used to determine the quality of plant and animal products [17]. Fluorescent spectroscopy can be used in dairy products, fruits, juices, oil, grain, etc. It is used to define, verify, classify the parameters needed in the processing, storage and storage of food products and to perform the optimization of these parameters in a non-invasive and fast way [18]. Studies using fluorescence spectrometry in the literature are examined below.

Botelho et al. (2017) suggested in their study that fluorescence spectroscopy can be used to distinguish four different coffee types grown in Minas Gerais State of Brazil [19].

Zekovic et al. (2012) used fluorescence spectroscopy for classification and analysis of cereal flours (rice, rye, corn, barley, wheat and buckwheat) to classify specified flour types by partial least squares separation analysis, principal component analysis and cluster analysis methods [20].

Karoui et al. (2007) performed fluorescence spectroscopy, principal component analysis (PCA) and factorial discriminant analysis (FDA) methods for the classification of samples of seven Swiss honey species according to their botanical origins [21].

Fang et al. (2021), in their study, proposed 4 different methods for the classification and characterization of pale lager beers grown by different manufacturers in China, using fluorescence spectroscopy data obtained in different ways. The best classification result was obtained with parallel factor analysis (PARAFAC) data fission and *k-nn* [22].

Liu et al. (2020) in their study, the accuracy of the verification and calibration sets with the partial least squares discriminant analysis (PLS-DA) algorithm was 86.96% and 92.54%, respectively, to demonstrate the usability of fluorescence spectroscopy to detect non-destructive, microbial and chemical spoilage indicators and freshness of beef. [23].

Bartolic et al. (2022) used two anti-invasive multispectral imaging (MSI) and optical fiber fluorescence

spectroscopy methods to distinguish aflatoxin B1 (AFB1) from corn seeds from uncontaminated and contaminated seeds [24].

Sabancı et al. (2022) used fluorescence spectroscopy data and machine learning algorithms to classify red onion varieties in an objective and non-destructive way [13].

Ropelewska et al. (2022) used fluorescence spectroscopy data of three different tomato species to classify yeast-inoculated and non-inoculated tomato varieties by combining them with machine learning techniques [25].

Ropelewska et al. (2022), in their study, they classified the fluorescent spectroscopy data of five different onions grown in irrigated agriculture and onions grown in dry agriculture using machine learning methods [26].

As can be seen from recent studies, fluorescent spectroscopy data is used in the classification of liquid (oil, dairy products, and fruit juices) and food products. In this study, fluorescence spectroscopic data were used for the characterization and classification of garlic. Approaches to classify spectral data obtained from six different garlics using machine learning techniques add innovation to our study. In order for the proposed models to produce optimum results, the success of the methods has increased in general by

performing hyper parameter analysis and performance metrics have been compared. Garlic producers can use recommended methods for processors to identify garlic species. This will be useful to ensure the purity of the species and to prevent mixing. The combination of machine learning and Fluorescent spectroscopy is a unique approach for objective, non-destructive and rapid differentiation of garlic species.

2 MATERIALS AND METHODS

This section presents the methods for analyzing and classifying six different garlic varieties. The block diagram of the proposed method in our study is given in figure 1. First, fluorescent spectroscopy data of garlic cultivars were obtained. Then, the data set obtained from the received data was classified by Machine Learning algorithms. In order to increase the classification accuracy, the hyperparameters of the Machine Learning methods were adjusted and reclassified. Finally, the classification performances of the models were compared. All processes are explained in detail below. The block diagram of the study is given in Fig. 1.

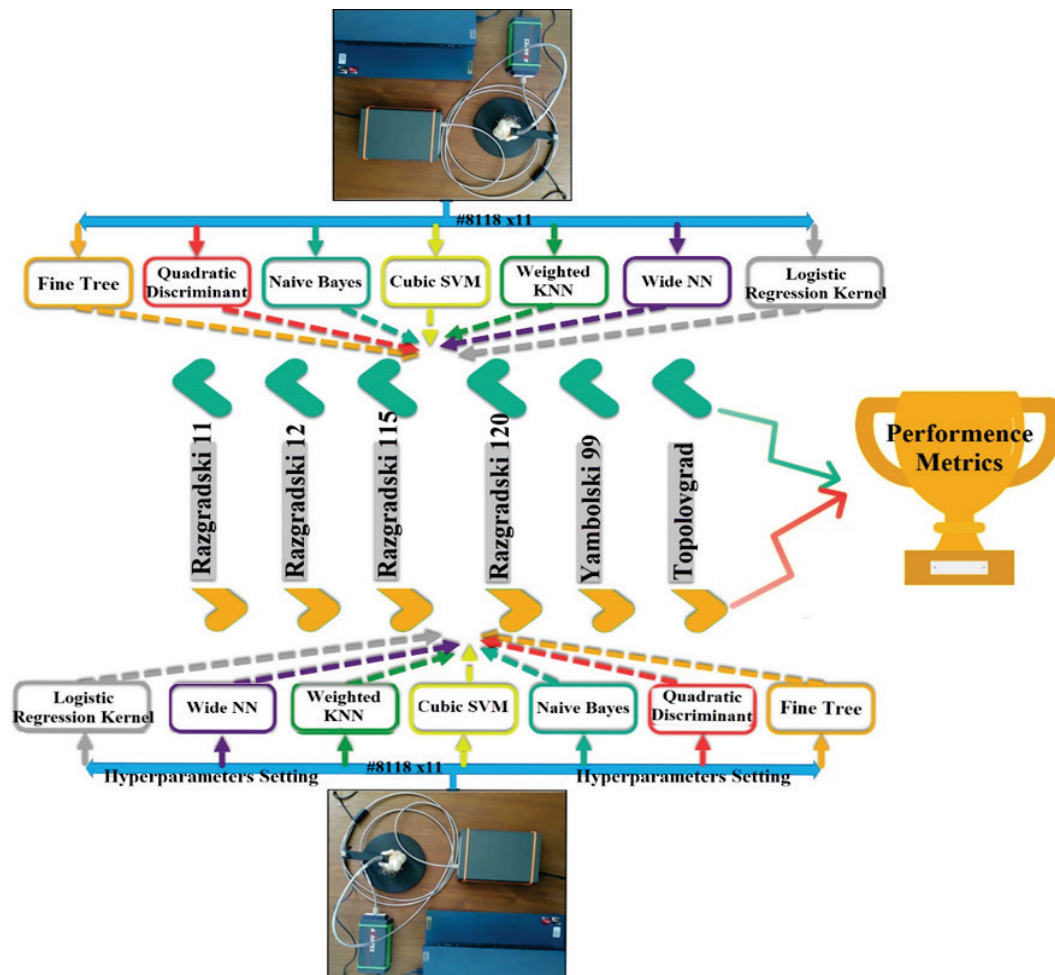


Figure 1 Block diagram of the study, obtaining data, classification with standard parameter values and machine learning methods, parameter optimisation and classification with machine learning methods, comparison of performances.

2.1 Dataset

The garlic used in this study consists of proprietary and breeding garlics. Six types of garlic and their main characteristics are given below.

Razgradski 11: Specimen of winter garlic characterized by medium-sized bulbs with closely spaced clippings. The bulb weighs 40 g. Dry matter content measured refractometrically 33%

Razgradski 12: Specimen of winter garlic characterized by medium to large bulbs with loosely arranged cloves. The bulb weighs 60 g. Dry matter content measured refractometrically 31%.

Razgradski 115: Specimen of winter garlic characterized by small bulbs weighing 30 g, cloves closely spaced. Dry matter content measured refractometrically 32%.

Plovdiv 120: Specimen of winter garlic characterized by medium-sized bulbs weighing 45 g, with densely arranged cloves. Dry matter content measured refractometrically 32%.

Yambolski 99: Specimen of winter garlic characterized by large bulbs weighing 70 g with densely spaced cloves. Dry matter content measured refractometrically 40%.

Topolovgrad: Specimen of winter garlic characterized by large bulbs weighing 70 g, with densely spaced cloves. Dry matter content measured refractometrically 30%.

The accessions that are the subject of the study are Razgradski 11, Razgradski 12, Razgradski 115, Plovdivski 120, Yambolski 99 and Topolovgradski were grown at the "Maritsa" Vegetable Crops Research Institute in the period 2021-2022, with an experimental plot area of 4.8 m², according to the scheme 85 + 25 + 25 + 25×6 cm, according to the accepted technology for growing ripe garlic. Garlic was planted in mid-October and harvested in mid-June, after which it was left to dry in a storage room. The agro-technical events were carried out in the optimal terms for the culture.

2.2 Fluorescence Spectroscopy

Fluorescence is the light emission that remains after the absorption of ultraviolet light of a fluorescent component called a fluorophore, which absorbs energy of a certain wavelength and releases energy at a higher wavelength [17]. The Jablonski diagram showing the general principles of fluorescence spectroscopy is given in Fig. 2 and you can find detailed information in the related study [17].

The fluorescence study was carried out using a fiber-optic portable spectrometer model AvaSpec-ULS2048CL-EVO. The sensitivity of the spectrometer is in the range of 200 nm to 1200 nm. Its resolution is $\Delta\lambda = 5$ nm. An AvaLight High Power LED with an emission wavelength of 285 nm was used as an excitation source. The sources are of high power and generate a pulse spectrum signal at the output of the circuit. The signal from the source is taken to the bulbs by means of a U-shaped optical fiber. The useful fluorescence signal is measured in a direction that is less than 180° to the excitation radiation with the selected sample for analysis positioned vertically on a duralumin stand with a pitch black coating. The coating prevents glare and reduces

aberrations. As shown in Fig. 3, a higher quality fluorescent signal is produced.

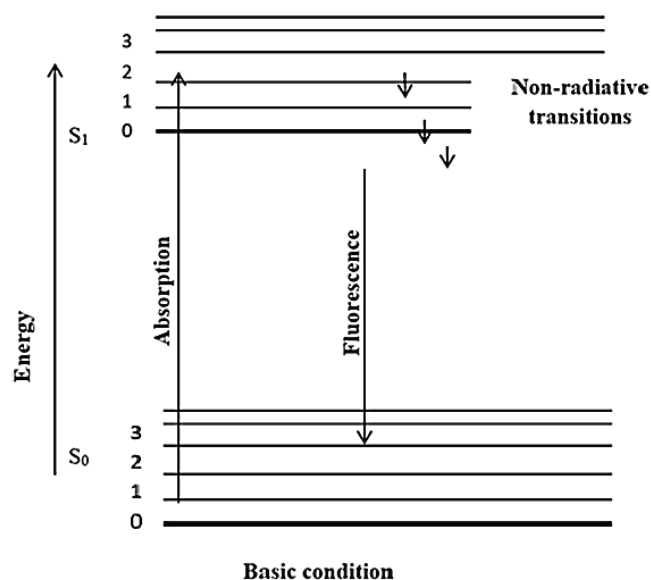


Figure 2 Representation of the basic principle of fluorescence spectroscopy with the Jablonski diagram



Figure 3 Fluorescent spectroscopy experimental setup

The fiber-optic installation makes it possible to record both the emission spectrum and the spectrum of the excitation source. The emission spectrum is defined by the emission wavelength distribution measured for one constant excitation wavelength, and the excitation by the dependence of the emission intensity measured for one scanning wavelength against the excitation wavelength. The spectral distributions are generated by means of two-dimensional graphs, as the abscissa shows the emission wavelengths for a specific bulb from a selected branch of garlic, and the ordinate shows the signal intensity. The signal is taken to the sample by means of prisms with a reflection coating with a reflection rate of 95 %. The signal from the bulb is captured by a system of lenses to compensate for chromatic aberration. The anti-reflective coating of the prisms, in turn, reduces the reflection coefficient to 0.2%. By means of an optical fiber

with a core diameter of 200 μm with a step index of refraction and a numerical aperture of 0.22, the signal is taken to the detector. In the spectrometer, the light signal is converted to electrical-digital using a USB 2.0 wire, downloaded to a

computer with AvaSoft8 software and exported to Excel. This allows analysis, processing and visualization of the results of the conducted research.

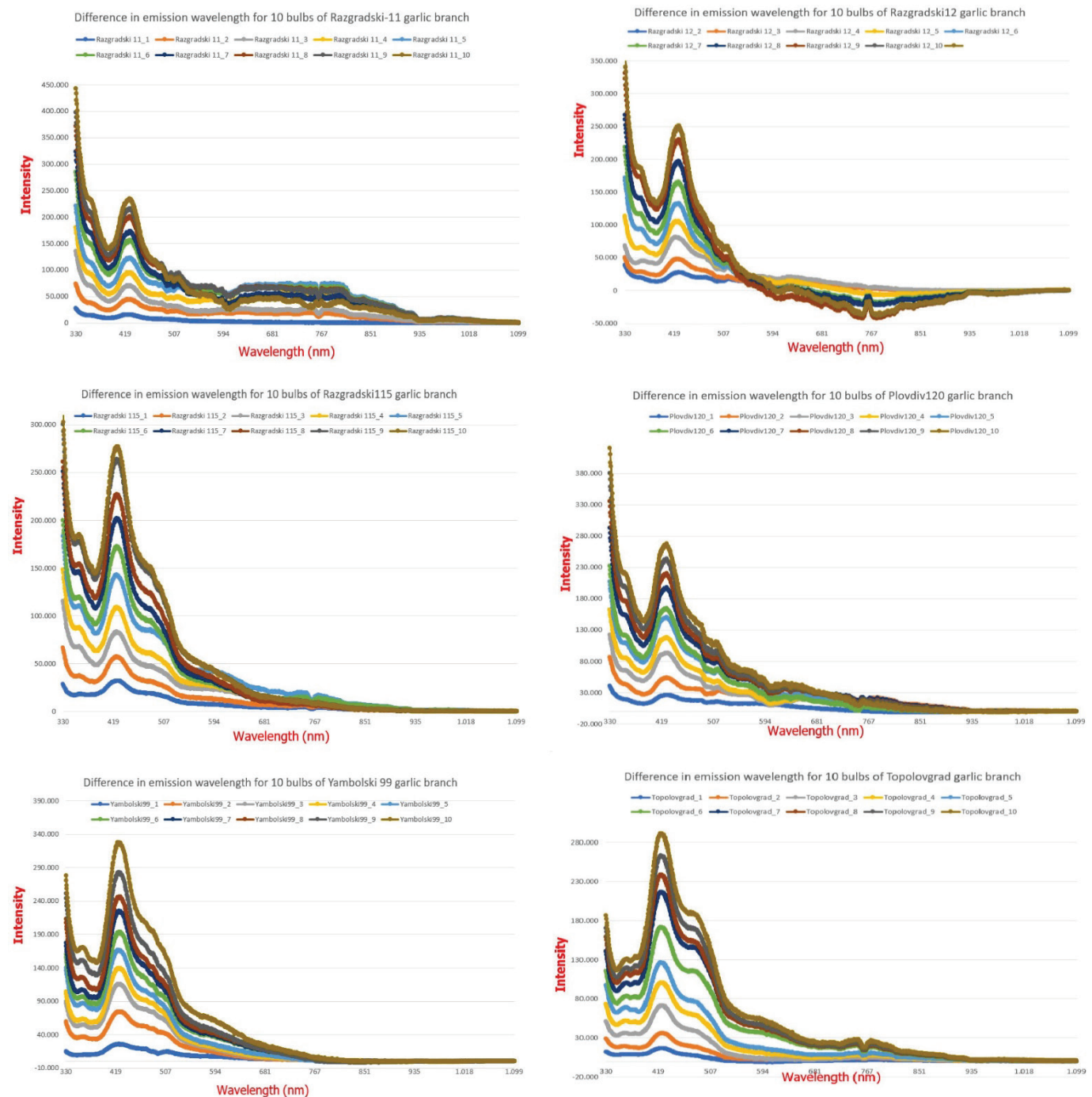


Figure 4 Difference in emission wavelength for 10 bulbs of a garlic branch

2.3 Separating Garlics with Machine Learning Methods

Each bulb of a specific branch of garlic reacts specifically, according to its cell-morphological and bacterial composition, to irradiation with ultraviolet light, correspondingly, it exhibits a unique spectral distribution

characterized by a specific wavelength and intensity level immediately after recultivation. This is due to its organic and inorganic composition and its cell-morphological composition. A difference in the emission fluorescence signal of the different branches is clearly observed. Fluorescence spectroscopy can be successfully applied as a

rapid tool to establish the origin of unknown bulbs. By tracking signal intensity, one can monitor the stability of a branch and its common blacks with other branches. In this study, 8118×11 fluorescent spectroscopy dataset was created by taking the fluorescent spectroscopy data of ten bulbs of a specific garlic branch for each garlic variety. The fluorescence spectroscopy graphic of ten onions from a bulbs garlic branch for each garlic variety is shown in Fig. 4.

The fluorescent spectroscopic data measured for each garlic species were used to construct a machine learning

model for class differentiation of garlic cultivars. These models have been developed using 10 folds cross validation mode and ML algorithms to make the classification and analysis process more objective and free from randomness. In the 10 folds cross validation process, the data set is divided into 10 equal parts, nine of which are used for training and one for testing. By repeating this process with 10 turns, the average accuracy calculation is made by using all the data in both training and testing. Fig. 5 shows the cross validation process used in this study.

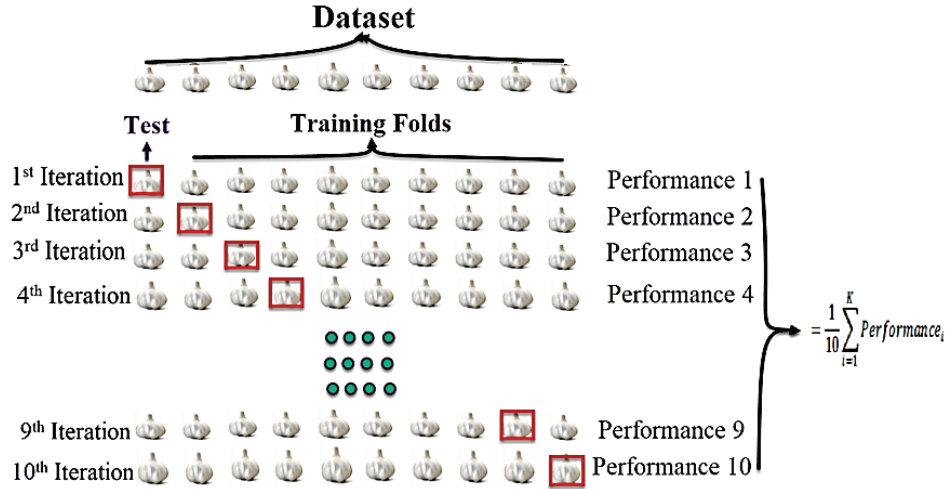


Figure 5 k-folds Cross-Validation

Because of the training and testing processes, Fine Tree, Quadratic Discriminant, Naive Bayes, Cubic Support Vector Machine (SVM), weighted KNN, wide Nural Network and logistic regression kernel models were selected as the algorithms providing the most satisfactory results. Fig. 6 shows the confusion matrix for dual class confusion matrix and multi class classification [27]. In each model, confusion matrices, accuracy, recall, specificity, F1-Score, Precision, and Matthews correlation coefficient (MCC) values were determined according to Eqs. (1)-(6) [28].

		Predicted Class	
		Pozitif (P)	Negative (N)
Actual Class	Pozitif (P)	TP	FN
	Negative (N)	FP	FP

(a)

		Predicted Class			
		C1	C2	...	CN
Actual Class	C1	C1,1	FP	...	C1,N
	C2	FN	TP	...	FN

	CN	CN,1	FP	...	CN,N

(b)

Figure 6 Confusion matrix examples. (a) Binary classification problem confusion matrix. (b) Multiclass classification problem confusion matrix.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \times 100, \quad (1)$$

$$Recall = \frac{TP}{TP + FN} \times 100, \quad (2)$$

$$Specificity = \frac{TN}{TN + FP} \times 100, \quad (3)$$

$$F1 - Score = 2 \times \frac{Sensitivity \times Precision}{Sensitivity + Precision} \times 100, \quad (4)$$

$$Precision = \frac{TP}{TP + FP} \times 100, \quad (5)$$

$$Mcc = \frac{TP \times TN - FP \times FN}{\sqrt{(TP + FP) \times (TP + FN) \times (TN + FP) \times (TN + FN)}} \times 100. \quad (6)$$

In the study, the hyperparameter settings of each model were updated and the parameter was updated for optimum classification accuracy. Because of this, the performance metrics of the classification accuracy obtained were calculated and the models were compared.

3 RESULTS AND DISCUSSION

In this study, machine learning techniques Fine Tree, Quadratic Discriminant, Naive Bayes, Cubic Support Vector Machine (SVM), weighted KNN, wide Nural Network and logistic regression kernel models were used in the separation and classification of garlic varieties. The implementation of these models was carried out using Matlab R2022b software on a performance laptop with Intel Core i7-10750H-2.60 GHz CPU, 32 GB RAM 2.93 GHz, NVIDIA GeForce GTX 1650 Ti 4 GB and 500 GB NVMe2 SSD HDD. Classification of fluorescent spectroscopic data measured from whole garlic was performed with 10 folds cross validation using standard parameters of machine learning. The confusion matrix results

of the classification results obtained by machine learning methods using standard parameter values are given in Fig. 7.

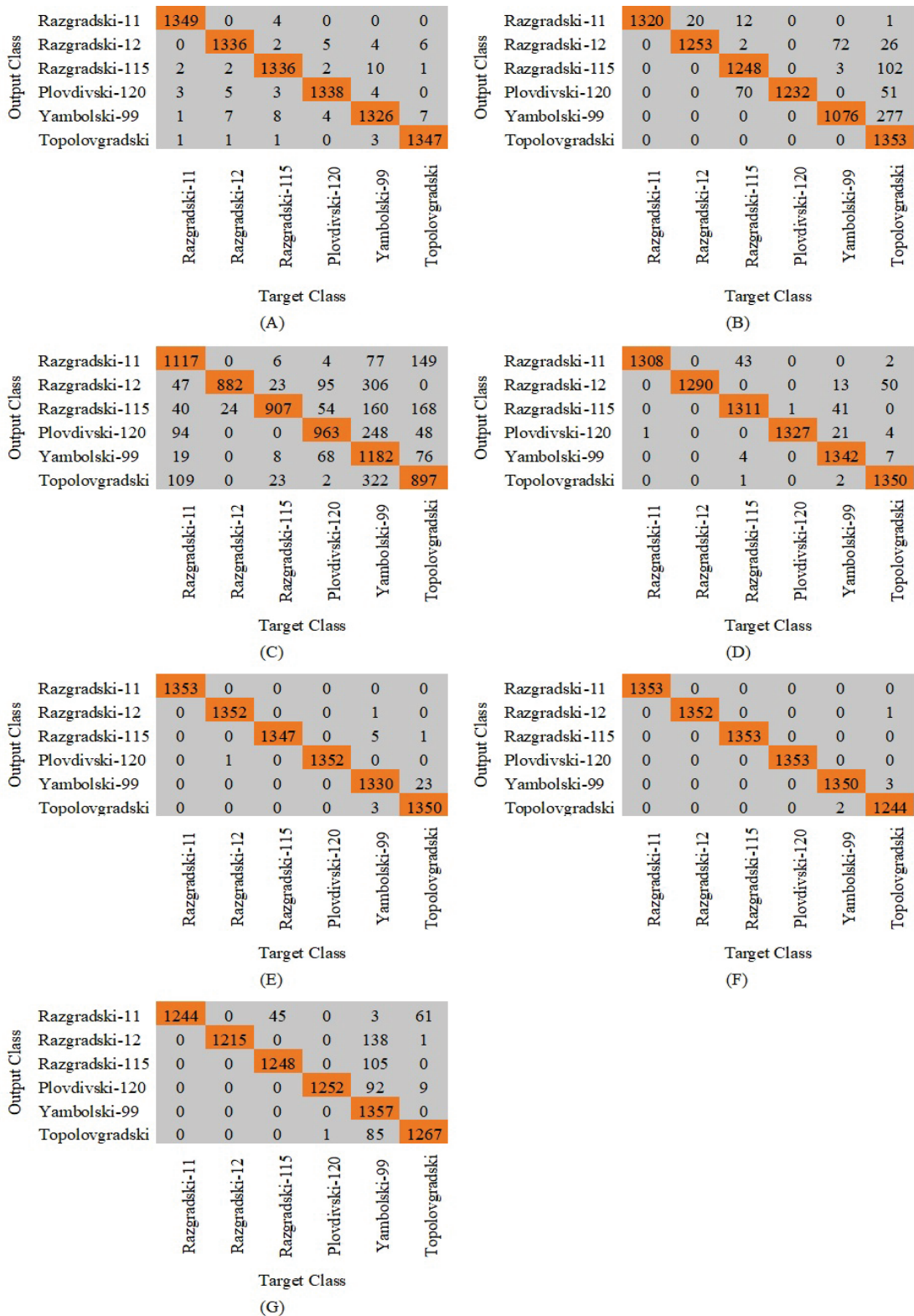


Figure 7 The confusion matrix results of the classification results obtained by machine learning methods using standard parameter values: A) Fine Tree Confusion Matrix, B) Quadratic Discriminant Confusion Matrix, C) Naive Bayes Confusion Matrix, D) Cubic SVM Confusion Matrix, E) Weighted KNN Confusion Matrix, F) Wide NN Confusion Matrix, G) LRK Confusion Matrix

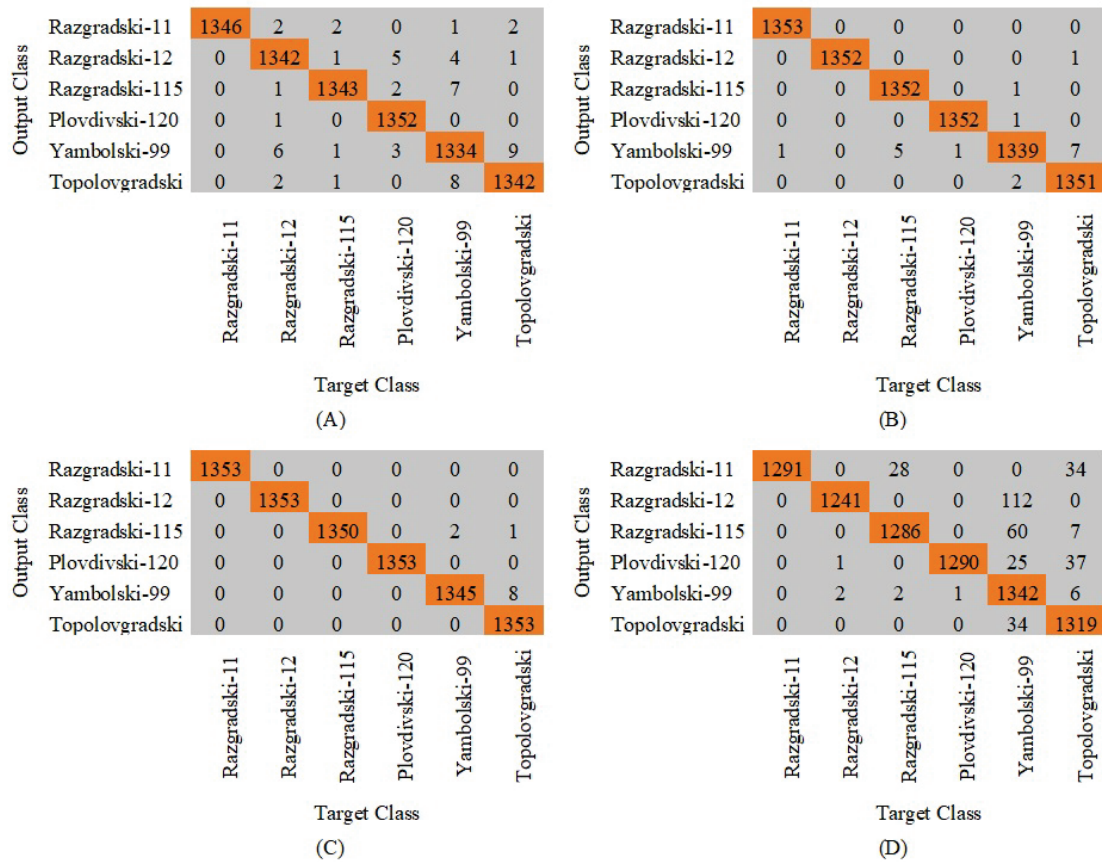


Figure 8 The confusion matrix results of the classification results obtained by machine learning methods using hyper parameter values: A) Fine Tree Confusion Matrix, B) SVM Confusion Matrix, C) Weighted KNN Confusion Matrix, D) LRK Confusion Matrix

The confusion matrix results of the classification results obtained by machine learning methods using hyper parameter values are given in Fig. 8. The accuracy rates of the models obtained in the classification of garlic varieties with the default parameters Fine Tree, Quadratic Discriminant, Naive Bayes, Cubic Support Vector Machine (SVM), weighted KNN, wide Neural Network and logistic regression Kernel (LRK) were 98.9%, 92.2%, %, respectively. 73.3%, 97.7%, 99.6%, 99.9% and 93.4%. Performance metrics obtained from the confusion matrix of the models are given in Tab. 1.

Table 1 Classification performance metrics using standard Parameter values

Model	Accuracy	Recall	Specificity	F1-Score	Precision	Matthews correlation coefficient (MCC)
Fine Tree	98.94	98.94	99.79	98.94	98.94	98.73
Quadratic Discriminant	92.17	92.17	98.43	92.33	93.39	91.09
Naive Bayes	73.27	73.27	94.65	74.00	78.20	69.93
Cubic SVM	97.66	97.66	99.53	97.67	97.74	97.22
Weighted KNN	99.58	99.58	99.92	99.58	99.58	99.50
Wide NN	99.93	99.93	99.99	99.93	99.93	99.91
LRK	93.36	93.36	98.67	93.59	94.56	92.53

The performance metrics obtained from the confusion matrix according to the optimized hyper parameter values of the models are given in Tab. 2. Standard parameters and

optimized hyper parameters of the models are given in Tab. 3.

Table 2 Classification performance metrics using the optimum Parameter values of the models

Model	Accuracy	Recall	Specificity	F1-Score	Precision	Matthews correlation coefficient (MCC)
Fine Tree	99.27	99.27	99.85	99.27	99.27	99.13
Cubic SVM	99.77	99.77	99.95	99.77	99.77	99.72
Weighted KNN	99.86	99.86	99.97	99.86	99.87	99.84
LRK	95.7	95.70	99.14	95.77	96.12	95.01

In this study, in the first stage, the data set created from the fluorescent spectroscopic data of garlic images was classified using innovative models in machine learning techniques. Classification by combining non-destructive fluorescent spectroscopic techniques and artificial intelligence methods may be useful to use this method in practice. In the second stage, the parameters of the models were changed and the models were classified by machine learning methods by updating the parameters in order to reach the optimum classification accuracy. It was observed that the classification performance of Fine Tree, Cubic SVM, Weighted KNN, LRK models increased compared to standard parameters. With the performance values obtained,

it is seen that garlic species can be classified by machine learning techniques using fluorescence spectral data.

Table 3 Standard and optimized hyper parameter values

Standard Model Parameters	Optimized Hyper Parameters
Fine Tree	Fine Tree
Maximum number of splits: 100	Maximum number of splits: 100
Split Criterion: Gini's Diversity index	Split Criterion: Twoing rule
Surrogate Decision splits: Off	Surrogate Decision splits: On, using a maximum of 10 surrogates
Cubic SVM	Cubic SVM
Kernel Function: Cubic	Kernel Function: Cubic
Box constraint level: 1	Box constraint level: 6
Kernel Scala Mode: Auto	Kernel Scala Mode: Auto
Multiclass Method: One-vs-One	Multiclass Method: One-vs-All
Standardize Data: Yes	Standardize Data: Yes
Weighted KNN	Weighted KNN
Number of Neighbours: 10	Number of Neighbours: 10
Distance metric: Euclidean	Distance metric: Correlation
Distance weight: Squared inverse	Distance weight: Inverse
Standardize data: Yes	Standardize data: Yes
LRK	LRK
Learner: Logistic Regression	Learner: Logistic Regression
Number of expansion dimensions: Auto	Number of expansion dimensions: Auto
Regularization strength (lambda): Auto	Regularization strength (lambda): Auto
Kernel Scala: Auto	Kernel Scala: Auto
Multiclass Method: One-vs-One	Multiclass Method: One-vs-All
Iteration limit: 1000	Iteration limit: 1000

4 CONCLUSION

The study involved a new approach combining fluorescence spectroscopy and traditional machine learning algorithms to distinguish garlic varieties. The procedure, performed by precise parameter tuning to improve the success of traditional machine learning methods, was innovative against the background of existing literature for garlic quality evaluation. Machine learning models built based on spectroscopic data allowed six different types of garlic to be classified with up to 99.93% accuracy. The most effective algorithms in the conducted study were the Wide NN classifier. It was observed that the classification performance of Fine Tree, Cubic SVM, Weighted KNN, and LRK classifiers increased in the classification process with parameter adjustment.

Future studies may include other spectroscopic techniques in studies of garlic cultivar classification or discrimination of species, cultivars and breeding lines, as well as various aspects of garlic seed quality assessment to be used as garlic seeds.

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Reducing ACO Population Size to Increase Computational Speed

Luka Olivari

Abstract: Ant Colony Optimization (ACO) is a powerful metaheuristic algorithm widely used to solve complex optimization problems in production and logistics. This paper presents a methodology for enhancing the ACO performance when applied to Traveling Salesman Problems (TSP). By reducing the number of ants in the colony, the algorithm's computational speed improves but solution quality is sacrificed. An optimal number of ants to produce the best results in the shortest time is specific to the problem at hand and can't be defined generally. This paper investigates the effect of ant population reduction relative to the problem size by measuring its impact on solution quality and execution time. Results show that for certain problem sizes ant population and execution time can be halved with practically no reduction in solution quality, or they can be reduced 5 times at the price of slightly worse solution quality. Reduction of ant population is much more impactful on reduction of execution time than it is on solution quality.

Keywords: ACO; Ant Colony Optimization; colony population; number of ants; speed up

1 INTRODUCTION

Ant Colony Optimization (ACO) is considered to be a reliable and efficient algorithm for solving many problems in production such as facility layout design to determine the optimal arrangement of machines to minimize material handling; job scheduling on the CNC machines to optimize the scheduling of jobs on machines in manufacturing processes, ensuring efficient resource utilization and minimizing completion times; tool path optimization on CNC machines to increase production and reduce costs; and many more problems that can be approximated with Traveling Salesman Problem (TSP). ACO is also often used in logistics for Vehicle Routing Problem (VRP) to optimize the routing and scheduling of vehicles, reducing travel distances and operational costs.

Both TSP and VRP belong to the NP-hard problem category [1, 2], implying that solving them using exact methods becomes significantly more challenging as the problem size increases. Due to long calculations, exact methods are not feasible for practical use. Heuristics and metaheuristics, such as ACO, are used for finding near-optimal solutions in time acceptable for practical use. Fast execution time is increasingly important as many of today's real-world problems are dynamic in nature, and solutions need to be found on the go. ACO is considered to be a more popular algorithm than any other metaheuristics with publications in highly reputed journals [3] whose convergence has been analytically proven. [4] These are some of the reasons why ACO still attracts the attention of many researchers to further its performance. It's important to clarify that an algorithm's performance encompasses both efficiency (finding solutions with minimal resource consumption, like time) and effectiveness (achieving solutions with the highest fitness or quality).

ACO population size corresponds to the number of generated solutions in each iteration. What is called "an ant" is actually one generated solution by the algorithm in one iteration. As a larger population means more generated solutions, it is expected that more ants will have a higher chance of producing a better-quality solution. Also, a bigger

population means more computational time is needed to generate all solutions in each iteration.

This research investigates how reducing the ant colony population relative to the problem size affects the efficiency and effectiveness of the ACO algorithm when applied to TSP instances. In essence, the study seeks to optimize the trade-off between computational speed and solution quality. Reducing the number of ants in each iteration is expected to reduce the execution time of the ACO algorithm, with an expected trade-off of lower solution quality.

The literature survey shows that an optimal number of ants as an integer is specific to the case at hand and can't be defined generally. This paper is unique because it investigates a number of ants in relation to the size of the problem in the hope of finding a pattern that can be applied generally to problems of similar size. A similar research was conducted but it focused on the Ant Colony System (ACS) unlike the Ant System (AS) which is a focal point of this paper.

The aim of this paper is to quantify the impact of reducing the ant colony population (i.e., the number of ants) on the efficiency and effectiveness of the Ant System algorithm, focusing on problem sizes ranging from 100 to 200 nodes. Additionally, it aims to provide guidelines for enhancing the performance of ACO algorithms used to tackle similar problems. The novelty of this research lies in its focused investigation into the impact of population size reduction in ACO and the identification of population size "sweet spots" for balancing efficiency and effectiveness in solving TSP instances.

The authors hope that the research findings can serve as benchmark data for comparing the efficiency and effectiveness of ACO variations and other optimization algorithms in solving TSP and related problems. Also, these insights can help practitioners using ACO algorithms for optimization problems to make it more feasible to find solutions in dynamic and time-sensitive situations which can lead to cost savings in terms of increased operational efficiency and reduced computing resources.

Section 2 provides an overview of the Ant System and speed-up techniques unique to ACO algorithms, as well as a

literature survey. Section 3 presents the time analysis of AS, details the methodology and experiment, and finally presents the results of the research. In Section 4, we discuss findings, present guidelines, and conclude with Section 5.

2 ANT COLONY OPTIMIZATION

Ant Colony Optimization (ACO) is a metaheuristic framework that incorporates algorithms inspired by the indirect coordination of ants in nature. Simple agents, ants, without memory and unaware of each other are able to solve complex tasks by modifying their environment. Ants communicate indirectly by depositing pheromone trails and marking paths from the colony to food sources. Pheromone quantities on different paths vary. Shorter paths will accumulate more pheromones than longer paths due to pheromone evaporation, as it takes an ant more time to travel the longer path, pheromones will have more time to evaporate.

If there are multiple possible paths to reach the destination an ant will select a path semi-randomly based on pheromone levels. Shorter paths with higher pheromone concentrations hold a greater probability of selection. Repeated use of a shorter path results in added pheromones, increasing its appeal until competing paths lose all pheromones, rendering them unviable options. The described mechanism is imitated by ACO to solve complex problems like TSP and VRP. [5]

ACO metaheuristic framework encompasses a variety of ant-inspired algorithms, including the Ant System (AS), the first algorithm in the ACO family proposed in 1992 by Marco Dorigo in his PhD thesis. [6] AS was introduced to solve the classical Traveling Salesman Problem (TSP). [7] The objective of TSP is to find the shortest path while visiting every city exactly once and then return to the origin. The problem is represented with a complete graph in which nodes represent cities. The solution to TSP is a Hamiltonian cycle of minimal length. Ants in the AS algorithm “move” through the graph, from node to node, until all nodes are visited, and ant returns to the starting node. Ants choose the next node probabilistically based on pheromone levels on edge between nodes and heuristic information i.e., the distance between nodes. After the tour is complete, ants mark their path with pheromones according to path length i.e., solution quality.

To avoid infeasible paths that might have acquired large pheromone amounts by chance, a pheromone evaporation mechanism is employed. Before the deposition of pheromones in the current iteration of the algorithm, evaporation occurs reducing the overall pheromone levels on all edges between nodes. The evaporation rate is set to values between 0 and 1. The 0 represents no evaporation at all, and 1 represents 100% evaporation of pheromones.

Several techniques are available to enhance algorithm performance, including coding style adjustments, and algorithm refinements. Usually, coding style speed-up techniques shouldn't impact the algorithm's effectiveness only its efficiency. Coding style techniques include reducing the complexity of calculations if possible, minimizing

redundant operations, using vectorization instead of loops, minimizing function calls to avoid overhead, avoiding unnecessary display of the results and visualizations, etc.

Improvements made to the algorithm usually intend to enhance efficiency or effectiveness. Sometimes, improvements are realized in both, as is the case with the Rank-Based Ant System (RAS). [8] This variant of AS reinforces pheromone deposition of the top-ranked solutions, effectively increasing the convergence rate and quality of the solution, and simultaneously reducing the computational time as only a limited number of ants update their pheromone trails. It is a considerable reduction in computation, compared to the AS where all ants update their pheromone trails. Another improvement of AS is the MAX-MIN Ant System (MMAS), where typically the iteration-best or overall-best ant alone updates pheromone trails. [9] MMAX has a slower convergence rate compared to AS or RAS, but it produces better solutions in the long run.

Certain efficiency-focused methods can compromise the algorithm's effectiveness. In such scenarios, the trade-off between efficiency gains and potential drawbacks should be carefully evaluated. One such method is the use of *Candidate lists*. For big problems, when constructing a solution, an ant has a large number of possible choices for movement which causes an increase in execution time. Using *Candidate lists*, a list of nearest neighbors for each node in the problem, the computation can be accelerated. During the construction of the tour, an ant can move to nodes that are not on the *Candidate list* only if every node on the list is already visited. Although an optimal solution often can be found within a reasonably small number of nearest neighbors, this technique can make it impossible to find the optimal solution. [5, 10]

On the other hand, increasing the effectiveness of the algorithm often comes at the price of longer computational time. A good example is combining ACO with Local Search (LS) algorithms. ACO and LS complement each other rather nicely, as ACO is able to quickly find good quality near-optimal solutions, and Local Search is used to fine-tune those solutions as its effectiveness is largely influenced by the starting solution. There are many ways to combine ACO and LS, use it only to improve the final solution or use it to improve solutions in each iteration. Also, advanced LS algorithms produce better-quality solutions, but the general rule is always the same, better-quality solutions come at the price of longer execution time. [5, 11]

The construction of the tour is independent for each ant, which means that ACO naturally allows *parallel implementation* of the algorithm. Communication overhead can be a problem for smaller problems, resulting in longer computational time than it was initially. Because of this, and many other factors that influence *parallel implementation*, the exact problem size, when parallelization becomes beneficial, should be determined. [5] A case where multiple colonies run on multiple processors is common, although the easiest and most effective way of parallelizing ACO is to independently run many ACO algorithms. [7, 8]

Finally, the choice of programming language could significantly impact algorithm efficiency. This may not be

the case for small problem sizes where a solution is generated in a fraction of a second. However, it becomes a considerable influence for large problems. Generally, lower-level programming languages, like C, exhibit greater speed compared to higher-level counterparts like C# or Python. The reason is that higher-level programming languages are user-oriented to be more accessible to a wider audience, while lower-level languages are machine-oriented, which makes them easier to process by the machine, but it makes coding more complex compared to higher-level languages.

Another aspect to consider is the distinction between compiled and scripted languages. Compiled programming languages with superior speed come at the price of overhead. Using compiled language, a user must edit, compile, run, and debug code to test it. Scripted languages allow interactive coding and easy testing of parts of the code but are generally considered to be slower. MATLAB, as a higher-level, scripted language proved to be slower than other programming languages, such as C#, R, or Python for small problem sizes. As problem size increases MATLAB turns out to be a very efficient programming language with faster execution speed than the mentioned programming languages, which could be a result of optimized internal functions and processes. [14, 15]

2.1 Literature Survey

In [16] authors try to overcome the low efficiency of the Ant Colony System (ACS), an extension of AS, in solving TSP within a limited time. The authors define the correlation coefficient between the initial population size and the number of nodes in the problem. Improvement was tested on benchmark instances ranging from 30 to 127 nodes.

In [10] authors present an analysis of the number of ants in the Ant Colony System (ACS) algorithm. The paper studies the effect of gradually changing the number of ants from 1 to 100 on the algorithm's behavior. Tests were performed on *eil51* and *kroA100* TSP benchmark instances. The authors conclude that a large number of ants did enhanced the algorithm performance, and for tested problems small number of ants in ACS is recommended.

On the other hand, in [17] authors discuss the application of hyperpopulated ant colonies to solve TSP. The authors propose an increased number of ants in the colony or assigning more colonies to the same problem to reduce the number of iterations in finding the solution. The parallel implementation makes it possible to reduce processing time.

In [18] authors investigate the number of ants (in the range of 3 to 12) used in a hybrid method based on ACO and Artificial Neural Networks in relation to the number of iterations, penalized objective function, and optimization time. The authors note that the optimum number of ants is specific to the dataset considered, and report that for their data set best results were achieved with five ants, and increasing the number of ants resulted in increased execution time.

In [19] authors introduce k-means clustering to group nodes in TSP and apply ACO to individual groups. Finally, using the connection technique join these groups into a single

route. This way computational time of the ACO algorithm is reduced to 32% of the original run without clustering. Improvement was tested on benchmark instances ranging from 30 to 150 nodes.

In [20] authors made the basic alterations in the Ant Colony System (ACS) and Max-Min Ant System (MMAS) with respect to the Ant System (AS). Also, they compare the results based on different parameter adjustments for chosen algorithms. One parameter adjustment was the number of ants. The authors increase the population size from 16 ants to 52 ants in five steps. According to their findings, the MMAS execution time grows fastest with increased population compared to the other two algorithms.

In [21] authors introduce a novel *Partial ACO* (P-ACO) variant for solving larger TSP cases, achieved through the reduction of extensive memory demands, utilization of parallel CPU hardware, and the introduction of a substantial efficiency-enhancing strategy. By partially modifying the best tour only this approach resulted in increased efficiency and effectiveness of the algorithm. The algorithm was applied to TSP instances of up to 200 000 nodes and achieved solutions that are 5-7% longer than the best-known tours so far.

In [22] authors study the ACO algorithm's performance variations with the number of ants. They conclude that less ants favors exploration, while more ants favors exploitation, so the optimal number of ants depends on each specific problem.

In [23] and [24] authors have studied the influence of the number of ants on the performance of the MMAS algorithm, applied to the multi-objective problem of wireless sensor network design. In the first paper, they fixed the number of iterations and increased the number of ants from 1 to 10 incrementally. In the second paper, they compared the influence of the number of ants and the number of iterations on solution quality.

In [25] authors focus on the number of ants in the Simplified Ant Colony Algorithm (SACO) using the optimization of grillage structure. They conclude that there is a correlation between the number of ants and the number of design variables as more ants are required to achieve the optimum solution in the cases with more design variables. This correlation cannot be defined with a regular function.

In [26] authors propose a warm-up procedure for ACO, which initializes the pheromone matrix to provide a good starting point to obtain better results in fewer iterations. The warm-up procedure is based solely on the graph that formalizes the problem. The procedure was tested on benchmark instances as well as on a simulation of the real warehouse which was represented by the graph with 380 nodes.

In this study [27] the effect of optimization parameters in ACO, such as the number of ants, was investigated. The authors used 21 colonies with 5 to 5000 ants. Depending on the increase in the number of ants, the number of iterations decreased, and the optimization time increased nonlinearly. The authors conclude that the optimum number of ants is crucial for reaching the best solution in a short time.

In [28] authors propose a dynamic adaptive ACO algorithm (DAACO) that dynamically determines the population size of the colony to prevent falling into the local optimum, it also implements a hybrid local selection strategy to increase the quality of solution and reduce the execution time. Algorithm was tested on benchmark instances ranging from 291 to 1577 nodes with results showing that DAACO has advantages in convergence and solution quality compared to similar ACO algorithms.

3 METODOLOGY AND EXPERIMENT

3.1 Time Analysis of the Ant System

In this paper Ant System (AS), the first algorithm in the ACO framework, was applied to Traveling Salesman Problem (TSP).

Ant System algorithm consists of the following integral parts: *Initialize Algorithm*, *Main Loop*, and *Display Results*. The *Main Loop* is further divided into several steps: *Construct Tour* using the *Roulette Wheel* function, *Calculate Fitness*, *Update Pheromones*, and *Optional Actions*. The procedure of AS can be visualized with the pseudo-code presented in Fig. 1.

```

Ant System
  Initialize Algorithm
  Main Loop
    For i = 1 : Max. Iterations
      Construct Tour
        Roulette Wheel
      Calculate Fitness
      Update Pheromones
      Optional Actions
    end Main Loop
  Display Results
end Ant System

```

Figure 1 Ant System in pseudo-code [author]

The problem and parameters (such as pheromone evaporation rate and stopping criteria) are defined in the *Initialising Algorithm* section of the code. In this case, the stopping criteria are the maximum number of iterations. Initial pheromone levels are deposited according to the solution obtained with the Nearest Neighbour algorithm. *Construct Tour* manages ants in the colony that independently “walk the graph” i.e., construct solutions. Individual ant chooses the next node using the *Roulette Wheel* function based on pheromone levels and heuristic information. Each ant represents one possible solution to the TSP. When all tours are constructed, their lengths are calculated using the *Calculate Fitness* function. Before each ant deposits pheromones based on tour fitness using the *Update Pheromone* function, existing pheromones must partially evaporate. *Optional Activities* can include a Local Search algorithm to further improve tours, depositing additional pheromones on the best-so-far tour, etc. This paper did not incorporate any optional activities within the ACO algorithm. Finally, solution (order of visiting nodes) and solution fitness (tour length) are displayed.

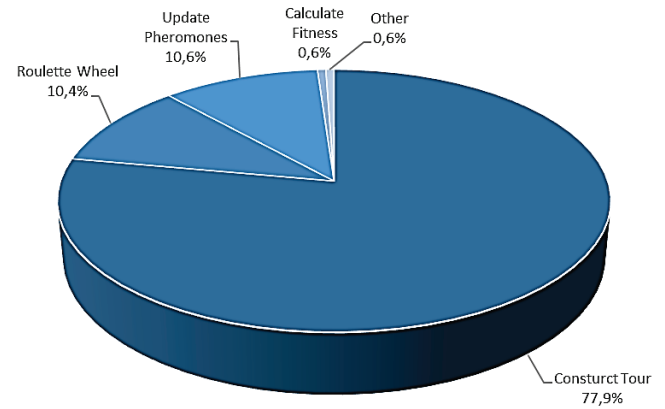


Figure 2 Time analysis of Ant System [author]

For time analysis, the AS algorithm used in this paper was applied to the *kroA100* benchmark problem and analyzed using MATLAB's *Run and Time* option. The colony population was 100 ants, and the stopping criteria were 500 iterations. Time analysis, illustrated in Fig. 2, shows that most of the computational time was consumed by the *Construct Tour* function. Considering that the *Roulette Wheel* function is called from within the *Construct Tour* function it is clear that constructing solutions takes almost 90% of the total time needed to run the algorithm.

3.2 Methodology

As mentioned before, the efficiency of the algorithm refers to computational speed which is the execution time of an algorithm for a limited number of iterations. Effectiveness refers to solution quality which is measured by tour length, a shorter tour indicates higher quality.

To quantify the impact of the reduced number of ants on the efficiency and effectiveness of the Ant System, the algorithm was applied to classic TSP benchmark instances kroA100, kroA150, and kroA200 found in TSPLIB [30]. These benchmark problems were chosen because of their round number of nodes in order to minimize the need for rounding adjustments in ant numbers during experimentation. Recommended parameters from [5] were used.

Parameters are as follows: $\alpha = 1$, $\beta = 5$, $\rho = 0.5$, and initial pheromone levels before the first iteration, are calculated according to the equation $\tau_0 = m/C^{mn}$. Where the number of ants is denoted with m and C^{mn} stands for the tour length obtained through the Nearest Neighbor algorithm. The recommended number of ants (m) is the same as the number of nodes (n) in the problem ($m = n$) for general good performance. [5]

A total of 12 tests were conducted for each benchmark problem (kroA100, kroA150, and kroA200).

First, results for each benchmark problem were obtained using 100% of the recommended number of ants. For kroA100, 100 ants were used. For kroA150, 150 ants were used. For kroA200, 200 ants were used. For future reference, these first tests will be called *Test 1*, as other tests will be compared to it.

Subsequent tests involved a gradual reduction of ants by 10%. Test 2 used 90% of the recommended ant population, Test 3 used 80%, Test 4 used 70%, and so on, down to Test 10, which employed 10% of the recommended number of ants. The final two tests were carried out with 6% and 2% of the recommended ant count.

The tour lengths of subsequent tests were compared to the optimal solution and the tour lengths obtained in *Test 1* for each benchmark problem. The execution time of subsequent tests was compared to the execution time of *Test 1*.

Experiments were performed using MATLAB R2021a on the Windows 10 64-bit operating system. The computer configuration was Intel(R) Core(TM) i5-10210U CPU 2.10 GHz, installed RAM 8 GB. The algorithm used is accessible through the GitHub repository [31]. Results are averaged for 10 independent runs due to the probabilistic nature of ACO and to reduce the influence of background processes.

3.3 Experiment results

Test results for each benchmark problem are presented in Tabs. 1, 2, and 3. The first column (*No. Ants*) shows the percentage of ants used in the test - 100% corresponds to the number of nodes in the problem ($m = n$). For the kroA100 benchmark, *Test 1* (first row) employed 100 ants, followed by 90 ants in the second test (second row), and so forth.

Table 1 Test results for benchmark instance kroA100

No. Ants	Solution quality	Deviation from the optimum	Deviation from the Test 1	Execution time (s)	Reduction of execution time
100%	22756	6.9%	-	135.2	-
90%	22800	7.1%	0.2%	120.5	89.1%
80%	22955	7.9%	0.9%	105.4	78.0%
70%	23007	8.1%	1.1%	92.65	68.5%
60%	23051	8.3%	1.3%	79.4	58.7%
50%	23088	8.5%	1.5%	66.7	49.3%
40%	23193	9.0%	1.9%	53.6	39.6%
30%	23180	8.9%	1.9%	40.6	30.0%
20%	23251	9.3%	2.2%	27.55	20.4%
10%	23343	9.7%	2.6%	14.5	10.7%
6%	23510	10.5%	3.3%	9.2	6.8%
2%	24170	13.6%	6.2%	3.4	2.5%

The second column (*Solution quality*) shows the lengths of an average solution obtained in 10 runs of the algorithm. In the third column (*Deviation from the optimum*) obtained solutions are compared to the optimal solution. The percentage of deviation from the optimal solution is given. It's calculated using the equation $((\text{average solution length} / \text{optimal solution length}) * 100\%) - 100\%$. This value represents the percentage by which the average tour length surpasses the optimal tour length. For instance, when using 100 ants in the kroA100 benchmark test, the resulting tour was 6.9% longer than the optimal solution.

In the fourth column (*Deviation from the Test 1*) results of subsequent tests (tests 2 to 12) are compared to the *Test 1*.

It presents a comparison of tour lengths obtained with a reduced ant count against those obtained using the recommended number of ants (100% ants). The values show how much longer or shorter are the tour lengths compared to *Test 1*. For example, the average solution for benchmark problem kroA100 using 90 ants is 0.2% longer than the average solution using 100 ants. A negative percentage means that the tour was shorter than the average solution in *Test 1*.

The fifth column (*Execution time [s]*) shows the average execution time for one run of the algorithm. Execution time was measured using *tic* and *toc* functions in MATLAB, and the results are expressed in seconds.

The sixth column (*Reduction of execution time*) shows the difference in execution time between tests 2 to 12 with the reduced number of ants and *Test 1*. For example, for benchmark problem kroA100 using 90 ants produced a solution in 120.5 seconds, which is 89,1% of the time needed to produce a solution using 100 ants (135,2 seconds) in *Test 1*.

Table 2 Test results for benchmark instance kroA150

No. Ants	Solution quality	Deviation from the optimum	Deviation from the Test 1	Execution time (s)	Reduction of execution time
100%	28733	8.3%	-	375.1	-
90%	28620	7.9%	-0.4%	337.5	90.0%
80%	28552	7.6%	-0.6%	299.6	79.9%
70%	28616	7.9%	-0.4%	264.6	70.5%
60%	28742	8.4%	0.0%	225.65	60.2%
50%	28727	8.3%	0.0%	189.9	50.6%
40%	28831	8.7%	0.3%	152.45	40.6%
30%	28811	8.6%	0.3%	115	30.7%
20%	28887	8.9%	0.5%	76.7	20.4%
10%	29094	9.7%	1.3%	39.05	10.4%
6%	29379	10.8%	2.2%	23.9	6.4%
2%	29973	13.0%	4.3%	9.8	2.6%

Table 3 Test results for benchmark instance kroA200

No. Ants	Solution quality	Deviation from the optimum	Deviation from the Test 1	Execution time (s)	Reduction of execution time
100%	32129	9.4%	-	811.2	-
90%	32172	9.5%	0.1%	736.3	90.8%
80%	31878	8.5%	-0.8%	643.3	79.3%
70%	32071	9.2%	-0.2%	563.4	69.5%
60%	32189	9.6%	0.2%	482.5	59.5%
50%	32206	9.7%	0.2%	401.6	49.5%
40%	32326	10.1%	0.6%	322	39.7%
30%	32403	10.3%	0.9%	243.6	30.0%
20%	32347	10.1%	0.7%	163.3	20.1%
10%	32983	12.3%	2.7%	82.4	10.2%
6%	33452	13.9%	4.1%	49.7	6.1%
2%	34170	16.4%	6.4%	17.4	2.1%

Data from the tables is visually represented in Figs. 3, 4, and 5 for benchmark instances kroA100, kroA150, and kroA200, respectively.

It is clearly shown that computational time increases linearly with the number of ants. Computational time is directly related to the number of ants. For example, using 50% of ants will complete the calculation in half the time compared to *Test 1*. 50 ants in kroA100 instance will complete the calculation in 66,7 seconds, which is roughly 50% of the total time needed to produce a solution using 100 ants (235,2 seconds) in the same problem.

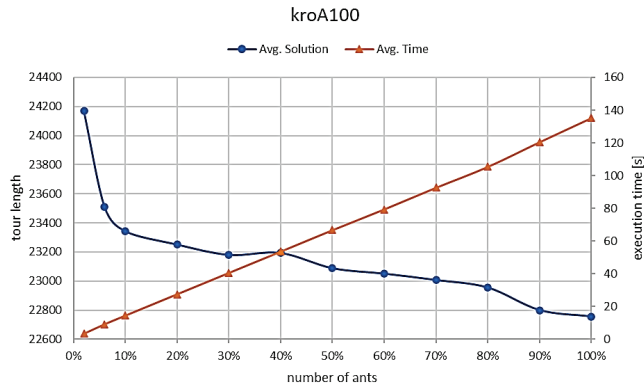


Figure 3 Tour length and execution time for kroA100

For benchmark problem kroA100, using the recommended number of ants (*Test 1*) produced a solution 6.9% longer than the optimum. Using the recommended number of ants, the kroA150 solution was 8.3% longer, and the kroA200 solution was 9.4% longer than the optimal solution. Using 100% of the ant population produces increasingly worse solutions as the problem size grows.

The smallest ant count in these tests was 2% of the recommended population size, which expectedly reduced computational time to approximately 2% of execution time compared to *Test 1*. The solution obtained with 2% of the recommended population size was 13.6% longer than the optimal solution for the kroA100, 13% longer for the kroA150, and 16.4% longer for the kroA200. Compared with results obtained with *Test 1*, using 2% of ants produced tours 6.2% longer for kroA100, 4.3% longer for kroA150, and 6.4% longer for kroA200. Using a very small population generates noticeably worse solutions compared to *Test 1*.

In all three cases, the solution quality drastically improves when the ant population is increased from 2% to 20% of the recommended population size. For example, the solution for kroA100 using 2% of the recommended population deviates 6,2% from the solution obtained in *Test 1*. While using 20% of the recommended population, the solution deviates 2,2% from the solution obtained in *Test 1*. Solutions for kroA200 using 2% ants deviate 6,4% from the solution obtained in *Test 1*, while using 20% of ants solution deviate 0,7% from the solution obtained in *Test 1*.

Increasing the population up to 50% still increases solution quality but at a slower rate. For example, using 50% of ants in kroA100 problem, the solution is 1,5% longer compared to the solution obtained in *Test 1*.

For kroA100 problem, increasing population size beyond 50% gradually increased solution quality, and using 100% ants produced the best results.

For kroA150 and kroA200 problems, increasing the population beyond 50% didn't show a significant increase in solution quality. It is interesting that using 70 or 80% of the population in both cases produced slightly better results compared to *Test 1* (using 100% of the ant population), but this can be credited to the probabilistic nature of ACO.

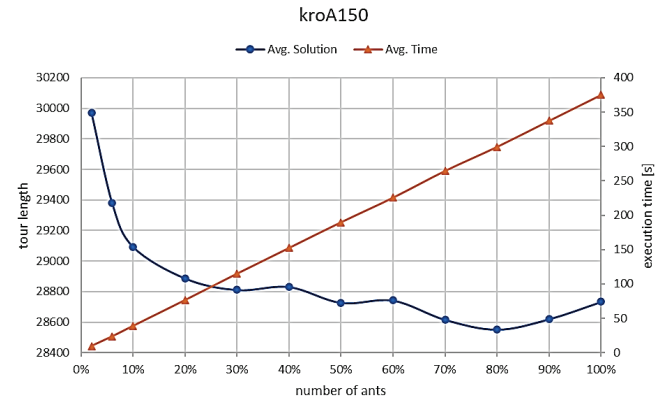


Figure 4 Tour length and execution time for kroA150

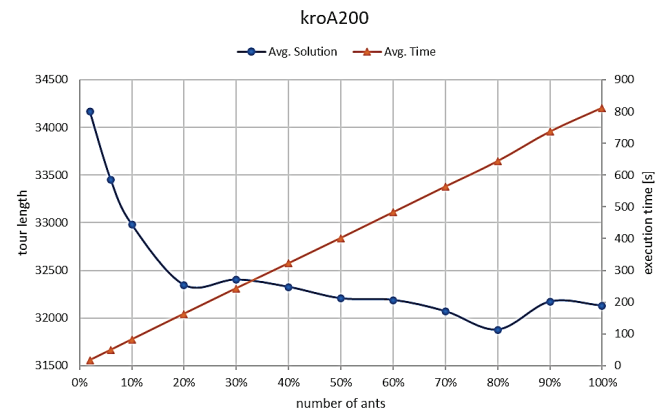


Figure 5 Tour length and execution time for kroA200

4 DISCUSSION

As indicated in the literature survey, some papers (like [18], [22], and [25]) try to determine an optimal number of ants as a constant number and conclude that the optimal number of ants is specific to the case at hand and can't be defined generally. In this paper, we investigate the population size of the Ant System (AS) in relation to the size of the problem to find a good compromise between computational speed and solution quality. Similar research was conducted for other ACO algorithms, specifically Ant Colony System (ACS) in [16] and [29] in which authors initialize population size relevant to the number of nodes in the problem.

Decreasing the ant population decreases solution quality and computational time. The decrease in computational time is much more prominent than the decrease in solution quality. The computational time scales linearly with the proportion of the recommended ant number, equating to the corresponding fraction of the ant population. This means that by reducing population size computational time can be reduced predictably.

Tests show that reducing the number of ants has a stronger effect on the solution quality of smaller problem sizes (100 nodes) than it has on larger problem sizes (200 nodes), this could be because of the smaller absolute number of ants.

Solution quality increases rapidly with the increase of population size from 2% to 20% of the recommended population size, after which it gradually increases up to 50% of the recommended population size. Using more than 50% of the recommended number of ants doesn't increase solution quality noticeably.

For problems with 150 and 200 nodes using 80% of ants produced better results than using 100% of ants. That effect could be because ACO is a probabilistic method. The influence of randomness, or "luck", could be decreased with more runs of the algorithm to average out the results. But this effect could also indicate that using more ants over a certain threshold doesn't necessarily improve solution quality.

For problem sizes similar to kroA150 and kroA200, two values could be considered "sweet spots" for a good efficiency/effectiveness ratio, using 50% or 20% of ants. With 50% of the population size computational time could be halved with solutions quality remaining approximately the same as in *Test 1*. Using 20% of ants produces 0.5% and 0.7% longer solutions for kroA150 and kroA200 benchmark instances compared to *Test 1* while computation is five times faster.

For benchmark instance kroA100, and problems of similar size, "sweet spot" is an even lower number of ants, concretely 10% of the population. In that case, computational time would be 10 times faster. An increase in computational speed comes at the price of a noticeable 2.6% longer solution. The second "sweet spot" is using 70 or 80% of the population which produces roughly 1% longer solution compared to *Test 1*.

It should be noted that using improved variants of the ACO algorithm would produce better overall results in a shorter time. For example, in a Rank-based Ant System (RAS) only a limited number of ants deposit pheromones which increases computational speed compared to AS. In MAX-MIN Ant System (MMAS) only one ant deposits pheromones in each iteration, which reduces computational time even more. It is proven that RAS and MMAS produce better solutions than basic AS. [5]

For future research, the influence of reduced population size on the improved ACO algorithms such as the MAX-MIN Ant System, the Rank-Based Ant System, and many new variants are often proposed in the literature. Also, bigger problems should be tackled as benchmark problems in TSPLIB can go up to tens of thousands of nodes.

5 CONCLUSIONS

It has been a while since Ant Colony Optimization (ACO) established its place as a reliable and efficient algorithm for solving many problems in production and logistics, but it still attracts the attention of many researchers who are determined to increase its efficiency and effectiveness. As an increased number of problems in the real

world are dynamic in nature it is paramount to increase the computational speed of ACO to be useful in practice.

One method of increasing ACO efficiency is reducing the number of ants which considerably increases computational speed but slightly lowers solution quality. As the optimal number of ants depends on a specific case, we focused on the reduction of population size relevant to the number of nodes in the problem.

For problems of approximate size 150 - 200 nodes, the number of ants can be reduced by 50%, effectively halving computational time while solution quality remains roughly the same. For the same problem sizes, by reducing the number of ants to 20%, computational speed can be 5 times faster for a 0.5% to 0.7% reduction of solution quality. The reduction of ant population has a much stronger, positive, effect on computational speed than it has a negative effect on solution quality.

The limitation of this research lies in the probabilistic nature of ACO. In each test, the algorithm was run 10 times to reduce the influence of "luck" in generating solutions. More runs are always better, but also more time-consuming. Theoretically, the infinite number of runs would eliminate the effect of lucky guesses, but that is not possible to do because of obvious reasons.

In future research, the influence of reduced population size on bigger problems and improved ACO variants should be investigated.

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Unveiling the Impact of Social Media Usage on Firm Performance: The Mediating Influence of Organizational Agility and Innovation Capability

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Abstract: The current research tended to examine the impact of social media usage on firm performance with the mediating role of organizational agility and innovation capability. The methodology used was descriptive correlation with structural equation modelling. For this purpose, 148 managers, deputies and experts of the German automotive industry participated in the study. Data collection was conducted using a questionnaire while analysis of the data utilized the structural equation modeling based the partial least squares method. The findings suggest that social media usage has a substantial and positive impact on innovation capability, organizational agility, and firm performance. Additionally, innovation capability has a notable positive influence on organizational agility and firm performance. Furthermore, organizational agility significantly contributes to firm performance. Both innovation capability and organizational agility play an important mediating role in the relationship between social media usage and firm performance. Moreover, innovation capability acts as a mediator between social media usage and organizational agility, while organizational agility mediates the effect of innovation capability on firm performance. Thus, it can be inferred that social media usage facilitates improvements in firm performance by enhancing organizational agility and innovation capability.

Keywords: firm performance; innovation capability; organizational agility; social media

1 INTRODUCTION

Performance plays a crucial role in the examination of organizations. The significance of performance in attaining objectives, along with the elements that contribute to its effectiveness and efficiency, receive significant attention across various public and private entities. In modern competitive world, organizations constantly need to improve their performance in any environment they operate in, and they must use all their efforts to achieve performance excellence [1]. At present, a majority of organizations find themselves functioning within an environment characterized by intense competition and constant fluctuations. This environment is marked by ongoing shifts in both internal and external factors, making it exceedingly challenging to anticipate and foresee these changes. In contrast, organizations invest substantial resources and effort in planning, organizing, and executing strategies with the aim of realizing their organization's long-term objectives and visions. Therefore, it is very important for managers and organizations to know to what extent their performance has been towards achieving goals and where their position is in current complex and dynamic environment. Therefore, survival and success of organizations in modern competitive environment, which is characterized by change and transformation, complexity and uncertainty, requires the adoption and implementation of effective strategies and continuous performance improvement [2]. The ongoing enhancement of organizational performance plays a pivotal role in fostering growth, development, and advantageous prospects for organizations. Various entities such as governments, organizations, and institutions are actively engaging in progressive efforts to achieve this. However, the continuous improvement of performance necessitates an examination of progress and goal attainment, as well as identifying challenges and obtaining feedback and information regarding policy implementation and areas requiring substantial improvement [3]. Consequently, this

study aims to investigate the impact of social media usage on firm performance, considering the mediating influences of organizational agility and innovation capability.

1.1 Organizational Agility and Firm Performance

In its literal sense, the term "agile" refers to swift movement and activity. Agility, on the other hand, encompasses the capability to move rapidly and effortlessly, as well as to think quickly and intelligently. The origin and foundation of agility can be traced back to agile manufacturing, which has gained popularity in recent times and is recognized as a successful strategy by manufacturers aiming to enhance their performance [4]. In such an environment, every organization must possess the capacity to concurrently manufacture diverse products with short lifespans, modify product designs, adapt production methods, and respond effectively to changes [5]. A manufacturer that has such capabilities can be considered to be an agile organization if it has those capabilities. Agility is the ability to adapt to changes and identify and effectively use the opportunities that arise as a result of change. Agile organization tends to satisfy its customers and employees. It is essential that every organization has the ability to respond to continuous changes in its business environment. In such organizations, agility thinking also aims to leverage opportunities and create stable conditions for innovation and capability growth [6].

Organizations need agility for several reasons. The first reason is limited business opportunities; in fact, presence of many competitors prevents long-term presence of the opportunities that have arisen, and every organization tends to achieve these opportunities with all its strength. The second reason is the lack of organizational capabilities necessary for rapid penetration of new products in the market. The third reason that has made agility necessary for current organizations is unpredictability of continuous changes at various levels of the market. The organization

may be enabled to distribute the existing risk among several cooperative companies by creating virtual organizations. The fourth important and key reason and advantage is creation of a virtual organization, which brings together all the capabilities available in all scattered companies [7]. Despite this, organizations must follow some rules and principles in order to create agility and accelerate responsiveness and flexibility so that they can achieve this goal quickly and effectively. Adherence to these principles indicates a culture of acceptance of organizational agility [8-9]. The conducted studies also show the role of organizational agility in improving firm performance [10-13]. Therefore, the following hypothesis is developed:

H₁: organizational agility is effective on firm performance.

1.2 Innovation Capability, Organizational Agility and Firm Performance

Increasing the competitive advantage of companies in the 21st century will largely depend on the ability of their organizations to develop innovative capabilities [14]. Having a clear understanding of the importance of innovation tends to make organizations more aware of effective ways of improving their innovation capabilities over time [15]. Throughout history, there has been a gradual transition between simple labor, raw materials, and consumption markets giving way to science and technology as the most important factors in national development. The rapid acceleration of converting data into information, information into knowledge, and knowledge into technology highlights the critical significance of creativity and innovation for the survival of both companies and countries. This assertion is further supported by empirical research [16]. In today's highly competitive business environment, one thing that remains consistent is the presence of change. The rapid advancements in technology across different industries, coupled with shorter product and service life cycles and heightened competition, have significantly emphasized the significance of innovation within organizations [17].

Innovation in the competitive world is not only necessary for growth of organizations but also for their survival [18]. New ideas and methods quickly replace previous methods and change has become a normal routine. Modern organizations require rapid and continuous innovation in products, services, technologies and processes. Due to rapid changes and intense competition, companies have no choice but to innovate. Companies that cannot consistently provide innovative products and services are doomed to failure. Therefore, the ability to continuously innovate products, services, and work processes is critical for organizations. Accordingly, "innovation" has been increasingly regarded as a research topic over the past twenty years [19]. Organizations that possess a higher level of innovation, as well as the ability to create and develop new skills and resources that enhance their overall performance, will be more effective in adapting to dynamic environments [20]. This is why innovation has been regarded as the most important factor of sustainable competition of the

organization [21]. The conducted studies also show the role of innovation in increasing organizational agility [22-24] and improving firm performance [25-30]. Therefore, the following hypotheses are developed:

H₂: innovation capability is effective on firm performance.

H₃: innovation capability is effective on organizational agility.

1.3 Social Media, Innovation Capability, Organizational Agility and Firm Performance

Recently, technological advances and increased use of social media have changed how organizations interact with their customers globally [31]. At present, social media is emerging as a crucial platform for businesses to engage and interact with customers. The utilization of social media in business communication can be attributed to the rapid growth of the online user community [32]. With the remarkable surge in social media usage, both individuals and various entities such as businesses and governmental organizations are embracing these platforms as their means of communication [33]. In the business realm, acquiring data from social networks and reaching a wider audience through information dissemination, as well as incorporating diverse channels into marketing strategies, play crucial roles in crafting effective branding approaches via social media [34]. Social media is easily available and can lead to increased communication. According to Fernando [35], organizations can develop connections with customers, leading to the establishment of relationships and a deeper comprehension of customer requirements, market conditions, and competitive positions. This understanding allows them to effectively introduce and promote their goods and products.

According to Mahmoud et al. [31], research findings indicate that companies utilize social media platforms, such as social networking sites, to establish direct connections with customers, boost website traffic, discover fresh business prospects, foster relationships, disseminate informational content, gather customer feedback, and overall enhance their brand. Therefore, rapid changes in modern world have challenged companies, but within this group, there exist prosperous enterprises that capitalize on the possibilities generated by managerial techniques and emerging technologies [36]. According to the research conducted, it has been observed that utilizing social media platforms has a favorable and noteworthy impact on the agility of organizations [37, 38]; innovation capabilities [39-41] and improving firm performance [42-47]. Therefore, the following hypotheses are developed:

H₃: social media usage is effective on firm performance.

H₄: social media usage is effective on innovation capability.

H₅: social media usage is effective on organizational agility.

H₆: innovation capability has a mediating role in the impact of social media usage on firm performance.

H₇: organizational agility has a mediating role in the impact of social media usage on firm performance.

H₈: innovation capability has a mediating role in the impact of social media usage on firm performance.

H₉: organizational agility has a mediating role in the impact of innovation capability on firm performance.

In general, the existing theoretical literature has highlighted the significance of social media usage, organizational agility, and innovation capability in relation to firm performance. However, upon reviewing empirical studies, it becomes apparent that only a limited number of research works have examined the impact of social media usage on firm performance, taking into account the mediating roles played by organizational agility and innovation capability specifically within the automotive industry. Consequently, the primary objective of this study is to develop a model that explores the influence of social media usage on firm performance, considering the mediating effects of organizational agility and innovation capability within the German automotive sector. Based on insights derived from the relevant theoretical literature and framework, Fig. 1 illustrates the conceptual model for investigation.

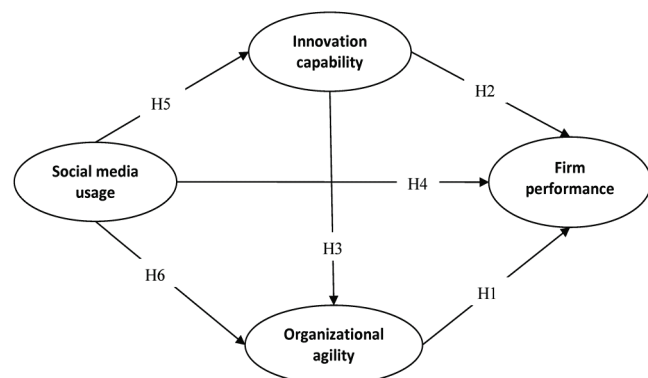


Figure 1 Conceptual model

2 RESEARCH METHODOLOGY

This study employs a descriptive correlational approach with structural equation modeling (SEM) using partial least squares (PLS) to investigate the associations between variables.

2.1 Sampling

The study involved individuals in managerial, deputy, and expert roles within the German automotive sector. A total of 200 surveys were disseminated among this population. Out of these, 148 questionnaires (74%) were successfully filled out and subjected to analysis.

2.2 Data Collection Instruments

We utilized a questionnaire to assess social media usage, which was developed by Dodokh and Al-Maaitah [48] based on existing research conducted by Boshoff and Elliot [49], Moen et al. [50]. The questionnaire comprises 15 items that gauge social media utilization for marketing (5 items), customer relations and service (5 items), and information

accessibility (5 items). For measuring innovation capability, we employed the questionnaire developed by Janssen [51] and Akman and Yilmaz [52]. This questionnaire includes 15 items, assessing both individual innovation capability (9 items) and organizational innovation capability (6 items). To assess organizational agility, we used the questionnaire developed by Lu and Ramamurthy [53]. This questionnaire consists of 6 items, measuring investment agility in the market (3 items) and operational agility (3 items). Lastly, firm performance was measured using the questionnaire developed by Rai et al. [54], which comprises 6 items. All items were rated on a five-point Likert scale, ranging from "totally disagree" (1) to "totally agree" (5).

3 RESULTS

3.1 Validity and Reliability

To assess reliability, the study employed Cronbach's alpha coefficient and composite reliability. Validity was evaluated through factor loadings, average variance extracted, and the Fornell-Larker test. Composite reliability index proposed by Hair et al. [55] is better than Cronbach's alpha. Because in Cronbach's alpha index, the observable variables of each measurement model have the same weights. In fact, it equates their relative importance, but this assumption does not exist in composite reliability. In fact, composite reliability uses the factor loadings of the items when calculating; this change in calculation shows more and better composite reliability values than Cronbach's alpha ratio. Like Cronbach's alpha coefficient for internal consistency of the measurement model, value of this index is 0.7 or higher. According to Saeidi et al. [56], Nazari-Shirkouhi et al. [57], in confirmatory factor analysis, a factor load of 0.6 or higher for each item signifies that the construct is clearly defined. According to Table 1, the factor loadings for items of the variables are more than 0.6; as a result, the factor loadings are confirmed. The important point here is that if calculation of factor loadings between the construct and its indicators lead to values less than 0.6, we should modify those indicators (questionnaire items) or remove them from the model. Average Variance Extracted (AVE) was used to check convergent validity. Fornell and Larcker [57] suggest utilizing AVE values of 0.5 or higher, indicating that the construct accounts for 50% or more of the variance in its markers [56]. The variables' factor loadings, composite reliability, and AVE are presented in Tab. 1. The values of these tables show the adequate and appropriate reliability of the constructs. Fornell and Larcker [57] propose that an AVE value of 0.5 or higher is desirable, indicating that the construct accounts for at least 50% of the variability in its indicators. The results presented in Tab. 1 include the factor loadings, composite reliability, and AVE values for the variables. These findings demonstrate the satisfactory and suitable reliability of the constructs.

The Fornell-Larker index was employed to assess the discriminant validity of the constructs. For this criterion to be met, the square root of the AVE for a given construct should exceed the correlation between that construct and other constructs. This suggests that the correlation between the

construct and its indicators is stronger than its correlation with other constructs. The outcomes of the correlation analysis and the second validity criterion, i.e., the square root of AVE, are presented in Tab. 2.

Table 1 Factor loadings, composite reliability and AVE of variables

Variable	Item	Factor	α	CR	AVE
Social media for marketing	1	0.861	0.835	0.884	0.604
	2	0.778			
	3	0.756			
	4	0.778			
	5	0.704			
Social media for customer relations and services	1	0.773	0.870	0.906	0.659
	2	0.825			
	3	0.811			
	4	0.799			
	5	0.849			
Social media for information accessibility	1	0.777	0.813	0.870	0.573
	2	0.710			
	3	0.783			
	4	0.743			
	5	0.768			
Individual innovation capability	1	0.776	0.933	0.944	0.653
	2	0.771			
	3	0.808			
	4	0.845			
	5	0.827			
	6	0.848			
	7	0.774			
	8	0.815			
	9	0.802			
Organizational innovation capability	1	0.872	0.927	0.943	0.732
	2	0.848			
	3	0.868			
	4	0.839			
	5	0.844			
	6	0.864			
Market investment agility	1	0.883	0.822	0.895	0.740
	2	0.902			
	3	0.791			
Operational agility	1	0.880	0.742	0.854	0.661
	2	0.782			
	3	0.773			
Firm performance	1	0.731	0.865	0.899	0.599
	2	0.731			
	3	0.824			
	4	0.805			
	5	0.791			
	6	0.755			

Table 2 Matrix of correlation and root square of AVE of variables

Variable	Social media usage	Innovation capability	Organizational agility	Firm performance
Social media usage	0.70			
Innovation capability	0.50**	0.79		
Organizational agility	0.51**	0.50**	0.77	
Firm performance	0.60**	0.67**	0.59**	0.77
Note: The diagonal entries of the correlation matrix correspond to the square root of the AVE				

Based on the findings presented in Tab. 2, it can be observed that the square root of AVE for each variable exceeds its correlation with other variables. This indicates

that there is discriminant validity among the variables. Furthermore, the values below the diagonal in the correlation matrix were examined to assess the relationships between these variables. It is evident that all variables possess a positive and statistically significant correlation coefficient.

3.2 Structural Model Testing

To anticipate the performance of a company, an investigative study was conducted using a proposed conceptual model and SEM. The estimation of the model was accomplished utilizing the PLS method in accordance with the hypotheses. To assess the significance of path coefficients, t-values were calculated through the bootstrap method, employing 500 sub-samples. Fig. 2 illustrates the tested model, portraying the interconnectedness between variables. As depicted in Fig. 2, social media usage exhibits a positive and significant impact on innovation capability, organizational agility, and firm performance. Likewise, innovation capability demonstrates a positive and significant influence on both organizational agility and firm performance. Furthermore, organizational agility exerts a positive and significant effect on firm performance. The numbers enclosed within the circle represent the explained variance of the respective variables. Tab. 3 presents the path coefficients and the amount of explained variance for the variables.

Table 3 Path coefficients and explained variance

Variable	β	t-value	p-value	Variance
On firm performance vie:				
Social media usage	0.26**	2.927	0.01	0.59
Organizational agility	0.26**	3.456	0.001	
Innovation capability	0.42**	4.849	0.001	
On organizational agility vie:				
Social media usage	0.34**	3.574	0.001	0.34
Innovation capability	0.33**	3.601	0.001	
On innovation capability vie:				
Social media usage	0.50**	6.651	0.001	0.25

* $p < 0.05$; ** $p < 0.01$

Based on the findings presented in Tab. 3, it can be observed that social media usage has a positive and significant impact on innovation ability, organizational agility, and firm performance. Furthermore, innovation capability also exhibits a positive and significant relationship with organizational agility and firm performance. Additionally, organizational agility demonstrates a positive and significant influence on firm performance. Moreover, the model variables account for 59% of the variance in firm performance, 34% of the variance in organizational agility, and 25% of the variance in innovation capability, indicating their explanatory power. The indirect coefficients are reported in Tab. 4.

The findings presented in Tab. 4 indicate that both innovation capability and organizational agility play a crucial role in mediating the positive impact of social media usage on firm performance. Specifically, innovation capability acts as a significant mediator in the relationship between social media usage and organizational agility. Additionally, organizational agility also mediates the effect of innovation

capability on firm performance. Furthermore, the results of hypotheses testing are summarized in Tab. 5.

In PLS analysis, the Goodness of Fit (GOF) index serves as a comprehensive measure to assess the validity and quality of the model. It evaluates the overall predictive capability of the model and determines its effectiveness in predicting the

endogenous variables. In this study, the absolute fit index of GOF for the tested model was found to be 0.67, indicating a suitable fit. A value above 0.36 is considered adequate and acceptable, suggesting that the model demonstrates good quality.

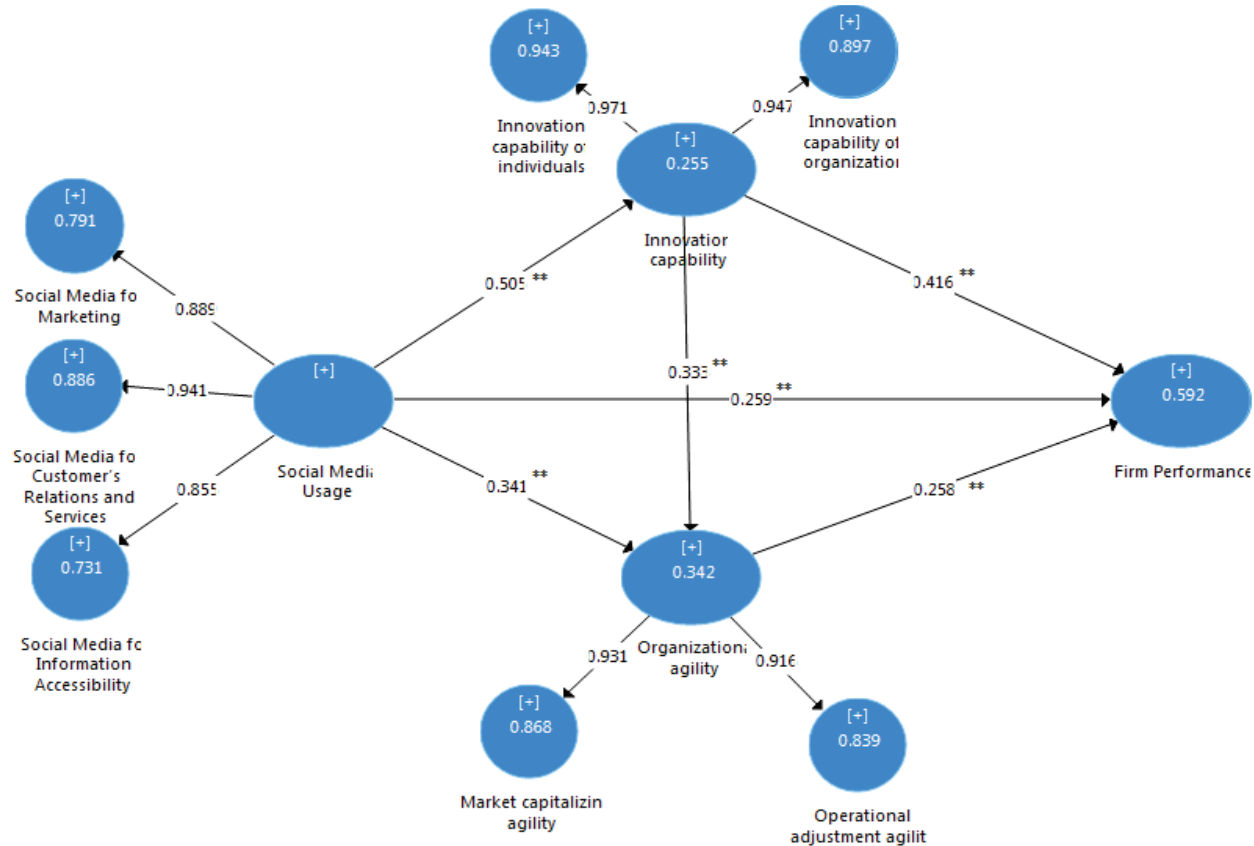


Figure 2 The tested model

Table 4 Indirect coefficients

Indirect paths	Indirect effects	t-value	p-value
Social Media Usage → Innovation capability → Firm performance	0.210	3.771	0.000
Innovation capability → Organizational agility → Firm performance	0.086	2.482	0.013
Social Media Usage → Innovation capability → Organizational agility → Firm performance	0.043	2.469	0.014
Social Media Usage → Organizational agility → Firm Performance	0.088	2.368	0.018
Social Media Usage → Innovation capability → Organizational agility	0.168	3.121	0.002

Table 5 Results of hypothesis testing

Hypothesis	Result
H1: Organizational agility is effective on firm performance	Confirmed
H2: Innovation capability is effective on firm performance	Confirmed
H3: Social media usage is effective on firm performance	Confirmed
H3 Social media usage is effective on firm performance	Confirmed
H4: Social media usage is effective on innovation capability	Confirmed
H5: Social media usage is effective on organizational agility	Confirmed
H6: Innovation capability has a mediating role in the effect of social media usage on firm performance	Confirmed
H7: Organizational agility has a mediating role in the effect of social media usage on firm performance	Confirmed
H8: Innovation capability has a mediating role in the effect of social media usage on firm performance	Confirmed
H9: Organizational agility has a mediating role in the effect of innovation capability on firm performance	Confirmed

4 DISCUSSION

The purpose of this research was to examine the impact of social media usage on a company's performance, taking

into account the mediating roles of organizational agility and innovation capability through SEM. The findings indicated that the suggested model demonstrated a satisfactory fit with the collected data and managed to account for 59% of the

variation in firm performance, 34% of the variation in organizational agility and 25% of the variation in innovation capability.

The findings from the SEM indicate that utilizing social media has a favorable and substantial impact on innovation capability, organizational agility, and overall firm performance. Therefore, social media usage leads to an increase in innovation and organizational agility and improves firm performance. This discovery aligns with the research conducted by Zhang et al. [37], Ahmadi and Ershadi [38], Le and Chakraborty [39], Borah et al. [40], Noruzy et al. [42] and Nguyen et al. [43]. In order to elucidate this discovery, innovation and organization agility will increase and firm performance will improve if the organization uses social media to promote its products, promotes its brand through social media, evaluates its marketing performance by receiving feedback (like, share and follow in Instagram, Facebook and Twitter), strategically gathers customer feedback from various social media platforms and establishes strong connections with its customers by engaging in ongoing communication through these channels. It conducts customer service activities on social media, leveraging the feedback received to enhance the quality of its products. Additionally, the company utilizes social media as a means to reach out to potential customers, while also utilizing it to acquire valuable insights about the target market and competitors. Furthermore, the company effectively employs social media to provide comprehensive information about its products. In general, social media are useful and valuable for network participants because they increase and promote activities and use of resources. In market conditions, social media provide significant benefits, including improving the economic value of organizations.

Another finding of the model is that innovation capability positively influences organizational agility and firm performance. Therefore, innovation capability leads to increasing organizational agility and improving firm performance. This discovery aligns with the research conducted by Hatunoğlu [22], Cepeda and Arias-Pérez [24], Ravichandran [12], Bahta et al. [25], Chen et al. [26], Saunila et al. [29] and Calantone et al. [30]. To explain this finding, organizational agility will increase and performance will improve if the organization has the ability to offer new products/services to customers, has introduced new processes and service methods, has created new management methods, has used new marketing methods, has created new business models, believes that it is necessary to deliver products/services to customers according to the latest technologies, and tries to provide the highest quality for customers, is able to develop new products before competitors, actively adapts itself to customer needs, and allocates more funds to research and development compared to competitors. Therefore, organizations equipped with the ability to innovate have a distinct advantage in swiftly addressing environmental challenges and effectively capitalizing on emerging products and market prospects, surpassing their non-innovative counterparts. Consequently, this enhances overall business performance.

The model's findings indicate that organizational agility plays a crucial role in enhancing firm performance. Consequently, the study demonstrates a positive and

noteworthy impact of organizational agility on overall business outcomes. These results align with the research conducted by Wamba [10], Felipe et al. [5], Nazari-Shirkouhi et al. [11] and Ravichandran [12]. According to this finding, firm performance will improve if the organization makes appropriate decisions and implements quickly in the face of market/customer changes, considers market-related changes and apparent chaos as an opportunity for quick investment, has the ability to rapidly improve products/services to meet customer expectations, responds and fulfills customer demands quickly and customers have confidence in this ability whenever there is a disruption in supply, the organization can quickly make replacement adjustments and internal adjustments, and has the ability to deal with changes in the market and customer demand in business processes physically and quickly. Organizational agility describes business flexibility and the ability to respond in the market environment. Companies that tend to remain in this environment must constantly search for new business opportunities. Organizational agility makes organizations learn to make rapid changes and be able to transform and renew the company without losing opportunities and thus achieve business success.

5 MANAGERIAL REMARKS

Automotive industry managers are suggested to consider social media usage for marketing, for customer relations and services, and for information accessibility. Because social media usage facilitates identification of potential customers, facilitates the identification of customer view in obtaining important market information, facilitates the identification of potential customers to communicate in the market. In addition, it makes them aware of the market conditions, the nature and intensity of competition in it, so that they can adopt appropriate strategies to adapt to the market and allocate more resources and time to the activities needed to improve firm performance.

Considering the role of innovation capability, it is suggested to managers of the automotive industry that delivery strategy of the company be in accordance with the latest technologies of the day, be able to develop new products before the competitors, actively adapt itself to customer needs, allocate more budget to R&D department, improve its business processes and use new managerial approaches.

Considering the role of organizational agility, the managers are suggested to discover environmental changes quickly, identify opportunities and threats in the environment, make decisive decisions to cope with environmental changes, adopt clear decisions to manage coping opportunities and respond to changes in the business environment.

6 CONCLUSION

The findings indicate that the utilization of social media, the capability to innovate, and organizational agility are predictors of firm performance. Furthermore, the study reveals that innovation capability and organizational agility play a positive and significant mediating role in the

relationship between social media usage and firm performance. Similarly, innovation capability mediates the effect of social media usage on organizational agility, and organizational agility mediates the impact of innovation capability on firm performance. In conclusion, it can be inferred that incorporating social media into online marketing strategies is crucial for companies to enhance their performance through fostering innovation and organizational agility. Failure to engage with social media deprives companies of valuable opportunities to connect with consumers, given the increasing ubiquity of the Internet and the growing significance of social media as an essential tool in digital marketing efforts.

7 LIMITATIONS

This study involved a limited number of managers, deputies, and experts from the German automotive industry, making it difficult to generalize the findings. The results are solely based on self-reported data. For further research the impacts of social media usage in the automotive industry, future studies should consider incorporating qualitative and mixed research methods. It is important to note that the current study is correlational in nature and does not support causal inferences.

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Forecasting Daily Air Quality Index and Early Warning System for Estimating Ambient Air Pollution on Road Networks Using Gaussian Dispersion Model with Deep Learning Algorithm

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Abstract: The rapid growth of the vehicle population is a major factor in heavy air pollution and public health issues. Traffic-related air pollutants (TRAPs) on roads are often much higher than ambient values, leading to high exposure levels in vehicles. This research proposes a hybrid forecasting model for early detection and early warning systems (EWS) of road networks during real-world travels. Data is collected from Kannur, Calicut, Palakkad, and Coimbatore using real-time sensors, including surrounding discussion information, activity information, vehicle speed, and stopping events. The study predicts ambient air quality (AAQ) levels on the road network using the Gaussian Dispersion model (GDM) and measures the risk sensitivity of PM₁₀ and PM_{2.5} in selected regions. This helps formulate powerful prevention strategies and prevent negative health impacts. The air pollution module for predicting concentration has an innovative hybridization model that combines an improved cuckoo search (CS) and differential evolution (DE) algorithm with a stacked LSTM model to increase forecasting accuracy of six major environmental pollution levels. This model predicts the AAQ level and is effective and robust for warning one day before the pollutant event occurs based on the risk level of an ambient air pollutant from the RN.

Keywords: Air Quality Index (AQI); Ambient Air Pollution (AAP); EWS; GDM; Hybrid Forecasting Method; LSTM; Road Networks

1 INTRODUCTION

Atmospheric oxidation capacity (AOC) is the main factor promoting the development of multidimensional air pollution in the troposphere and the near-surface atmosphere, it regulates both the pace at which trace gases are removed and the rate at which secondary pollutants are produced [1]. Governmental agencies use the AQI to estimate air pollution levels and educate the public. The growth in AQI is anticipated to have major negative health implications on a sizeable section of the population [2]. A pollution concentration and an air monitor during the average period that is predetermined are necessary for the AQI measurement [3]. An EWS uses integrated communication technologies as a climate change adaptation strategy to assist communities with potentially dangerous climate-related events. Long-term sustainability is supported by the successful EWS by preserving people, jobs, land, and infrastructure [4]. Initiator monitoring poses major hazards, such as those brought on by the use of CBRN (biological, radiological, chemical, and nuclear) agents, which are crucial given the increasing threat of war and terrorism [5]. There is a need for safety systems that can identify these dangerous substances, continuously monitor the air, and protect people from them [6]. It has become vital to install stationary pollution and radiation identification sensors in public utility facilities, vehicles, and buildings so that continuous air quality monitoring and protection is carried out at significant places [7].

Pollutant levels such as PM_{2.5}, NO₂, and SO₂ can be determined using data obtained from various air quality monitoring stations [8]. Some gases, such as CO₂ and CO can even be found using portable sensors. An AQI and a category, such as good, average, and unhealthy, are used to quantify air quality [9]. The effect of numerous factors, including traffic flow, fast urbanisation, land use, massive industry, and population density causes large location- and time-specific variations in urban air quality [10]. Every country's economic development depends on a large part of its RN. To provide reliable connections between the various

portions of geographical territory, it is crucial to foresee a deliberate and ongoing extension and adequate maintenance of these networks [11]. Air quality is negatively impacted by traffic-related concerns such as outdoor parking and the density of the system of roads [12]. A Geographic Information System (GIS) that incorporates sub-models enables the use of geographical coordinates to represent the layout of urban areas, transportation networks, and the dispersion of pollutants in the atmosphere [13]. Monitoring the polluting gases regularly is vital to control air pollution. In the literature, several sensor network-based air contamination supervision systems have been developed, implemented, and evaluated [14]. The methodology employed the evaluation attributes, the testing location, the pollutants assessed using sensors, the system performance, the communication device used, and the microcontroller used are all considered when compared to the pollution monitoring systems [15]. To evaluate AAP on RN, the research will analyse the index of air quality and EWS using a GDM and deep learning algorithm. The remainder of the report is organised as follows: Section 2 describes the research's literature review, and Section 3 describes the problem definition and research's rationale. The proposed approach is shown in section 4, the experimentation and findings are shown in section 5, and the research's conclusion is explained in section 6.

2 LITERATURE SURVEY

The spatial qualities of each type of road and the average annual PM₁₀ concentration relationship were investigated by Sohrab et al. [16]. The study's findings are utilized to reduce conflicts between the environment and transport that affect air quality in urban, urban-rural fringe, and rural (agricultural) environments. Accordingly, Song et al. [17] evaluated the relative value of features, the meteorological set of characteristics is the most relevant, followed by the land use features. Using a small number of air pollution monitoring stations, the suggested Multi-AP approach might

be used to calculate air pollution exposure in a city. Galán-Madruga et al. [18] investigated a method for estimating benzene air concentrations from the associated factors. The calculated and the regional distribution of the most typical benzene levels were identical. Finally, a synthetic neural network located the AQMN's fixed benzene monitoring locations that were the most representative. To improve human health, an IoT-qualified Environmental Toxicology for Air Pollution Monitoring expending the Artificial Intelligence method (ETAPM-AIT) is developed by Asha et al. [19]. The experimental results demonstrate how well the suggested ETAPM-AIT model outperforms more recent methods. A pattern of inexpensive IoT systems for tracking AQI and traffic flow was presented by Martn-Baos et al. [20]. The suggested architecture is to be validated and enabled with a range of climatic and traffic circumstances, which is the experimentation with data from many cities reflecting various scenarios.

Modern high-resolution European emission inventories for air quality models were studied by Kuenen et al. [21]. Emissions from shipping (both on land and at sea) are estimated using the results of an emission model like separate shipping, which based emissions on real ship movement data and the agricultural waste burning emissions on satellite observations. To forecast short-term local NO_2 and O_3 concentrations, Res-GCN-BiLSTM, a new deep learning (DL) based hybrid model that combines the bidirectional long short-term memory (BiLSTM) and residual neural network (ResNet) was investigated by Wu et al. [22] and graph convolutional network (GCN). The Res-GCN-BiLSTM model performed better than the best-performing baseline model in terms of pollutant adaptation and forecast accuracy, with mean absolute error improvements for NO_2 and O_3 of almost 11% and 17%, respectively. Moses et al. [23] assessed the cadmium and allowed them to monitor the AAQ. According to the study, none of the dust that was spread across the exposed vegetable leaves in each market had any cadmium. To demonstrate the interrelated issues of emissions, behaviour, and the anticipated exposure to PM_{10} for groups of drivers and underground commuters in Seoul CBD by using an agent-based simulator for traffic Shin et al. [24]. The air quality measurements showed that background PM_{10} was much lower than roadside PM_{10} by about 25-30%. For the West Midlands region, Zhong et al. [25] simulated the street-scale resolution air quality. An effective tool for assessing prospective regional mitigation and local air pollution measures is the coupled air quality modelling system for WM. Using the GDM and a DL algorithm, this research study presents an AQI and EWS for evaluating AAP on RNs. Data mining constitutes a stated removal of hidden information about predicting from large files. From the large database, the necessary information is fetched using the data mining process. Here, Neelaveni et al. [26] discussed how data mining techniques are applied in the agriculture field.

3 RESEARCH PROBLEM DEFINITION AND MOTIVATION

A series of environmental issues, including air pollution, deforestation, solid waste management, the release of toxic materials, and many more, have accumulated further consideration than ever before as a finding of urban areas'

continuous expansion and population growth. There is an essential for fast information regarding changes in the level of pollution because the issue of air effluence in cities has gotten so severe. One of the causes of air contamination is vehicle exhaust emission during transportation activities. Congestion may be caused by an increase in motor vehicle traffic, a reduction in road space, and activity along the roadside. The primary contributors to air pollution are fossil fuel oil for motor vehicle exhaust emissions. Nitrogen oxide (NO_x) in the forms of nitrogen dioxide (NO_2) and nitric oxide (NO), carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM_{10}), sulphur oxides (SO_x) in the forms of sulphur dioxide (SO_2) and sulphur trioxide (SO_3), and hydrocarbons (HC) are among the pollutants that are released by motor vehicles. These vehicles emit toxic pollutants that, if exposed continuously and over an extended period, have a detrimental effect on human health. Therefore, the goal of this research is to determine how well air pollution levels in the environment may be calculated using the infrastructure's road structural characteristics.

In India, the revelation of ambient particulate thing is the main environmental risk factor. However, Indian cities rank high in the world for $\text{PM}_{2.5}$ air pollution, which has serious negative effects on health. Numerous monitoring locations all over India record continual transgressions of NAAQS breaches and high concentrations (CPCB, 2016). High ambient $\text{PM}_{2.5}$ concentrations have been linked to anthropogenic activities such as fossil fuels burned for electricity generation, industrial processes, road transportation, and traditional residential cooking in India. Without adequate controls, it is conceivable to anticipate additional decays in air superiority due to rising levels of polluting economic activity. Global history shows that clean air may be attained without compromising social and economic progress, though. Numerous research on the impact of traffic-related motor vehicle emissions on air pollution has been done. Through vehicle consumption emission and traffic simulation calculation using Matlab software, the research's goal was to examine the execution of the selected area's RN and vehicle exhaust emissions.

4 PROPOSED RESEARCH METHODOLOGY

In our novel approach for forecasting daily Air Quality Index (AQI) and implementing an Early Warning System (EWS) to estimate ambient air pollution on road networks, we propose a hybrid methodology that combines the Gaussian Dispersion Model with a state-of-the-art Deep Learning Algorithm. Firstly, we leverage the spatial dispersion patterns obtained from the Gaussian model to enhance the understanding of pollutant behaviour across road networks. Subsequently, we integrate a deep learning algorithm, such as a Convolutional Neural Network (CNN), to capture complex temporal and spatial dependencies in the air quality data, ensuring accurate and robust predictions. Our methodology not only provides precise daily AQI forecasts but also establishes a proactive EWS for timely pollution alerts, facilitating effective mitigation strategies.

Monitoring and lowering air pollution begins with the evaluation of air quality. The air supply's suitability for a particular application depends on its properties. Criterion air pollutants are one of the prevalent air pollutants in India. Traffic is extremely diverse on Indian roadways in general and Indian urban highways in particular, with a broad range of static and dynamic characteristics present. Due to the heterogeneity, lane discipline is difficult to enforce, and the vehicles occupy positions on any area of the road depending on available space. Therefore, a suitable modelling method must be created to recreate the traffic flow conditions that have been specified. The complete road space is regarded as a single unit in the proposed simulation technique, without any designated traffic lanes. The vehicles will be visualised as rectangular blocks with dimensions that occupy a predetermined portion of the road space. The coordinates of an origin will be used to indicate the vehicle's position. The interval scanning approach with fixed addition time improvement is the foundation of the simulation model. The length and width of the road stretch can be changed for simulation purposes according to user specifications.

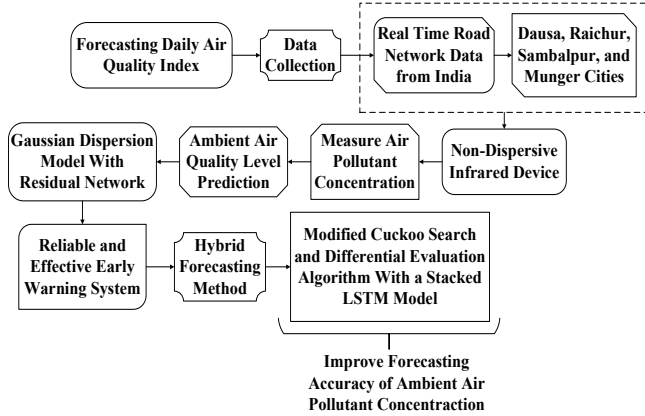


Figure 1 Block Diagram for the Proposed Work

Fig. 1 depicts the flow diagram of the research work. Its accurate real-time air pollution predictions are essential for providing early particle matter warnings. This study determines to forecast that particulate matter concentrations will change over time. A high-volume air sampler (HVAS) device was used to test the concentration of PM10 pollution, a non-dispersive infrared device was used to measure the concentration of CO pollutants, and an impinger tube was used to measure SO₂, O₃, and NO₂ pollutants. DL is a leading statistical technique, which is crucial for anticipating outdoor air quality. The development of prediction models using DL is further guaranteed by the fact that air pollutant concentrations are typically connected with other characteristics, such as SO₂, O₃, CO and NO₂, and these parameters can be detected by real-time sensors. To construct a three-level architecture, this study proposed an end-to-end prediction technique that combines ResNet features with the stacked LSTM variants. The objective is to fully materialise a spatiotemporal association characteristic for PM concentration estimation.

(a) Data Collection: The primary data of this study were obtained directly from the research site, while secondary data were obtained from other sources. The search locations are Kannur, Calicut, Palakkad and Coimbatore Road. The main data used in this study are traffic data such as vehicle speed, traffic volume and number of parking times obtained from a survey at the research site, air pollution data obtained by direct on-site measurements using sensors in collaboration with the Transport Road Research Laboratory and on-road data geometry, obtained by direct measurement at the study site. Actual environmental data in ambient air was collected for three months, from October 2022 to December 2022, as part of the main data collection of the first phase. The weather was sunny with an air temperature of 32 °C at the time the survey collected data.

The surveyors on each road section on the Kannur, Calicut, Palakkad, and Coimbatore RN recorded traffic volume, vehicle speed, and parking events. Traffic data collection also involved traffic volume, vehicle speed, and parking data. Traffic volume data were recorded hourly for each road segment between the hours of 8:00 AM to 10:00 PM. By sampling 30 variable types of vehicles on the selected RN, a speed gun was used to measure the data on vehicle speed. As a result, parking data were acquired by collecting parking events after the entry and exit times of the vehicles at the parking spot in the selected region. The crossroads in Kannur, Calicut, Palakkad, and Coimbatore that had the most traffic and the highest levels of vehicle exhaust emissions were where the ambient air pollutant concentration was measured. Data collection on pollutant content in ambient air took place from 8:00 AM to 10:00 PM for a year, from June 30, 2023, to June 30, 2023. The background for the RN in data processing will be provided by aerial images obtained with Google Earth software as secondary data, respectively.

(b) Ambient Air Quality Level Prediction: When assessing the air quality, the AAQ is crucial. The main air contaminants that, if present at harmful levels, could potentially impair human health are typically included in an air pollution index system. Instead of using the actual concentration of air pollution, an AAQ system is typically constructed in easily understandable ranges of values as a means of reporting the air quality or level of air pollution. To extract the highest level of abstraction from the data, the residual network and GDM are introduced in this study.

(i) GDM: The complex system of different equations that describes the pollutant concentration as a finding of dispersion processes is approximated analytically by the Gaussian plume:

$$\hat{C}(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) \right] \quad (1)$$

Where \hat{C} represents the estimated concentration at a specific location, Q defines the rate of emission of pollutant from a point source at the origin of the coordinate system x , y and z are the crosswind, downwind, and vertical distances

from the source. \hat{u} defines the time-averaged fast wind at the effective release height H along the x-axis, whereas σ_y and σ_z stand for the crosswind standard deviations. Eq. (2) specifies the effective height of release.

$$H = H_s + \Delta h \quad (2)$$

Where, H_s defines the point of emission's height and Δh is the ascent of the plume. The Gaussian plume model (GPM) is predicated on several hypotheses, such as a uniformly turbulent wind field, steady-state airflow, a steady-state point source of pollution, and total reflection of the pollutant from the ground. It serves as the foundation for several widely used mechanistic air pollution models.

The GPM was parameterized to allow for utilisation as a non-linear regression model. Only vigilant (high-end) estimates are available from regulatory organisations, and the emission rates in this study region are not available with absolute certainty. The actual emission rates are estimated to be αQ where, $0 \leq \alpha \leq 1$ such that the ground-level ($z = 0$) concentration can be stated as follows, presuming that the relative errors in the emission rates are comparable for all sources.

$$\hat{C} = \frac{\alpha Q}{\pi \sigma_y \sigma_z \hat{u}} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \exp\left(\frac{H^2}{2\sigma_z^2}\right) \quad (3)$$

There are numerous methods for parametrizing the dispersion standard deviations. Power-law relationships with the downwind distance from the source were selected due to their widespread use, mathematical simplicity, and relatively low number of required parameters.

$$\sigma_y = \frac{x^{p_7}}{\sqrt{2p_6}}, \sigma_z = \frac{x^{p_9}}{\sqrt{2p_8}} \quad (4)$$

Where the optimization parameters are denoted as p_{6-9} . In this concept, emissions from traffic are portrayed as local sources. In the Gaussian formulation, this offset is designated as p_4 . Additionally, it is believed that some unidentified factor p_2 converts traffic attributes to emission rates homogeneously (in space but not in time). The full Gaussian function estimates the concentration at the i th grid cell as described below, taking into consideration all the point and area sources in the study region.

$$\hat{C}_i = p_1 + p_2 \sum_{j=1}^M T_j \cdot g_t(x_{ij}, y_{ij}, \hat{u}) + p_3 \sum_{j=1}^K Q_j \cdot g_q(x_{ij}, y_{ij}, H_j, \hat{u}) \quad (5)$$

Where, p_1 denotes a spatially uniform baseline concentration, T_j denotes the amount of traffic in the j th grid cell, M denotes the number of grid cells in the study area, K denotes the number of point sources in the study area, Q_j denotes the rate of emission from the j th industrial stack, and the following definitions of g_q and g_t are given.

$$g_q(x, y, H, u) = \frac{1}{u \cdot x^{p_7+p_9}} \exp\left(-\frac{p_6 y^2}{x^{2p_7}} - \frac{p_8 y^2}{x^{2p_9}} - p_5 x\right) \quad (6)$$

$$g_t(x, y, u) = \frac{1}{u \cdot (x+p_4)^{p_7+p_9}} \exp\left(-\frac{p_6 y^2}{(x+p_4)^2 p_7} - p_5 x\right) \quad (7)$$

Where, p_{7-9} is utilised to model the dispersion standard deviation and p_5 is the pollutant's first-order removal coefficient. In actuality, atmospheric chemical interactions may be much complex than first-order removal, that as predicted by p_5 . However, information like the concentration of hydroxyl radicals, which is frequently unavailable, is needed for an accurate description of these interactions.

(ii) Residual Network: The residual network prevents the disappearance or explosion of gradients by acting as a shallow exponential set. By including shortcut connections, ResNet can be optimised more easily. A few layers that include shortcut connections are referred to as residual blocks. The neural network's conventional input and output are x and $F(x)$, and its training target is $F(x) = H(x)$. In this ResNet, x serves as the neural network's input, $H(x) + x$ serves as its output, and $H(x) = F(x) - x$. $H(x)$ serves as its training objective. This refers to $H(x)$ as residual. $H(x)$ is simpler to train than $F(x)$. Assuming the size of the input pixel matrix is 32×32 , this ResNet unit.

- The convolutional kernel size is 1×1 and there are 64 convolutional kernels in the first layer. Batch Normalisation (BN) and the activation function ReLU() are then applied.
- The second layer's convolutional kernel is 3×3 in size, there are 64 of them, and the subsequent procedure is the same as it was for the first layer.
- There are 256 convolutional kernels in the third layer, with a convolutional kernel size of 11. There is only one 33 convolutional kernel in the shortcut connection. The residual convolution and BN are carried out following the third convolution.
- Finally, a full connection layer is employed to obtain the $32 \times 32 \times 256$ -sized ResNet output.

Accordingly, at daily time intervals, this model extracts and records spatiotemporal characteristics. A hybrid forecasting model, which is detailed in the following part, is used to input these extracted features into the EWS.

(c) Hybrid Forecasting Method for Early Prediction and Early-Warning System: The new early-warning system for air quality was examined, and its design was based on a hybrid forecasting technique. To generate a precise operating strategy to lessen the negative effects when air pollution events occur, this system is made to obtain correct air quality information in advance.

(i) Modified CS and DE Algorithm: To increase the estimation accuracy, prevent local optima, and optimize the initial weights and thresholds of the stacked LSTM model, a hybrid modified optimization technique between CS and DE is proposed in this part. Here, air pollution concentrations are predicted using a stacked LSTM model. The initial weights and thresholds of the stacked LSTM algorithm were optimized using a CS and DE combined update optimization method to increase convergence stability. The predictive ability was tested using top six ambient air pollutant data compiled in India. Based on the predicted air quality, it successfully operated the early warning system.

Cuckoo Search: With the help of the transformation parameter p_a , the CSA successfully integrates the local stochastic process and the global search stochastic process. It is possible to define the local stochastic process as follows.

$$x_i^{(t+1)} = x_i^{(t)} + \alpha s \oplus H(p_a - \varepsilon) \otimes (x_j^t - x_k^t) \quad (8)$$

Where, ε is a random number drawn from the random distribution, $H(\cdot)$ is the Heaviside function, x_j^t and x_k^t are two separate random sequences, and s is the step size. The Lévy flight process is used to implement the global stochastic process.

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \frac{\lambda \Gamma(\lambda) \sin(\pi \lambda / 2)}{\pi} \frac{1}{s^{1+\lambda}}, \quad s \gg s_0 > 0, 1 < \lambda \leq 3 \quad (9)$$

Where, the step size's scaling factor is defined as α .

Differential Evolution Algorithm (DE): The DE algorithm is the most potent random real-parameter optimisation method available today. It is a straightforward and effective global optimisation technique in continuous space. The parameter vector, mutation, initialization, selection and crossover are the first four processes in each iteration of the DE. An initial real parameter vector made up of NP individuals with d-dimension makes up the DE population. The following describes the expression of the population P^g and \tilde{x}_i^g :

$$P^g = \{\tilde{x}_1^g, \tilde{x}_2^g, \dots, \tilde{x}_n^g\} \quad (10)$$

$$\tilde{x}_i^g = [x_{1,i}^g, x_{2,i}^g, \dots, x_{n,i}^g] \quad (11)$$

By using the differential mutation approach described below, the donor vector $\tilde{v}_i^g = [v_{1,i}^g, v_{2,i}^g, \dots, v_{D,i}^g]$ corresponding to the i -th target vector \tilde{x}_i^g is produced:

$$\tilde{v}_i^g = \tilde{x}_{r1}^g + F \cdot (\tilde{x}_{r2}^g - \tilde{x}_{r3}^g) \quad (12)$$

Where, $F \in [0.4, 1]$ defines the proportionate coefficient and, \tilde{x}_{r1}^g , \tilde{x}_{r2}^g , and \tilde{x}_{r3}^g are independent parameter vectors selected at random from the current population. Using a binomial crossover, the trial vector corresponding to the i -th target vector \tilde{x}_i^g is produced as follows:

$$u_{j,i}^g = \begin{cases} v_{j,i}^g, & \text{rand}_{i,j}[0,1] \leq Cr \text{ or } j = j_{rand} \\ x_{j,i}^g, & \text{otherwise} \end{cases} \quad (13)$$

Where, Cr stands for the crossover rate, $\text{rand}_{i,j}[0,1]$ denotes the randomly chosen index value, and $\text{rand } j_{rand} \in [1, 2, \dots, D]$ is a random integer subject to a uniform distribution. The next stage of the algorithm determines whether the target vector or the test vector should be kept for the following generation to maintain the number of the offspring population constant.

$$\tilde{x}_i^{g+1} = \begin{cases} \tilde{u}_i^g, & f(\tilde{u}_i^g) \leq f(\tilde{x}_i^g) \\ \tilde{x}_i^g, & f(\tilde{u}_i^g) > f(\tilde{x}_i^g) \end{cases} \quad (14)$$

The variable $f(\cdot)$ stands for the minimised objective function in this situation. The algorithms DE and CS are excellent for optimisation. Although they are more rapidly convergent and have robust global search capabilities, a single optimisation model is effortlessly prone to local optimisation. As a result, the MCSDE is suggested as a novel exchange mechanism. In facilitating the transmission of information across both populations and limiting the development of local optima, this method increases the worldwide and local search capabilities of the optimization algorithm.

(ii) Stacked LSTM Model: A stacked LSTM architecture is a type of LSTM model that consists of many LSTM layers. Instead of sending a single value to the bottom LSTM layer, the higher LSTM layer sends a sequence. The model of accuracy is improved by the use of stacked LSTM, a stable method for solving difficult sequence prediction problems. A three-layered LSTM model is utilised in this work to fit the data. The LSTM model's training and prediction processes can be broken down into the following three parts. As the magnitude of the input data had an impact on the presentation of the LSTM models, the data were first rescaled and normalised to the range of 0 to 1. Instead of training several LSTM models for various values of n , the model is trained to predict the value for the following day since it predicts future n number of days pollutants. The time steps of the multivariate and univariate LSTM are set to 20/70, which implies that the incidence of the following day will be predicted using the data from the past 20/70 days. A three-layer layered LSTM structure was subsequently created. Every LSTM layer has an unseen layer with the neuron choices 6/40/90 that was pre-set for the LSTM model.

By accurately forecasting six daily air pollution concentrations (PM2.5, PM10, SO₂, NO₂, CO and O₃), the proposed unique hybrid forecasting technique evaluates total air quality, can and provide system-based air quality prediction early warning. Work must be done in terms of prevention and control to reduce air pollution and encourage the production of clean air. Developing air quality early warning systems will effectively monitor air pollution levels to reduce air pollutant emissions and encourage the development of cleaner production.

5 EXPERIMENTATION AND RESULT DISCUSSION

In this section, the proposed model's predictive power is evaluated using real data sets from a variety of Indian regions, including Kannur, Calicut, Palakkad, and Coimbatore in Southern India. For the current study locations, the risk analysis of PM10 and PM2.5 was evaluated using the AQI. The index for the daily and hourly average concentration was calculated using the revised WHO recommendation as the benchmark. By comparing data gathered before and after signal organization plans were implemented, the experiment's primary goal was to investigate the impact of signal coordination on vehicle emissions. The first stage in this pilot project was to gather sufficient data to characterise run variability, which would subsequently help determine the minimum number of runs

required to produce statistically meaningful comparisons. The quantity of runs and vehicles employed heavily depends on the study's objectives. Studies with various goals would have different designs. For instance, more vehicles would be used but fewer runs would be made per vehicle in research to characterise fleet average emissions.

PM_{2.5}, NO₂, SO, CO, and ozone were among the meteorological features that were collected hourly from 4 stations across India. The data was gathered during one year, from July 1, 2022, to June 30, 2023. The specifics of the implemented data sets and the datasets used for analysis can store data that can be utilised by a system program. The applications, such as system variables or parameters, macro libraries, or source programs, which is also required to store data sets. For both the training and testing sets of data, predictions are made using the stacked LSTM model to evaluate the model's performance.

Table 1 Pollutant Concentration of Ambient Air on RN

S. No	Measurement Date	Pollutant Concentrations					Unit
		CO	NO ₂	SO ₂	PM ₁₀	PM _{2.5}	
1	15.06.2022	10041	110	135	188	99	µg/Nm ³
2	29.08.2022	10117	105	142	97	171	µg/Nm ³
3	17.10.2022	10345	96	91	116	136	µg/Nm ³
4	02.01.2023	10205	117	121	158	275	µg/Nm ³
5	24.04.2023	11009	128	114	241	163	µg/Nm ³
6	26.06.2023	10849	136	138	167	301	µg/Nm ³

Tab. 1 shows information on ambient air pollutant concentrations caused by traffic in the South Indian cities of Kannur, Calicut, Palakkad, and Coimbatore. It measures the AAQ y and displays the values of CO, NO₂, SO₂, PM₁₀, and PM_{2.5} from October 2022 to December 2022, accordingly.

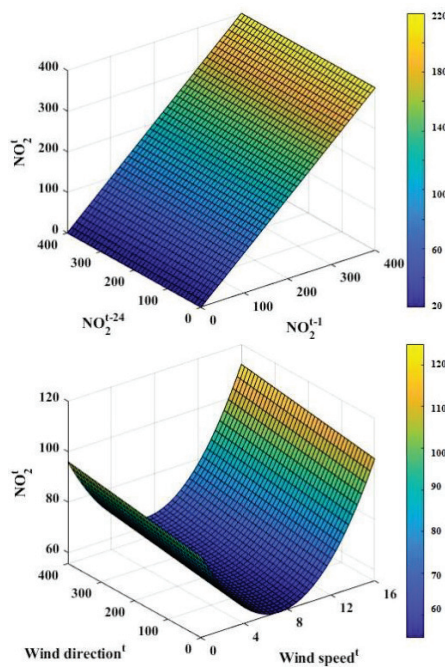


Figure 2 Predicted Results of NO₂ Timeline and Wind

The results for NO₂ in Ambient Air Quality measurements are depicted in Fig. 2. The wind direction input used an algorithm to calculate the half-hourly

representative wind from wind readings in the monitoring stations. As a result, the selected city's use of coal and oil also tended to decrease, and the level of NO₂ in the air similarly decreased.

Based on the analysis of traffic volume, vehicle speed, and parking occurrences, Fig. 3 shows the traffic flow rate results for this task. The traffic flow estimation is primarily reliant on historical and current traffic information gathered from real-time sensors. The forecast is intended to be made for a certain day, and the traffic profile matches that day. However, these traffic profiles were chosen from a pool of archival information and shared trends with the subject profile. This period is taken into account when comparing the applicant and subject profiles.

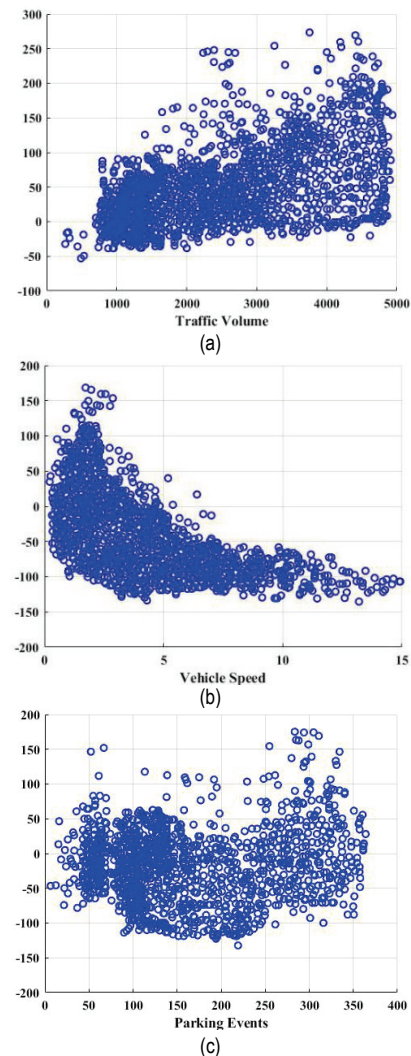


Figure 3 Predicted Traffic Flow Results

Fig. 4 illustrates the outcomes of the hybrid forecasting models' predictions of air pollution. Chemiluminescence technique is used in these monitoring stations to determine NO_x content. Calibration problems, power outages and other technical problems prevented the stations from recording concentrations during all 17,520 half-hour time points.

However, at that time, data from more than 35 sites was accessible.

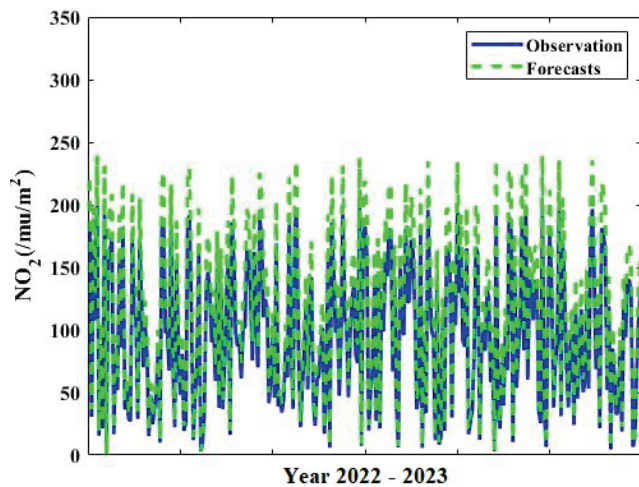


Figure 4 Ambient Air Pollutant Concentrations: Forecast and Observed Results

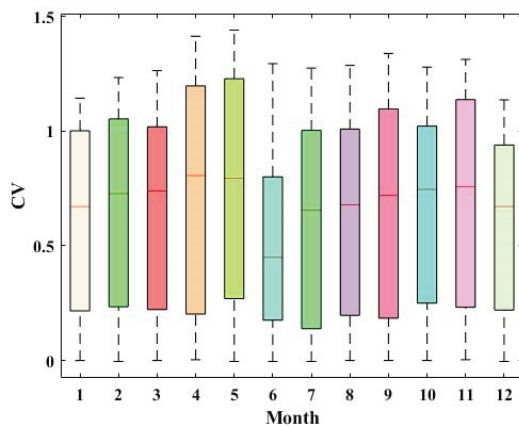


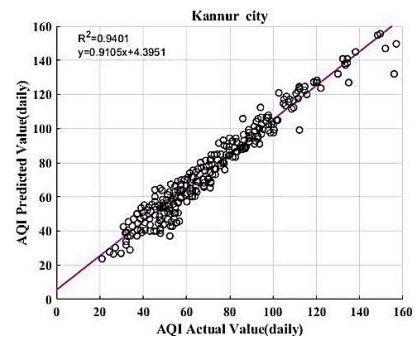
Figure 5 The coefficient of variation (CV) curve of NO_x concentration was modelled

Fig. 5 displays the CV graphs of the modelled NO_x concentrations for the year 2022. When considering the temporal activity patterns of individuals or exposures during particular periods, the granularity displayed by this model is anticipated to have an impact on exposure assessment. Even though it lacks direct input data on atmospheric stability, it complies well with the local climatic patterns.

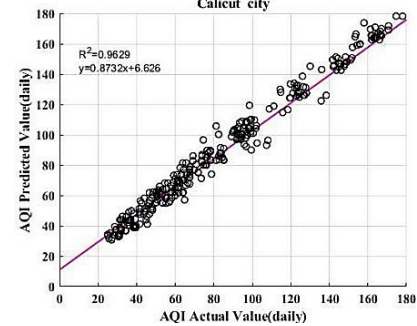
The regression analysis graph for AQI prediction in the cities of Kannur, Calicut, Palakkad, and Coimbatore is shown in Fig. 6. The trend break-line chart and regression analysis chart of these cities for the year from July 2022 to June 2023 are used in the prediction stage. This graph represents the majority of pollutant performance metrics and AQI values. For this AQI index prediction, the suggested hybrid forecasting model will produce superior results.

Fig. 7 shows the association between PM 10 and PM 2.5 for the 0.05 significant level for Kannur ($r = 0.9959$, $P = 0.05$), Calicut ($r = 0.9960$, $P = 0.05$), Palakkad ($r = 0.9962$), and Coimbatore city ($r = 0.9916$). The PM 10 vs. PM 2.5 scatterplot shown in Fig. 4 is also very tightly distributed about an underlying straight line. A clear linear connection can be seen in the quantified correlation between PM 2.5 and PM10 for Benin City. To simulate the more dangerous PM

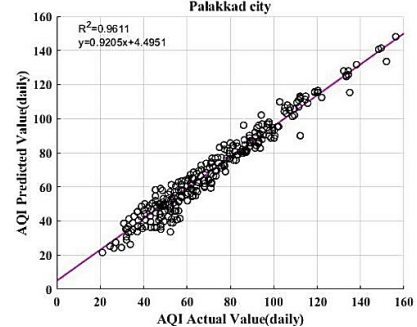
2.5's likely source location and dispersion patterns in the analyzed sites, a model of hybrid forecasting was utilized. For the study, the peak PM 2.5 values from the months with the greatest level of particulate material (by season and region) were taken into account. The linear link between the particulate matters indicated by the straight line suggests that the level of PM2.5 rises as the level of PM10 rises. Furthermore, comparable bases of PM10 and PM2.5 may be used to explain both the association and the tightly distributed pattern.



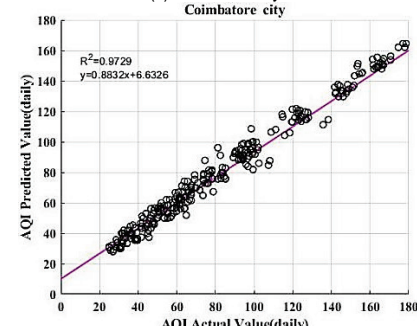
(a) Kannur City



(b) Calicut City



(c) Palakkad City



(d) Coimbatore City

Figure 6 Chart of Regression Analysis for Prediction of AQI

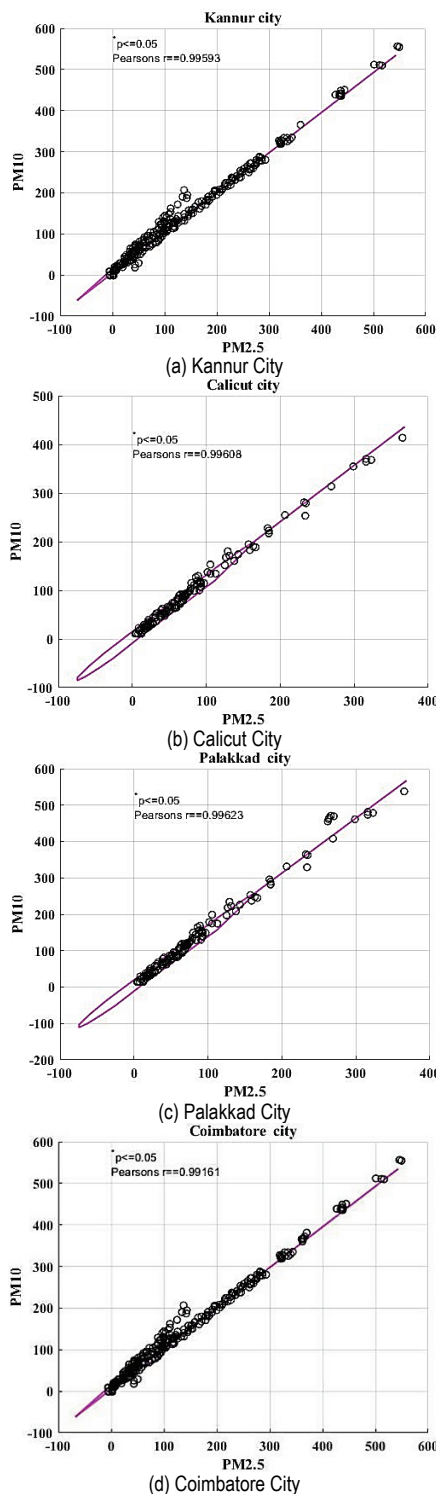


Figure 7 Pearson correlation coefficient between PM_{2.5} and PM₁₀ particles

The AQI plot based on daily collected data is shown in Fig. 8. The AQI was used to assess the risk analysis of PM₁₀ and PM_{2.5} for the current research regions. The new WHO recommendation was used as the norm for calculating the index for the daily average concentration.

The performance findings for the concentrations of ambient air pollutants are displayed in Tab. 2. It displays the SO₂, CO, O₃, PM₁₀, PM_{2.5}, and NO₂ MAE, RMSE, and R^2

values. For CO and SO₂, it yields the lowest MAE, RMSE, and R^2 values of 0.048, 0.109, and 0.579, respectively.

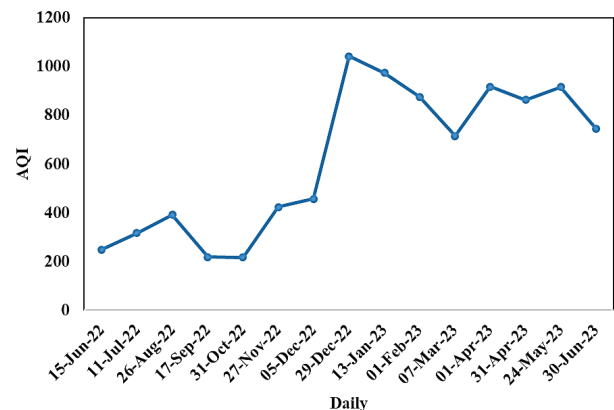


Figure 8 AQI Plot for Daily Measures

Table 2 Performance Results for AAP Levels

Pollutant	MAE	RMSE	R^2
SO ₂	0.739	1.586	0.579
CO	0.048	0.109	0.793
O ₃	3.846	5.549	0.905
PM ₁₀	4.830	7.445	0.640
PM _{2.5}	3.359	4.670	0.843
NO ₂	2.451	3.638	0.833

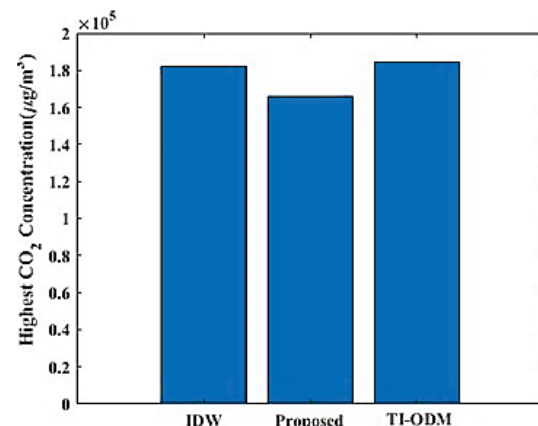


Figure 9 Comparison Results for the Highest Attention of Carbon Dioxide

Fig. 9 shows the comparison outcomes for the greatest carbon dioxide (CO₂) concentration. When compared to the current IDW and TI-ODM, the suggested technique yields less accurate findings than the others. As a result, the proposed approach reduces the attentiveness of air pollutants brought on by vehicle exhaust on the designated RN more than other existing approaches.

The comparison graph for the nitrogen oxide (NO_x) concentration with the highest value appears in Fig. 10. The outcome is contrasted with the current IDW and TI-ODM techniques. For nitrogen oxide (NO_x), the overall emission value has decreased from the current situation by 327.387 gr for the suggested approach and 562.601 gr for the existing work.

The cross-validated correlation coefficient between measurements of ambient NO_x and model values is shown in Fig. 11. The proposed method outperformed the IDW and TI-

ODM interpolation in terms of mean spatial Pearson correlation (MSPC) when compared to these existing techniques. This shows that, compared to the other investigated models, the suggested hybrid optimisation gives better accounts for the spatial patterns of NO_x . It is notably clear that the suggested work has better MSPC than TI-ODM. Given that midday strong vertical turbulence swiftly disperses traffic emissions, this may be yet another effect of the ODM's decoupling of the traffic and industry terms.

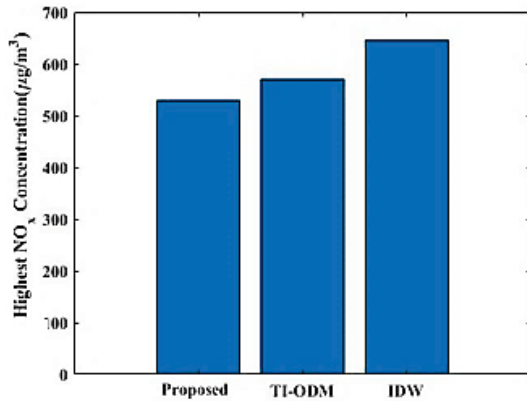


Figure 10 Results of Comparison for the Optimal Nitrogen Oxide Concentration

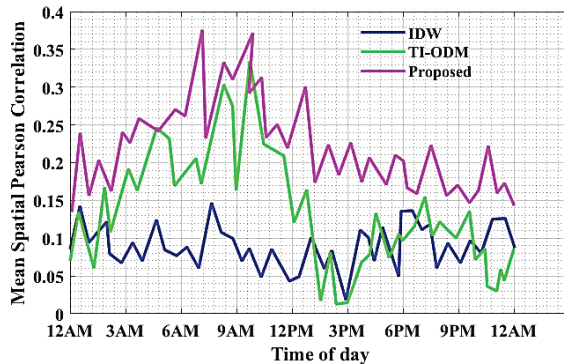


Figure 11 Measurements of Ambient NO_x and Cross-Validated Correlation Coefficient between Modelled Values

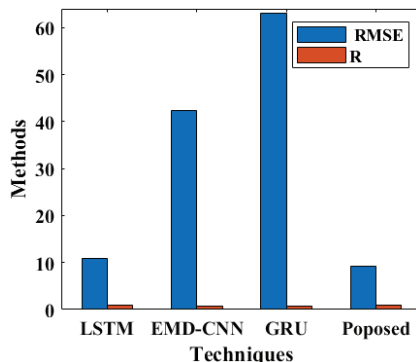


Figure 12 Comparison Results for RMSE and Correlation Analysis

The comparison between the findings of RMSE and regression analysis is shown in Fig. 12. It demonstrates that the RMSE of various approaches lowers as the depth increases, but at a particular depth, an inflexion point occurs, and the RMSE abruptly increases. The suggested approach is

contrasted with the current LSTM, EMD-CNN, and GRU models in this graph. The proposed technique yields higher R values and the RMSE value is very low in this figure, respectively.

The RMSE and Pearson coefficient compared to forecasted findings are displayed in Tab. 3. Here, the suggested approach yields higher R values of 0.98 and RMSE lower values of 9.17, respectively. Therefore, the proposed method outperforms the other available methods in terms of performance.

Table 3 Comparative Predictive Analysis

Techniques	RMSE	R
LSTM	10.9	0.97
EMD-CNN	46.26	0.81
GRU	63.1	0.65
Proposed	9.17	0.98

6 RESEARCH CONCLUSION AND FUTURE SCOPE

Air quality is known to have a considerable impact on health, predicting it is a very essential undertaking. More accurate and complex modelling techniques are required as environmental regulations become stricter to simulate measures and programmes that may successfully address air quality exceedances, which are frequent in major Indian cities, particularly for NO_2 . Since observed concentration values are the result of the interaction of several sources and processes spanning a broad range of geographical and temporal dimensions, modelling air quality in metropolitan settings is a relatively challenging task. Measurements of outdoor concentrations and individual exposure to CO , NO_2 , SO_2 , and O_3 will be made as part of this study using the real-time sensor and a pilot campaign. Traffic data in the form of traffic volume, vehicle speed, and number of parking times were collected by a pilot survey at the study site. Air pollution data was measured on-site with support from the Road Transport Research Technical Enforcement Unit. For each road segment, traffic flow is recorded every hour. AAP data were collected using an impact tube to measure NO_2 , SO_2 , and O_3 pollutants, a non-dispersive infrared instrument to measure CO pollutant concentrations, and an HVAAS instrument to measure PM_{10} pollutant concentrations. The most common method for estimating past exposures to air pollution is regression modelling, such as Land-Use Regression. To forecast AAQ levels, a GDM with a residual network model is provided.

However, using modules for air quality evaluation and prediction, the study develops a trustworthy early-warning system. A hybrid forecasting technique is introduced in the forecast module to anticipate pollution concentrations that accurately predict future air quality conditions. A pollution event happens; this model is used to develop an alarm protocol (one day in advance). The results were compared with ambient air measurements at the study site and alternative traffic-related solutions were proposed. The results show that although the forecast model outperforms other standard models in predicting pollutant concentrations, the assessment model is only suitable for reporting air quality levels compared to the actual situation. Therefore, the proposed system is expected to play an important role in

developing smart cities and reducing air pollution globally in the future. According to the test results, the newly developed SAP is significantly more suitable for air pollution research and monitoring, thus adding a new and viable alternative for decision makers. Furthermore, a health risk assessment was proposed to determine the risk sensitivity of PM10 and PM2.5 in the five districts of NEOM City. The results show that, compared with current state-of-the-art models, the proposed method with effective feature extraction can significantly optimize the accuracy of spatial air quality forecast-time. The MASE PM10 and PM2.5 values for the hour's prediction tasks were 97 and 99, respectively. Consequently, the suggested work is compared to another previous approach; in contrast to these existing methods, the proposed method yields greater correlation values, higher anticipated results, and a lower error rate. Consequently, with the early prediction and warning systems, the suggested approach offers a practical way to increase the level of alert for air pollution concentrations on India's RN while also being transferable to other regions around the world.

Future research in the field of forecasting daily Air Quality Index (AQI) and implementing Early Warning Systems (EWS) for ambient air pollution on road networks using the proposed Gaussian Dispersion Model with Deep Learning Algorithm could explore several promising directions. Firstly, investigating the integration of additional environmental factors, such as topography and land use, into the model may enhance its accuracy and broaden its applicability to diverse urban environments.

Furthermore, the exploration of ensemble methods that combine multiple forecasting models, including alternative dispersion models and machine learning algorithms, could offer a more robust and comprehensive approach to air quality prediction. Additionally, research focusing on real-time sensor data integration and the development of adaptive models capable of continuously learning from incoming data streams could further improve the system's responsiveness to dynamic and evolving pollution scenarios. Finally, assessing the scalability of the proposed methodology to larger urban areas and its potential integration with smart city initiatives would contribute to its practical implementation in real-world urban planning and pollution management strategies.

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Dependence of the Emotional Experience of Newspaper Photographic Illustration on the Medium of Realization

Krešimir Dragčević, Miroslav Mikota*, Ivana Pavlović, Marko Maričević

Abstract: The paper investigated the experience and emotional reaction of respondents to different newspaper photographic illustrations depending on the media of realization (print in newspaper press, laptop computer screen, and smartphone screen). Due to differences in the formation of basic visual psychophysical reactions in affirmative childhood, the respondents were chosen from two separate age groups: younger from 19 to 23 years and mature from 38 to 49 years. Respondents rated from 1 to 5 the emotional reaction caused by the observed photographic illustration according to the offered reactions: happiness, love, hope, fear, sadness, hatred, anger, envy, shock, sexual attraction, disgust, shame, pride, attraction, and sympathy. Through the research, the difference in experiences and emotional reactions depending on the gender and age difference was monitored. The results of the research indicate that depending on the medium of display, there are significant differences in the experience of photographic newspaper illustrations depending on the age of the respondents, gender, but that previous, but more current, habits of using display technologies also have a significant influence.

Keywords: emotion; experience; newsprint; photographic illustration; screen

1 INTRODUCTION

In this paper, 5 thematic areas specific to newspaper photography are analyzed and the impact it has through the experience of the respondents through visual stimuli through photographic illustrations. The research is based on the visual assessments of the respondents, which are carried out on the basis of photographic illustrations realized on calibrated output units (printing on paper, display on the screen and on a smartphone) under standard observation conditions (ISO 3664:2009) [1].

Newspaper photography is an extremely powerful communication tool that aims to attract attention and provide universally understandable and clear information that can be trusted.

Newspaper photography is realized through different forms, among which there are no sharp boundaries, namely: photo news, photo interview, photo commentary, photo interest, documentary photography, photo sequence, photo story, photo essay and photo reportage.

Photo news is realized through a single photographic image of an event and through a recognizable and convincing photographic image it shows a typical moment of that event.

During a photo interview, the photographer, while with a person, takes portraits showing the characteristic facial expressions of that person.

A photo commentary is a photographic image in which the photographer's attitude towards what was captured is particularly emphasized.

Photo interest is a photographic image that shows an unusual event, meeting, person in an unusual environment, etc.

Documentary photography in the narrower sense shows events, architecture, individuals, groups, natural events, etc. as facts through a completely realistic and objective presentation.

A photo sequence is a series of photographic images that represent an event, person or action in a very short time.

With a photo story, a description is created through several photographic images through the introduction, culmination, and end of a story.

A photo essay is a freer form of photojournalistic expression than a photo story in which a series of photographic images describe an event, their chronology, fashion trends, details from life, natural events, etc.

Photo reportage is the most typical type of newspaper photography, which, in fact, contains some or all of the previously mentioned types of photojournalistic expression and shows a current event through a large number of photographic images. The photos show the people participating in the event, the location of the event and the event itself. It is considered that there is one key photo that is basic for understanding photo reportage (usually photo news).

For newspaper photography, it is especially important that the photographer shoots with understanding, which enables the presentation of the decisive moment of the event. A good newspaper photo must be syntactically as simple as possible, and what is shown must be completely recognizable [2].

For research purposes, test photographic illustrations of selected motifs and specific types of newspaper photography are used. From the very beginning, the goal of journalism was to record and inform the public at the right time, objectively and truthfully, and the biggest role in attracting attention is achieved through visual stimuli, most often through photographs, regardless of whether it is printed or electronic media. Regardless of which segment of the newspaper photo it is about, its goal is to complete the newspaper text in an objective way because it creates public opinion. One of the types of newspaper photography is a very specific war photograph, as a direct link between sheltered civilians and the first lines of the battlefield. War photographs can even be used as evidence of war losses - human or material, victories and other war horrors. War photography can be classified as photo news, photo commentary, photo sequence, photo story, photo report or specific documentary photography, while most often they are photo reportage or photo news. Fashion

photography is a type of newspaper photography that can be documentary or artistic, and most often shows the fashion novelties of its time and is its most popular and most profitable branch that goes all the way to product photography. The black chronicle as a thematic area of journalism includes information related to death, loss, traffic or other accidents, mass damage, injuries and similar events that cause them. It is most often classified under photo news, photo story or photo reportage. Engaged photography is the kind of photography that most often assumes that motives are filled with social charge, and also stems from a critical practice that exposes and investigates the negative aspects of society, where it directly intervenes in the social context and often assumes interaction with the audience. Engaged photography is placed within the framework of modern and contemporary photography as a part of newspaper photography that constantly re-examines its basis and intention, at the same time reflecting the broader political reality of the author's position within its context. It most often belongs to the documentary form of newspaper photography. Sports photography as a part of newspaper photography has the duty to convey all information in a visual form, including emotions and attractions that took place during a certain sports event, but also moments that happened before or after the act of sports itself. It is most often associated with types of newspaper photography: photo news, photo sequence and photo reportage.

As a rule, a photographic image is recorded in the Adobe RGB color space when recording; in the recording with compression as an 8-bit recording per channel, and in the raw recording as more than 8-bit recording, depending on the characteristics of the camera's sensor. Regardless of how the 8-bit file format is defined, which is initially written in the Adobe RGB color space, the color from that space is redefined into the reproducible sRGB color space, from which the majority of output devices, such as monitors, smartphones, printers, projectors, etc. can realistically reproduce colors (Fig. 1).

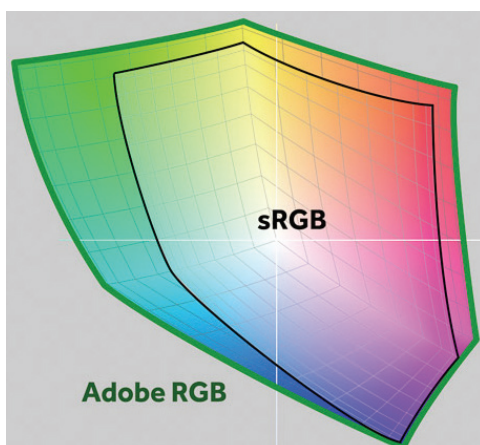


Figure 1 Adobe RGB and sRGB color space in Lab color space [3]

Converting image records from one color space to another color space is called rendering. There are four basic types of rendering: rendering with absolute colorimetric intentions, rendering with relative colorimetric intentions, rendering with saturation intentions, and rendering with

perceptual intentions, which is also called photographic rendering and is used in these examples [4] (Fig. 2).

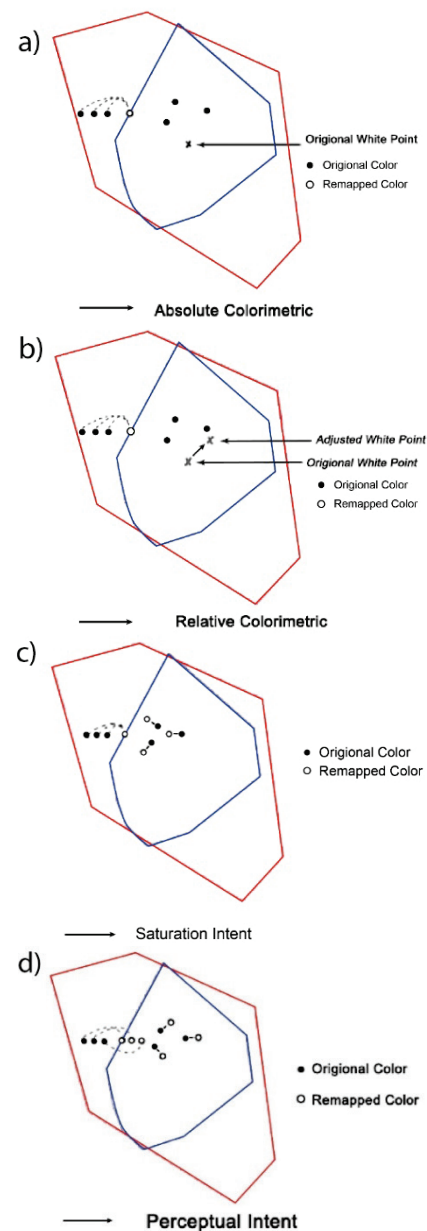


Figure 2 Types of rendering: a) rendering with absolute colorimetric intentions; b) rendering with relative colorimetric intentions; c) rendering with saturation intentions; d) rendering with perceptual intentions [5]

Rendering with the perceptual intentions of color transfers from one color space to another so that the perceptual overall impression of the image changes as little as possible. There are certain colorimetric color changes, whereby less saturated colors change less, and saturated colors more - by "compressing" into a smaller color space, but so that all the colors of the wider space still differ in the narrower color space. This rendering is reversible. For this reason, this rendering is usually used to convert the Adobe RGB record into the sRGB record of a photographic image.

In the presentation of photographic illustrations in modern communication systems, two fundamental principles

dominate. They are technologically, physically, but also communicatively significantly different [6, 7].

The first and older system is the construction of tone and color reproduction by subtractive synthesis of printed inks. This system is used in all printing techniques and in the most common version is with cyan, magenta, yellow and black process colors. The possibilities of reproduction in each printing system depend to the most significant extent on the composition of the printing inks (pigment concentration and size, type of binder), the thickness of the ink coating in the print, the possibility of reproducing details, the type and whiteness (color) of the paper or substrate on which it is printed, the speed of printing, etc. Due to the large number of parameters that affect the quality of reproduction in printing processes, standardized sequences of technological processes for processing photographic illustrations have been developed in recent decades, which, depending on the printing technique, aim to give a predictable result at the end of the communication sequence, i.e. on the print. So far, the standardization of printing techniques has followed the technological, physical, colorimetric parameters of the printed colors. The technique of newspaper printing, which is covered in this paper, is characterized by high printing speed, low printing cost, but due to the use of low-viscosity printing inks with a low pigment concentration, poor color reproduction power. However, in modern printing systems, the most common printing technique is still reproduction of photographic illustrations.

Another system of building tone and color reproduction by active synthesis of emitted electromagnetic radiation from screens, initially cathode screens, and in more modern systems from LCD monitors. In all commercial and more widely used screens, the construction of the image is based on the emission of red, green and blue colors, which, by active fusion, reproduce all other colors that are capable of reproducing that screen. Until the end of the 20th century, depending on the technology and display quality, there were considerable deviations in the colorimetric parameters of multicolor reproductions from the screen, but in modern commercial systems, the physical reproduction parameters are largely uniform. The laptop and smartphone screens selected in this paper are of a higher price range, but the results can be applied to the vast majority of commercial screens.

2 EXPERIMENTAL PART

2.1 Test Samples

The research analyzed the influence of three technologies for displaying photographic illustrations: newspaper printing, computer screen and smartphone screen. According to previous research, the examined technologies in the past 8 years represent the most significant in terms of communication and finance, and in the cumulative of all communication channels, the most represented technologies for the display of photographic illustrations.

All examined photographic motifs were recorded in the sRGB color space, so a standardized adaptation to the examined realization technologies was possible.

Newspaper printing is technologically simulated on an Epson Stylus Pro 7800 inkjet printer (Certified by the Fogra

Institute according to ISO 12647-2 standards) [8]. All photographic illustrations are printed in A4 format. For the purpose of the research, technological, tonal and colorimetric adjustments were carried out, according to the mentioned ISO standard, through the ICC profile for the simulation of one of Croatia's most widely circulated daily newspapers [9].

An HP ProBook laptop was used for computer screen research. Before the research, hardware calibration was performed with the X-rite i1Display Pro colorimeter according to the protocol and standard ISO 14861:2015. All photographic illustrations are viewed in full screen format [10].

The research used a Samsung galaxy S22 ultra smartphone with the colorimetric parameters of the screen display set to the original factory settings. All photographic illustrations are viewed in full screen format.

As stated in the introduction, war photography (Fig. 3) in the media space most often has the role of informing about the suffering of civilians and the negative consequences of war, but often has a propaganda role where a side in the war is glorified or emboldened or people are encouraged to get involved passively or actively in the war. In this research, war photography was chosen, which according to the previous assumptions of the author is globally politically neutral, in order to avoid the influence of political attitude on the emotional experience of photographic illustration in the research.



Figure 3 War photography [Pixel media d.o.o., Photo and video agency, Pixsell catalogue]

The thematic area of fashion photography (Fig. 4) is used to the greatest extent in the media space in order to advertise a brand, style or a certain way of life. As a rule, it is created with the aim of conveying positive emotions and experiences.

The thematic area of the black chronicle (Fig. 5) in the media context, in addition to journalistic information, very often also has the purpose of warning about an accident, accident or natural disaster with the aim of preventing the events presented. Without exception, in the primary context of creation, it aims to convey negative feelings and experiences that will be more strongly conveyed if the photographic illustration meets compositional,

technological, chromatically harmonious conditions. In modern media communication systems, the most significant feature of that thematic area, which is the transmission of negative feelings, becomes a flaw because it deters the potential consumer from continuing to observe the entire content. This too often leads to self-censorship of that thematic area in everyday media communications.



Figure 4 Fashion photography [Accademia Italiana]



Figure 5 Black cronicle [Pixel media d.o.o., Photo and video agency, Pixsell catalogue]



Figure 6 Engaged photography [Pixel media d.o.o., Photo and video agency, Pixsell catalogue]

The thematic area of engaged photography (Fig. 6), in its fundamental role in the media space, is the most diverse in terms of motives, pipes, semantics, target consumers, and the like. Basically, it aims to encourage the consumer to some form of action, to create new and maintain positive patterns of behavior. Therefore, the largest amount of controversies in the media space is related to this thematic area, according to earlier research, mostly among mature respondents.

The thematic area of sports photography (Fig. 7) is the most diverse in terms of shooting techniques and conditions, choice of motifs, dynamics and composition. The diversity comes from the wide range of different sports events and the specifics of each of them, but also from the authors and photographers themselves. In sports photography, the most up-to-date photographic equipment is used, which really pushes the boundaries of shooting possibilities, and is most often identified with the term professional photographic equipment.

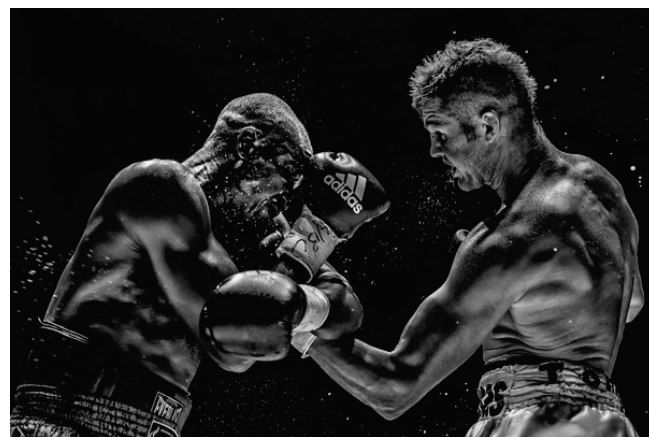


Figure 7 Sport photography 'The Left Uppercut' by Alexius van der Westhuizen [Pixel media d.o.o., Photo and video agency, Pixsell catalogue]

2.2 Respondents

All respondents who took part in the research passed the Ishikara color recognition test, according to their own testimony they do not suffer from or are being treated for any form of psychological disorders and are thoroughly familiar with the conditions of the research [11].

84 respondents participated in the research. Due to different media habits, and mainly due to the media environment and the availability of information in the affirmative age (approx. from 3 to 12 years old), the respondents were chosen from two age groups [12]:

- 1) Respondents between the ages of 19 and 23 (hereinafter referred to as younger respondents). 45 (54%) participated in the research
- 2) Respondents between the ages of 38 and 49 (hereinafter referred to as mature respondents). 39 (46%) participated in the research.

There are 55 women (65%) and 29 men (35%) among the respondents.

When examining media habits, 84% of respondents, according to their own testimony, use the screen (monitor or

smartphone) as the primary visual information technology. In accordance with expectations, 100% of younger respondents state the screen as the primary information technology, while 64% of mature respondents. Only 8% of the respondents use daily newspapers as the dominant source of information, while the majority of respondents indicate, in varying proportions, the use of all the examined information technologies. 17% of respondents from the group of younger respondents never use print media for information.

2.3 Test Methodology

The research was conducted on five photographic illustrations of different thematic areas of newspaper photography. All photographic illustrations were published in some prominent media newspapers or internet portals before the research, but none of the respondents had seen the photographic illustration before the research.

Before the research, each respondent is thoroughly familiar with the evaluation methodology and the meaning and difference in the interpretation of the evaluated feelings and experiences [13].

Respondents rated each offered feeling or emotion from 1 to 5, where the meaning of each rating is:

- 1) no experience
- 2) weak experience
- 3) expressed experience
- 4) a very pronounced experience
- 5) extremely strong experience.

Each subject looked at the evaluated photographic illustration for 30 s, and then in 120 s filled in the table with the offered emotions and experiences. Each respondent was recommended to rate at least 3 emotions/experiences. Only one display technology was always tested in continuity, and a minimum time interval of 45 min was defined between the tests of different display technologies in order to avoid emotional saturation with the subject or the test.

Emotions were evaluated: happiness, love, hope, fear, sadness, hatred, anger, envy. They represent primary human emotions and are related to all aspects of human activity.

Evaluated experiences: shock, sexual attraction, disgust, shame, pride, attraction, sympathy. They were added to the research because the literature related to the vision of newspaper photography states that the mentioned experiences have a significant and often the most intense influence on the perception of photographic illustration [2].

3 RESULTS AND DISCUSSION

In this paper, in the presentation and interpretation of individual research results for individual experiences, grades four and five are combined, as an indicator of a strong individual experience or emotion. Through the discussion part, the most attention was paid to verifying the most expressed experiences and emotions depending on the gender or age of the respondents. The tables show the five most pronounced emotional reactions for a certain age or gender group for each examined photographic illustration. In certain

thematic areas, the more significant emotional reactions are differences in age, and in some in gender, so when presenting the results, the groups of respondents with a significant difference in the emotional experience of the examined photographic illustrations are shown.

Some results emerge from the research, which, although in a smaller proportion, are completely contrary to earlier predictions or expectations, and in some cases are completely contrary to the target message of the thematic area. Although these results are not shown in the tables, they will be mentioned in the discussion section.

3.1 War Photography

Tab. 1 and Tab. 2 show the results of the emotional reaction to the examined wartime photographic illustration. There are significant differences in emotional reactions depending on the age of the respondents. For the interpretation of the results, it is important to note that all the mature respondents lived through a war experience in their own country, and none of the younger respondents lived through any war experience. Fear and shock are the most pronounced among younger respondents, and anger and shock among mature respondents. In all gender and age groups, shock is the most pronounced experience in the examined photographic motif, while other emotional experiences can be attributed to the lived war experience. Younger respondents have similar emotional reactions to any photographic motif that depicts misfortune, suffering, etc. while more mature respondents have a greater dose of empathy and compassion. Regardless of the emotional reaction in both age groups, the emotional reaction from the newspaper print is stronger, and the weakest reaction is from the smartphone screen.

Table 1 Representation of strong experiences/emotions in younger respondents of the observed war photographic illustration depending on the display technology

Display technology	Fear	Shock	Sadness	Hate	Anger
Newspaper	83%	74%	64%	57%	55%
Laptop	74%	57%	64%	64%	64%
Smartphone	64%	57%	57%	47%	43%

Table 2 Representation of strong experiences/emotions in mature respondents of observed war photographic illustrations depending on the display technology

Display technology	Anger	Shock	Sadness	Fear	Shame
Newspaper	91%	74%	71%	64%	64%
Laptop	83%	64%	64%	64%	64%
Smartphone	57%	57%	43%	47%	43%

3.2 Fashion Photography

Tab. 3 and Tab. 4 show the results of the emotional reaction to the examined fashion photographic illustration. There are significant differences in emotional reactions depending on the gender of the respondents. Although fashion photography is primarily intended for female consumers in terms of aesthetics and content, from the results of this research, as well as from previous research [14-16], it follows that the emotional experience is significantly greater

among male respondents. In this and earlier research in fashion photography, photographic motifs with a female model were used, so the primary emotional experiences of male respondents are love and sexual attraction, while happiness dominates as the most expressed emotional reaction among female respondents. Not a single negative emotional reaction was recorded in the male respondents, while in the female respondents of a more mature age, envy, sadness and hatred were present in a smaller percentage. In fashion photography, along with other aesthetic criteria, color composition plays the most important role in conveying the desired message to consumers. In this research, the photographic motif of the entire female figure was chosen in predominant red colors, which are reproduced with the lowest saturation by subtractive synthesis in print systems. This can be attributed to the fact that in all examined gender and age groups, this photographic motif has a significantly stronger emotional experience from the laptop screen.

Table 3 Representation of strong experiences/emotions in the male respondents of the observed fashion photographic illustration depending on the display technology.

Display technology	Love	Sexual Attraction	Attraction	Happiness	Sympathy
Newspaper	74%	57%	64%	57%	55%
Laptop	83%	74%	64%	64%	64%
Smartphone	64%	57%	57%	47%	43%

Table 4 Representation of strong experiences/emotions in the female respondents of the observed fashion photographic illustration depending on the display technology.

Display technology	Happiness	Love	Sympathy	Pride	Envy
Newspaper	64%	57%	53%	37%	32%
Laptop	74%	64%	64%	57%	32%
Smartphone	57%	57%	43%	32%	22%

3.3 Black Chronicle

Tab. 5 and Tab. 6 show the results of the emotional reaction to the investigated photographic illustration of the thematic area of the black chronicle. There are significant differences in emotional reactions depending on the age of the respondents. In younger subjects, the most pronounced emotional reaction is fear, and in mature subjects it is shock. In the selection of the photographic motif for this research, the photographic motif of a serious traffic accident was chosen, because it follows from earlier research that previous life experiences play a crucial role in the thematic area of the black chronicle. A traffic accident is an experience that the majority of respondents have encountered directly, which is more pronounced in the case of mature respondents, or indirectly, so emotional reactions are based on what has already been experienced. The photographic motif itself was chosen because it is primarily intended for printed editions. After the technological adjustment described in the experimental work for each medium of realization, the results show that with the selected motif, regardless of age and gender, the smallest difference in emotional reaction is from newspaper print, laptop screen and smartphone screen. The results indicate that the initial photographic motif was captured aesthetically, compositionally and technically with

high quality before technological adaptations to the medium of realization.

Table 5 Representation of strong experiences/emotions in the younger respondents of the observed black chronicle of the photographic illustration, depending on the display technology.

Display technology	Fear	Shock	Anger	Sadness	Disgust
Newspaper	83%	74%	74%	57%	55%
Laptop	83%	64%	64%	64%	64%
Smartphone	64%	57%	57%	47%	43%

Table 6 Representation of strong experiences/emotions in mature respondents of observed black chronicle of the photographic illustration depending on the display technology.

Display technology	Shock	Anger	Sadness	Fear	Hate
Newspaper	91%	74%	71%	64%	64%
Laptop	83%	74%	64%	64%	64%
Smartphone	57%	57%	43%	47%	43%

Table 7 Representation of strong experiences/emotions in the male respondents of the observed engaging photographic illustrations depending on the display technology.

Display technology	Love	Happiness	Attraction	Hope	Sympathy
Newspaper	83%	64%	64%	57%	43%
Laptop	91%	57%	57%	64%	54%
Smartphone	64%	46%	43%	47%	36%

Table 8 Representation of strong experiences/emotions in mature respondents of observed engaged photographic illustrations depending on the display technology.

Display technology	Happiness	Attraction	Love	Sympathy	Hope
Newspaper	91%	74%	71%	64%	54%
Laptop	83%	74%	71%	54%	54%
Smartphone	57%	57%	43%	47%	36%

3.4 Engaged Photography

Tab. 7 and Tab. 8 show the results of the emotional reaction to the engaged photographic illustration. There are noticeable differences in emotional reactions depending on the age of the respondents. It follows from earlier research that respondents show the biggest differences in emotional reactions in the thematic area of engaged photography. For this research, a motive was chosen that was assumed, and the results of the research confirmed that this photographic motive, regardless of gender and age, gives positive emotional reactions. The photographic motive was taken for the needs of a large European campaign that encourages care for children. Love is the most pronounced among younger respondents, and happiness among mature respondents. To interpret the results, it is important to note that no one from the group of younger respondents is a parent, and in the group of mature respondents 83% of respondents are parents. Although in both age groups the most pronounced positive feelings are the same, they differ in intensity. Although it is a black and white motif, the group of younger respondents shows a stronger emotional reaction on the laptop screen, which is the primary medium of realization for all younger respondents. Although the most expressed emotional reactions are uniform and positive in the group of younger respondents, fear and disgust appear in a small percentage, and in the case of mature respondents, sadness, envy and shame also appear in a small percentage.

3.5 Sports Photography

Tab. 9 and Tab. 10 show the results of the emotional reaction to the examined sports photographic illustration. Contrary to earlier predictions that the biggest differences in emotional reactions will be in age, there are significant differences depending on the gender of the respondents. In male respondents, fear, hatred and envy are the most pronounced, and in female respondents, attraction, fear and sexual attraction. In this research, a black and white photographic motif with two male figures was chosen. Throughout this research and earlier research [14-16], the greatest differences in emotional reactions were obtained on this photographic motif, both by age and gender, but also by media habits and the primary medium of realization used by the respondents. The emotional reaction from the newspaper printout and the laptop screen is uniform, and the experience from the smartphone screen is much weaker.

Table 9 Representation of strong experiences/emotions in mature respondents of observed sports photographic illustrations depending on the display technology.

Display technology	Anger	Hate	Envy	Pride	Shock
Newspaper	83%	74%	64%	57%	43%
Laptop	83%	67%	64%	64%	54%
Smartphone	54%	46%	43%	47%	36%

Table 10 Representation of strong experiences/emotions in the female respondents of the observed sports photographic illustration depending on the display technology.

Display technology	Attraction	Anger	Sexual Attraction	Shock	Sympathy
Newspaper	83%	71%	71%	64%	54%
Laptop	74%	74%	71%	54%	54%
Smartphone	57%	57%	57%	47%	36%

4 CONCLUSIONS

The applied research method verifies and quantifies with great accuracy the differences in emotional and experiential reactions of photographic illustrations depending on the medium of realization.

In most of the examined thematic areas, respondents show a stronger emotional experience on the primary medium of information, except when it comes to shock in the photographic illustration.

In the thematic area of war photography in all age and gender groups, shock is the primary emotional reaction, and other emotional reactions significantly depend on the lived war experience.

In the subject area of fashion photography, the emotional reaction is greater among male respondents. Regardless of age and gender, the emotional reaction on the laptop screen is stronger due to the greater power of color reproduction.

In the thematic area of the black chronicle on the investigated photographic motif, there are significant differences in emotional reactions by age group, but in all age and gender groups the strongest experience is from the newspaper print.

Based on this and earlier research, respondents show the biggest differences in emotional reactions in the subject area of engaged photography.

Based on the results of this and earlier researches, it can be concluded that black and white motifs in younger subjects show a stronger emotional reaction regardless of the medium of realization, with the exception of fashion photography.

In all examined photos, in all experiences on the smartphone screen, the experience is of lower intensity compared to the laptop screen or newspaper print.

We can conclude with great certainty that the emotional and experiential reaction of photographic illustrations fundamentally depends on the age and gender of the consumer, but that previous, but more current, habits of using the medium of realization also have a significant influence.

Given that photography can also be used as a manipulative element, the obtained results show to what extent it influences and whether it can be manipulated to some extent on consumers, and how important it is to adhere to journalistic ethics when publishing an article.

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Movable VOC Removal System: Enhancing Industrial Air Quality by Treating Exhaust Gas

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Abstract: In this study, we develop a mobile VOCs gas removal system that can remove volatile organic compound (VOCs) emissions from petrochemical facilities, metal painting factories, and surroundings of life, and can efficiently cope with situations occurring in the field. Regular repairs to petrochemical plants and semiconductor plants are carried out for a month every four to five years, and work such as replacing old pipes and repairing aging facilities, cleaning, removing residual gas, checking pipe connections and valves, and improving processes are carried out while the plant is shut down. During regular maintenance, a large-scale accident occurs in which gas remaining in the facility leaks or explodes due to rising pressure, and even after internal gas discharge and purge work is performed, it is scattered by the characteristics of raw materials remaining inside the pipe and reactor and discharged into the atmosphere. Therefore, there is always a possibility of causing safety accidents, and such accidents have a great socioeconomic impact as they are directly connected to the safety of workers as well as the safety of local residents. This system is designed to be adaptable according to the size of a number of outlets, and it is proposed to minimize the impact of VOCs harmful gases on the surroundings by developing it as a mobile type. The efficiency of collecting scattered VOCs gas is more than 90%, and the integrated operating system is demonstrated for 50 CMM class movable VOCs adsorption device, 5 CMM class treatment gas recirculation type non-flame waste heat recovery adsorbent regeneration treatment device, and two or more business sites.

Keywords: adsorption; carbon-free; regeneration; total hydro carbon; volatile organic compounds

1 INTRODUCTION

The agreement between 195 countries around the world to reduce greenhouse gases in response to climate change is to keep the global average temperature rise within 2 °C. The content of the agreement to reduce greenhouse gas is to keep the global average temperature rise within 2 °C compared to the pre-industrial period and to achieve 1.5 °C in the long run. Various air pollution reduction policies are being promoted in order to minimize the effects of greenhouse gases, which are the main causes of climate change [1-4].

Petrochemical plants, which greatly affect air pollution, emit volatile organic compounds (VOCs), generate photochemical oxidants in the atmosphere, cause ozone (O₃) and fine dust (PM_{2.5}) and have a very harmful effect on the human body [5-9].

Most petrochemical plants, metal surface treatment, and plastic manufacturing systems are repaired at least once every four to five years for a month or less. At this time, while the factory is shut down, various improvements such as replacing old pipes, repairing old facilities, cleaning, removing residual gas, checking pipe connection areas and valves are made [10]. In particular, during repair and maintenance, an explosion accident occurs due to a leakage of residual gas in the facility or a pressure rise. To prevent this, internal gas discharge and purge work are performed in advance, and harmful gases remaining inside the pipe and reactor are discharged into the atmosphere afterwards.

In general, most of the VOCs emitted from industrial processes are emitted into the atmosphere through a Regenerative Thermal Oxidizer (RTO) or scrubber facilities operated by adsorption or combustion. These are advancing continuously the strengthening emission regulations through the development of high-efficiency reduction technologies [11-14].

Among the harmful gas removal technologies, the adsorption technology uses an adsorbent with high

adsorption efficiency. However, secondary environmental pollution occurs due to adsorbent waste caused by periodic adsorption replacement. Since fires or explosions can occur due to high concentration of desorption gas generated during the adsorbent regeneration process, the adsorbent must be safely regenerated. In particular, the development of technology to remove pollutants by securing carbon tax emissions and improving filter performance is underway. VOCs removal technology through regenerative thermal oxidants (RTO) is a device to remove VOCs by burning a certain amount of fuel [15-17].

Dangerous facilities such as petrochemical plants are always prone to accidents, and such accidents have significant economic implications such as safety controversy and production because they are directly related to the safety of residents and workers around their lives. Design of collection ports that can adapt to pipes and nozzles of various sizes is required to handle regular maintenance and residual harmful gases (VOCs) at discharged industrial sites.

Technology for VOCs treatment has been developed, but technology for VOCs recovery and energy recycling is still in the research stage. Seoul National University of Science and Technology in Korea developed an energy-saving condensing device with 95 % solvent recovery at room temperature and atmospheric pressure in the study of adsorption source materials and gas separation processes for small-scale high-concentration emission VOCs [18].

C&G Tech developed zeolite adsorbents and modules with excellent adsorption function and regeneration ability in large-scale painting process studies such as shipyards, and obtained test results of 99 % dust collection efficiency, 96.68 % adsorbent regeneration efficiency, and 92 % VOC removal efficiency of the demonstration device under 9,000 CMH conditions [19].

The Korea Institute of Energy Technology developed a low-cost, high-efficiency rotary VOC adsorption and catalytic combustion device using ceramic paper containing

more than 40 % of ZSM-5 high-silica zeolite to remove less than 1,000 ppm of volatile organic compounds (VOCs) in the VOC adsorption and catalytic combustion process study [20].

VOC removal technology using photocatalysts has been actively studied in Japan, the United States, and Europe. However, in the US and European markets, Engelhard, Dupont, BASF, and Dow Chemical have occupied the market in this field for more than 50 years, and oxidation and adsorption technologies are used as traditional VOC removal technologies.

Ford, in the United States, has developed a technology to remove volatile organic compounds generated in painting factories in cooperation with DTE. With a system linking high concentration adsorption and desorption concentration system, and a reforming reactor using concentrated volatile organic compounds and fuel cell power generation, a technology that not only recovers volatile organic compounds but also utilizes them as an alternative energy source was developed [21].

EPA Company is actively promoting the resource conversion technology of volatile organic compounds by introducing them into the CO₂ reduction program. SRS Engineering in the United States has been fully automated and commercialized to recover volatile organic compounds generated in paint, coating, adhesives, ink, and petrochemical production processes [22].

The Capture & Control System supplied by Durr Environmental in Germany sells a system that heats and decomposes air containing volatile organic compounds by concentrating a large amount of volatile organic compounds by adsorption and then desorbing them [23].

Air Products' Cryo-Condap system commercialized a system to remove VOCs by lowering the temperature of volatile organic compounds using liquefied nitrogen, and which is concentrating and freezing them [24].

Japan's Kureha Techno Eng company has developed a technology to adsorb volatile organic compounds and desorb them with steam and inert gases [25].

The UK's Kurion Technologies Limited developed a RESx volatile organic compound adsorption system that combines fast regeneration technology by increasing the functionality of carbon or zeolite based on the adsorption process. At this time, it was applied to various volatile organic compound discharge processes ranging from small to large capacity [26].

VOCs are always prone to accidents, and such accidents are directly related to the safety of residents and workers around their lives, and have important socioeconomic implications such as safety controversy and productivity improvement. In this study, a mobile VOCs removal device is implemented. Design an adjustable variable collection port for application to outlets of various sizes. A multi-pipe is also proposed to efficiently collect contaminated gas scattered simultaneously from multiple outlets. At this time, a low concentration of VOC is adsorbed using activated carbon with a high specific surface area, and the adsorbent regeneration operation is performed through vacuum desorption under the heat supply condition of 70 °C in the adsorbent. The VOC discharged at a high concentration is

transferred to a condensation reactor filled with the cooling liquid through a watertight vacuum pump and condenses in direct contact with the cooling liquid. VOCs are recovered by 90 % or more using the specific gravity difference of the layer separation device.

2 MOVABLE VOCS ADSORPTION DEVICE

Most petrochemical plants, metal surface treatment, and plastic manufacturing systems are shut down for repair and maintenance. During maintenance such as replacing old pipes, repairing old facilities, cleaning, removing residual gas, checking pipe connection parts and valves, attention should be paid to the safety of explosion accidents due to leakage of residual gas in the facility or pressure increase. Fig. 1 is the VOCs emission site and consists of a complex duct structure and lots of workers.



Figure 1 VOCs emission site with complex duct structure and multi-worker

Internal gas emission and purge operations are performed in advance to perform safe work, and then pipes and harmful gases remaining inside the reactor are emitted into the atmosphere. The local exhaust port used at this time should be designed with pipes and facilities of various sizes according to the size of the pollutant source. If a collector that does not fit the size of the outlet is used, pollution gas spreads around the operator, resulting in significant socioeconomic losses due to lack of safety response as well as environmental pollution. Fig. 2 shows a variable collection device and a design diagram designed to be applied to ducts of various sizes.

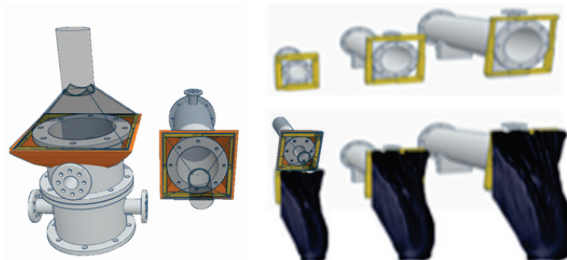


Figure 2 Variable collection device and design diagram to ducts of various sizes.

Multiple pipes are designed to efficiently collect contaminated gas scattered simultaneously from multiple outlets in order to collect gas suitable for the discharge amount of contaminated gas. A pressure sensor is configured

in front of the gas conveying blower, and the load operation of the emitted blower is controlled to enable optimal pollutant treatment and efficient operation of the pollutant treatment facility. Fig. 3 is a diagram applying the shape design of a multi-channel gas transfer pipe and VOCs collector.



Figure 3 Diagram applying for the shape design of a multi-channel gas transfer pipe and VOCs collector.

Fig. 4 shows the adsorbent selection criteria. The adsorbent selection criteria include multiple adsorption performance, long-term adsorptions, and reliability with moving replaceable cartridge adsorption modules.

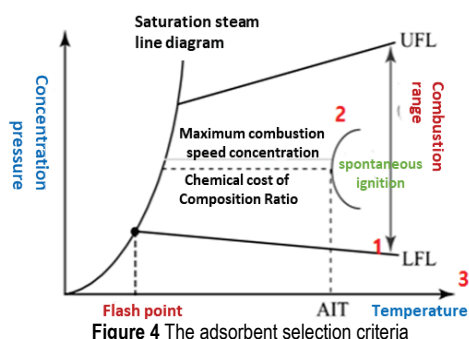


Figure 4 The adsorbent selection criteria

In Fig. 4, 1 (red) represents VOCs sensor, 2 (red) represents water spray and 3 (red) represents thermal imaging sensor.

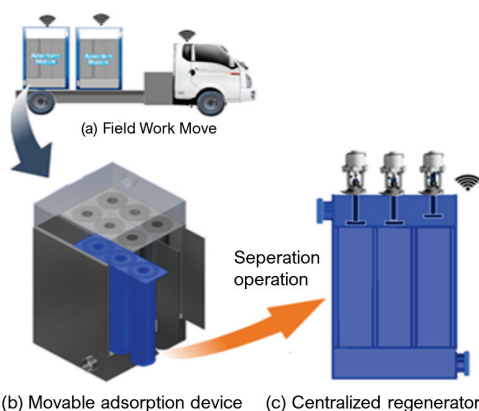


Figure 5 Sensor-based 50 CMM class VOCs adsorption device and a 5 CMM class non-flammable waste heat recovery type movable regeneration processing device with a gas treatment regeneration circulation method

Fig. 5 shows a sensor-based 50 CMM class movable VOCs adsorption device and a 5 CMM class non-flammable waste heat recovery type movable regeneration processing device with a gas treatment regeneration circulation method.

Fig. 6 shows in detail the adsorption device and regeneration device for VOC treatment in Fig. 5. The structural characteristics of this device are that three cylindrical cartridges constitute one module, and three modules of the transfer rotor are transported to one regeneration device. The adsorption module constituting the regeneration device supplies regeneration gas sequentially through nine valves and regenerates the adsorbent. The inside of the adsorption device is configured as a safety device that sprays water into the adsorption module through the water spray nozzle attached to the adsorption module and controls dangerous situations according to the detection of the thermal image sensor of the adsorbent.

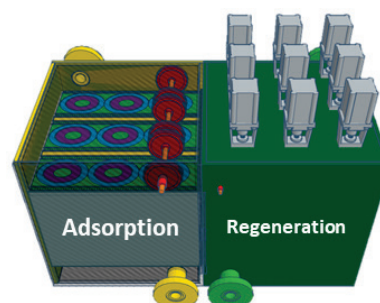


Figure 6 The VOCs adsorbent regeneration equipment

Fig. 7 shows the detailed structure that performs adsorption and regeneration functions. The regeneration device and the regeneration gas oxidation device are configured in a sealed form as one block.

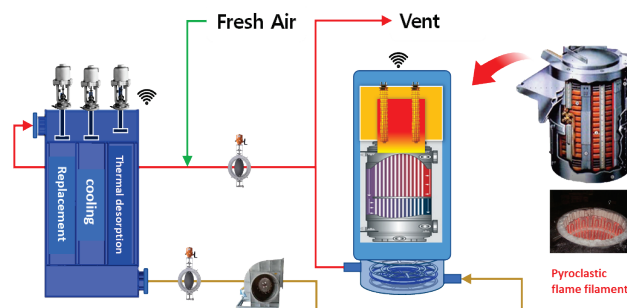


Figure 7 The detailed structure of the adsorption and regeneration device

The oxidation device uses a high-temperature heating element to oxidize volatile organic compounds containing regeneration gas. The temperature required to regenerate the adsorbent is supplied to the regeneration device. Regeneration gas continuously circulates between the regeneration device and the oxidation device and replaces the regeneration completed adsorption module and uses it for adsorption again. The device transfers the adsorption device to a state included in a block-shaped column so that the adsorbent is not exposed to the outside. The concentration of volatile organic compounds desorbed during the regeneration process can be adjusted by sequentially adjusting the valves built in the regeneration device, and the desorbed volatile organic compounds generate heat during combustion in the oxidation device, thereby reducing the energy cost required for the oxidation device.

3 EXPERIMENTAL RESULTS

Tab. 1 shows the operating conditions that the adsorption and regeneration device perform the condensation recovery shown in Fig. 7.

Table 1 The operating conditions of the condensation recovery

Test category	Unit	Operating condi.
Absorption	Inflow concentration	ppm
	Inflow flow rate	m ³ /h
	Activated carbon t amount	kg/tank
	Emission concentration	ppm
Detachable	Flow rate	m ³ /h
	Concentration	ppm
	Temperature	°C
	Pressure	mm H ₂ O
Syngas material	Seasonal VOCs input	kg/h
	VOCs for combustion	kg/h
	Seasonal temperature	°C
Syngas power	Inflow flow rate	m ³ /h
	Electricity output	kw/h

Tab. 2 shows the results of tests under various conditions using Tab. 1.

Table 2 The test results

Category	Unit	Test results		
		Tank1	Tank2	Tank3
VOCs adsorption amount	kg	32.85	32.18	33.00
VOCs adsorption capacity	g/g	0.41	0.40	0.41
VOCs desorption amount	kg	28.7	28.2	28.8
VOCs condensation efficiency	%	96.8	96.3	96.7
VOCs condensation recovery	L	43.64	69.51	99.38
Syngas production	m ³ /h	12.19 ± 0.82		
Electricity output	kWh	751 (Operating time 31 h)		

Fig. 8 shows the concentration change during all simultaneous and continuous regeneration. Here, the sequential reproduction characteristics must change constantly over time.

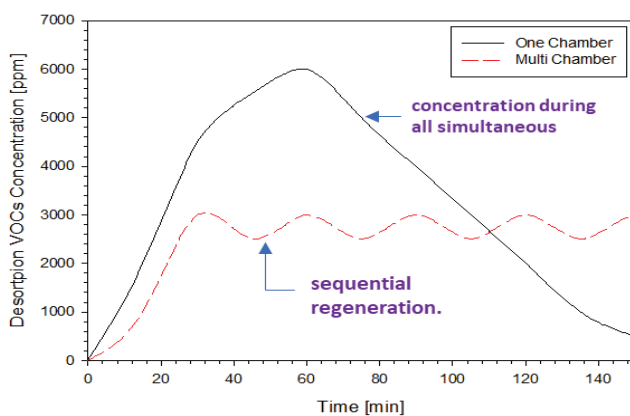


Figure 8 Desorption VOCs concentration during adsorbent regeneration

In the integrated control sequence, the operation of each chamber is basically controlled by the timer. The operation sequence of other chambers operated in connection is progressed based on the operating state of the chamber in which adsorption is performed. The blower operation is controlled by varying the number of revolutions to the

Inverter according to the filter differential pressure, and which is controlled to maintain a constant exhaust gas flow rate. If the Inverter variable criterion is proceeded as a linked operation criterion, a change in the exhaust gas flow rate may occur due to a temporary measuring instrument error or the influence of a production facility, and the operation is controlled to be varied according to the difference between the average filter differential pressure value measured for 2 to 5 minutes and the standard differential pressure value. Fig. 9 shows the operation of sequentially controlling the adsorption chamber 1 and the other adsorption chamber 2 in the order of 10-minute adsorption, 7-minute steam, and 3-minute drying.

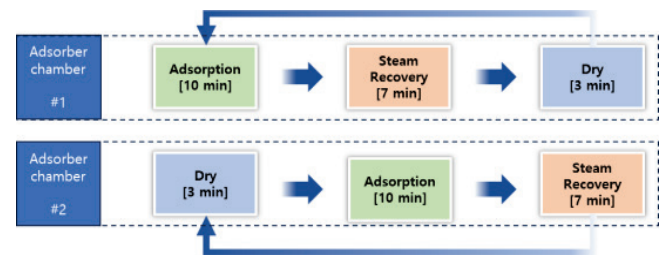


Figure 9 The operation of sequentially controlling

The computer analysis program used for steam flow analysis uses Solid Edge 2022 Classic version by Siemens. A standard steam supply of 350 kg/hr six times per hour is used for steam supply, reflecting the volume of steam supplied to commercial facilities. Fig. 10 shows the fluidity design of steam according to the filter shape.

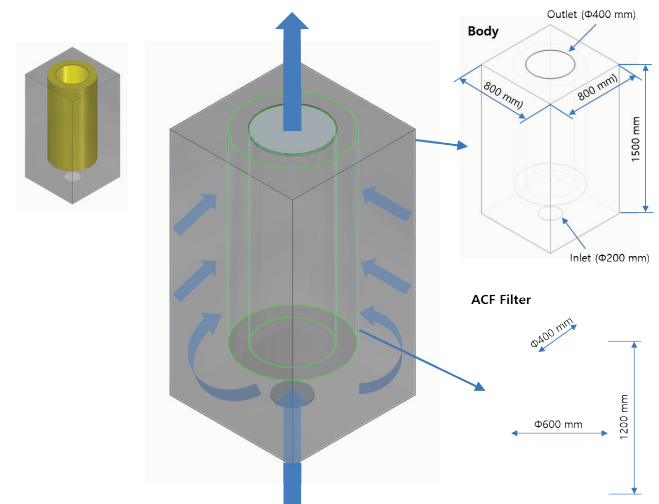


Figure 10 The fluidity analysis of steam according to the filter shape

Fig. 11 shows the flow analysis and flow trajectory of the adsorption filter. According to the results of the adsorption filter simulation, the treatment gas introduced into the lower side of the adsorption device has a strong swirling flow at the bottom of the filter, and according to the linear speed of the filter cross section, the treatment gas rotates inside the device, is evenly distributed throughout the filter and passes evenly. As the swirling flow moved to the upper filter, the swirling speed decreased.

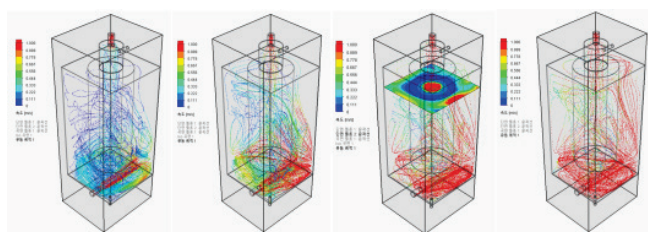


Figure 11 The flow analysis and flow trajectory of the adsorption filter

Fig. 12 shows the flow analysis of steam. In the filter design, when the lower opening length is smaller than that of the top, it is considered to be the most efficient for adsorption filter regeneration using a steam supplier. At this time, steam is supplied from the top to the bottom of the filter, and the amount of steam passing through the supplied steam increases by about twice as much as that of the bottom of the filter.

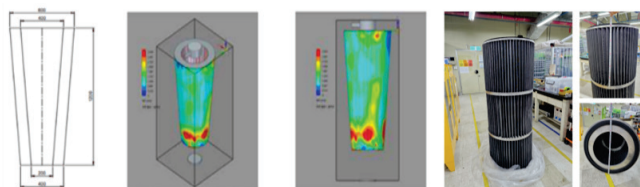


Figure 12 The fluidity simulation of steam to the adsorption filter

In Fig. 13, when the amount of dry air was 42 L/min, the supply position of dry air was adjusted to the upper part, lower part of the reactor and the lower part of the heat exchanger to compare the regeneration characteristics under each condition [10].

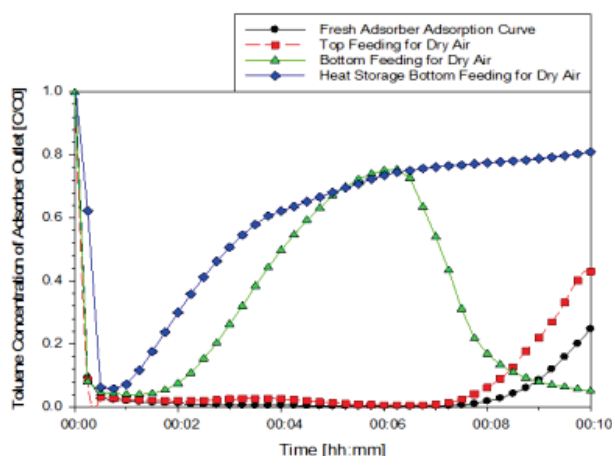


Figure 13 Comparison of regeneration characteristics by location of dry air

When supplying the upper part of the reactor, the regeneration efficiency decreased by about 96.4 % of the initial adsorption performance, and by 69.8 % and 42.2 % in the order of the lower part of the reactor and the lower part of the heat exchanger, respectively. When dry air is supplied to the lower part of the heat exchanger, the drying performance decreases due to the residual moisture inside the heat exchanger, and the regeneration performance of the adsorbent decreases

Fig. 14 shows the state in which the adsorption module inside the adsorption device moves to the regeneration device. In the adsorption module, the regeneration and adsorption devices are brought into close contact with the adsorption. Then the door open and the adsorption module moves to the regeneration device. The adsorbent is regenerated while working with the regeneration and oxidation devices. These processes work in order; each device can be operated through one control system.

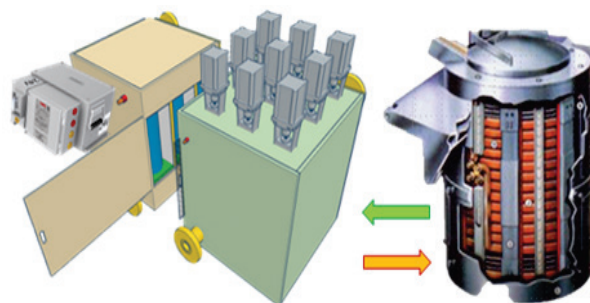


Figure 14 Movable VOCs processing system

Fig. 15 compares the adsorption characteristics of VOCs after 10 minutes of steam regeneration and the adsorption characteristics after 10 minutes of drying after 10 minutes of steam regeneration in the pilot test device [27].

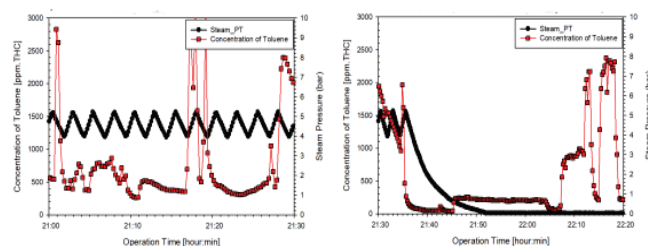


Figure 15 Comparison of the VOCs adsorption characteristics

The material used in the adsorption test was supplied with 400 ppm of Toluene, one of the types of VOCs, at a flow rate of 90 mL/min. In order to supply liquid Toluene in a gaseous state, it is supplied to the test gas inlet pipe in a atomized state. The steam supply is supplied at a cumulative flow rate of 146 kg/h, and the re-adsorption performance is confirmed through the adsorbent regeneration operation. The adsorption efficiency was 86% at 300 ppm after 10 minutes of steam regeneration, but when comparing adsorption after 10 minutes of steam and 10 minutes of drying treatment, the outlet concentration is 200 ppm, which is confirmed to be 90%. Note that when the ambient temperature decreases to below zero and the drying efficiency decreases, the adsorption effect also decreases.

Fig. 16 shows a movable adsorption and regeneration device using an inverter. In the figure, not only the blower operation but also the pollution gas collection speed can be constantly adjusted with the collector through the pressure gauge in front of the blower. A differential pressure sensor is built-in to control the appropriate flow rate and required power.

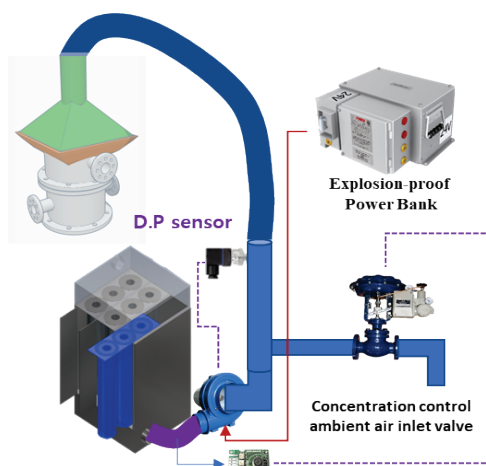


Figure 16 Movable adsorption and regeneration device

4 CONCLUSION

Most petrochemical plants, metal surface treatment, and plastic manufacturing systems are shut down for repair and maintenance. When maintaining old pipes, repair old facilities, cleaning, removal of residual gas, inspection of pipe connection parts and valves, etc., the safety of explosion accidents due to residual gas leakage or pressure rise in the facilities should be noted. During gas removal, internal gas discharge and purge are performed in advance, and then pipes and harmful gases remaining inside the reactor are discharged into the atmosphere. The local exhaust port used at this time should be designed with pipes and facilities of various sizes according to the size of the pollutant source. When a collector that is not suitable for the size of the outlet is used, pollutant gases spread around the driver, resulting in great socioeconomic losses due to environmental pollution as well as insufficient safety response.

This development technology implemented and tested optimal pollutant treatment and efficient pollutant treatment facilities by configuring a number of pipes to collect gases suitable for pollutant discharge and efficiently collect pollutant gases scattered from various outlets at the same time. Based on the CFD simulation and test results, adsorption and regeneration efficiency of 90 % or more were achieved. In particular, through the development of an adsorption regeneration filter, localization was achieved, and a plan to protect safe workplaces and lives from the dangers of VOCs gas was prepared. In particular, the variable collection port customized to the shape of the outlet of the maintenance facility secured the technology used to control the amount of processing gas transport. In addition, the distribution of diffusion discharge VOCs is detected using a differential pressure sensor, and the location of the collection port is selected and applied to the removal of mobile VOC gas.

During the pilot operation of the test device, there is a risk of fire and explosion due to the frictional heat of the pressure pump cylinder during the pressurization operation of the high-concentration VOC-containing gas, which requires attention. In addition, the condensed VOC of the condensing reactor had difficulty in maintaining the VOC

separation layer due to flow when the incoming cooling liquid and the mixed liquid were introduced.

Acknowledgments

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Airflow Characteristics in Conveyor Type Damper for Hot Air Temperature Changes

Yong-Gyu Chae, Hyun-Woo Won, Dong-Hyun Cho*

Abstract: The aim of this study was to present the characteristics of a hot airflow in a conveyor type dampers under the hot air temperature changes. The amount of space occupied by the damper was reduced by 50 %, and by efficiently managing the damper's airflow rate even in the face of extreme external conditions and constant air volume proportional control, a conveyor-type damper with a significant energy-saving effect has been explored. It was configured to control the degree to which it was opened by operating the folding conveyor drive mechanism, enabling the damper to modify airflow. In this study, the mass flow rate of heated air through the conveyor-type damper increased in proportion to the damper port's expansion. The mass flow rate of air decreased as the temperature of air intensified. In addition, the thermal energy of the air flowing in the conveyor-type damper improved in ratio to the increase in the damper opening. The findings indicate a 50 % reduction in the damper's occupied space, indicating a significant energy-saving impact of the conveyor-type damper. This is because the damper's air volume is effectively controlled even in the face of severe external conditions, as it is proportionately controlled throughout. The understanding of the properties of airflow for the hot temperature change is strengthened by this research. Furthermore, this study may provide useful direction for future research and industry optimization.

Keywords: air mass flow rate; air temperature; conveyor type damper; damper opening hydraulic; thermal energy

1 INTRODUCTION

The damper controls the air volume by adjusting the level of primary of the duct, but the control of the air volume is not easy because the air volume varies according to still pressure and the level of opening. A control of air volume is more difficult in the case of single-blade dampers because the air volume alterations non-linearly based on the degree of opening under the same static force [1, 2]. Local and international research on damper technologies tends to study multi-blade dampers to explain the nonlinearity issue. In addition, since multi-blade dampers cannot be easily made into round dampers, venturi-type dampers have been studied and reported [3]. Rectangular dampers or multi-blade louver dampers are common names for multi-blade control dampers. Based on the blade action—the direction in which the blades revolve within the control damper—these dampers are usually available in two different variants. Recently, blade-orifice dampers that has outstanding linearity as the blade is installed on the neck of the orifice have been studied, and their features has been compared with those of venturi type dampers [4, 5]. Yet, the air volume cannot be easily controlled in the case of blade-orifice type dampers since the density varies as the opening's degree is adjusted. In addition, as an important characteristic of a damper, the presentation of the damper is articulated by the flow coefficient, and a certain number of pressure drops are basically designed based on the stroke distance of the damper when manufacturing the damper. When the damper is opened rapidly, the opening begins, and the flow rate rapidly increases to the maximum flow rate. When the damper is opened linearly, the opening and the flow rate are proportional to each other at an equal ratio, and as the opening increases at an equal rate, the flow rate also increases at an equal rate as with the previous flow rate. The actual amount of pressure drops before and after the damper appear differently from the performance curve, and the amount of error is determined according to the design of the entire system. Therefore, the damper shows the error range of the damper designed with linear characteristics in the pressure

drop ratio of the entire system of a typical linear device, and dampers should be designed and manufactured based on the pressure drop ratios of various systems. The damper coefficient is the ratio of the maximum air volume when the damper is fully opened to the system pressure drop before and after the damper. Looking at the report on the performance curve, parallel blade dampers are suitable for two-point control, and in the case of opposed blade dampers, the necessity to reduce damper errors with fine control is high because the ratio of the pressure drop at full opening to that at closing is large. Considering the characteristic that the ratio of the amount of pressure drop in the phase is large, there is a great need to reduce the error of the damper by fine control. In addition, the air flowing through the duct has a characteristic that the density, which is the physical property of the air, changes greatly according to the temperature changes of the air. Therefore, if an adjustment in the density in the air according to a change in a temperature of the air is not considered, the error of the damper will greatly increase. As such, by designing and manufacturing the dampers based on the characteristics of dampers and the design theory, the errors are reduced, and the precision is improved in the process of controlling the air volume by adjusting the degree of opening of the duct. However, since most of damper manufacturers are small and medium-sized enterprises (SMEs), research and development of dampers are insufficient, and since dampers are manufactured based on experience values in the state where the design theory values are lacking in the damper manufacturing process, the continuous air volume cannot be easily organized. Many errors occur in the process of controlling the air volume by adjusting the degree of opening of the duct. In addition, in the forced ventilation fans, the damper controls the intake flow of air by adjusting the opening/closing angle of the vane damper to supply combustion air to the boiler, heater, and dryer [5]. As the need for energy saving in mechanical devices such as boilers, heaters, and dryers has been increasing in recent years, dampers with high efficiency and low power consumption are studied for forced ventilation fans [6, 7]. Therefore, in order to reduce power consumption,

forced ventilation fans are being developed to enable the adjustment of the air flow ratio based to the changes in external load conditions [8, 9]. The R&D of the forced ventilation fans as such is actively conducted because if such forced ventilation fans are used in boilers, heaters, dryers, etc., the air volume of the damper will be effectively controlled even when the external conditions change severely during operation so that the energy saving effect will be large [10, 11]. In addition, in order to reduce errors and improve precision when the damper is designed, the characteristics of the facility, the values of system loss characteristics, the values of pressure changes according to air flow changes, the performance curve values for the blower system action, the ratio of system pressure drop to the maximum air volume when the damper is fully opened, and the characteristic values of the density, which is the physical property of air, changing greatly depending on the air temperature changes should be considered accurately [12, 13]. Therefore, at the current level of domestic and foreign damper manufacturing technologies, study reports on dampers that considered all these variables are insufficient as it is difficult to satisfy all the variables with existing technologies. In this study, a blade folding damper that can satisfy all variables was developed. The purpose of this study was to describe the properties of a hot airflow for the hot air temperature of dampers at various authority levels. In this study, a blade folding damper that can satisfy all variables was developed. The blade folding damper occupies 50 % of the space that would be occupied by an existing damper and controls the constant air volume proportionally and effectively even when the external conditions change severely leading to a large energy saving effect.

2 METHOD AND DEVICE FOR EXPERIMENTATION

Fig. 1 explains the conveyor type damper experimental device. Fig. 1 represents the conveyor type damper is composed of the folding blade, a folding blade driving device, a blower fan, an inverter for controlling the air volume of the blower fan, a conveyor type damper rectifier grid, a blade folding damper opening proportional control device, and a hot air energy supply device with a gas burner.

The experimental device was configured so that the degree of opening of the conveyor type damper can be controlled by the driving of the folding blade driving device, to adjust the volume of air flowing with the conveyor type damper. To manage the amount of air passing by the damper, the blower was added with an inverter to regulate the fan's revolutions per minute. An experimental tool was configured in regulating the heat of the air go along in a conveyor type damper by supplying the hot air energy for the combustion gas of the gas burner. A flow velocity sensor was connected in the area of the duct outlet of the conveyor type damper to estimate the hot air flow velocity. A temperature sensor was installed in the section of the duct exit for temperature measurement of the air. In addition, hot air is introduced into the inlet of the duct of the conveyor type damper by the operation of the blower fan [14-17]. As such, the conveyor type damper experimental device was configured so that the air introduced into the inlet of the duct of the conveyor type damper passes over the rectifier grid so

that the flow velocity of the air is uniform. An experimental device was configured so that the velocity of the air go along by the damper area is maintained to be uniform by the rectifier grid installed at the front end of the inside of the duct.

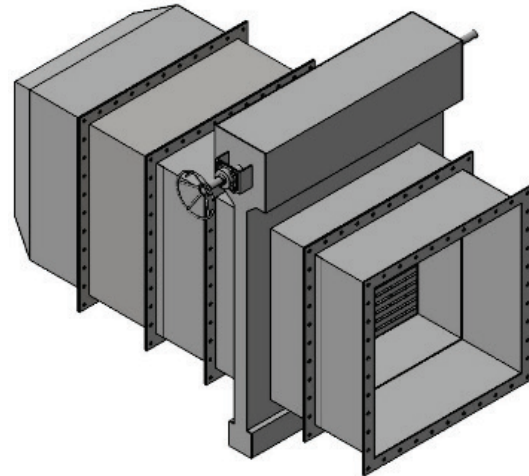


Figure 1 Experimental device of conveyor type damper

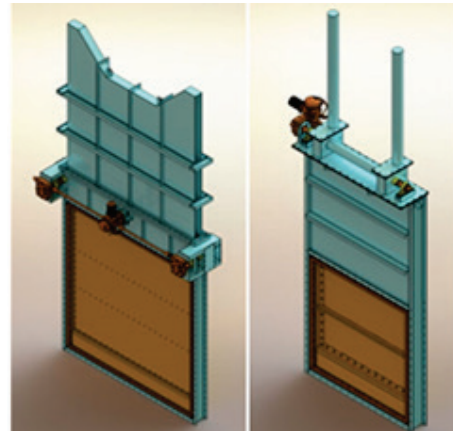


Figure 2 The folding blade drive unit with folding blades

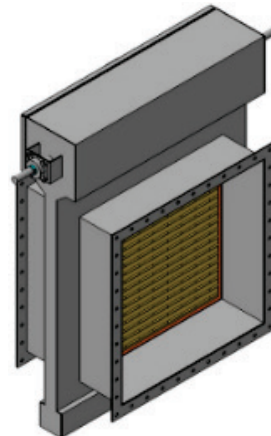


Figure 3 Drive system of blade folding damper

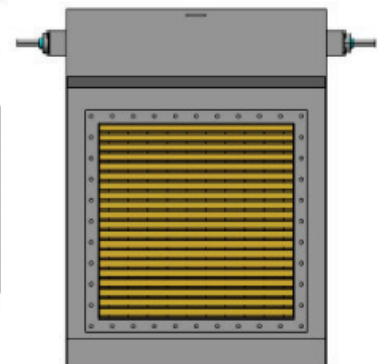


Figure 4 Front view of the drive system of conveyor type damper

Fig. 2 shows the driving device of the conveyor type damper. As shown, the driving device of the conveyor type damper was configured so that the folding blade proportionally adjusts the level of damper opening. The study

was conducted on a conveyor type damper applicable in a constricted area shown in Fig. 3 and Fig. 4. Existing plate-type dampers occupy a huge area when the level of opening of the damper is augmented. In order to solve the problem of such structure, a blade folding damper experimental device should proportionally control the continuous air volume based on the level of opening of the damper. We configured a blade folding damper that enables precise quantitative regulation with horizontal movement of the fluid when the degree of opening of the damper changes and minimized the space in which the ascending and descending blade is accommodated so that the damper can be installed regardless of the space even when the installation place is small.

Fig. 5 presents the specifications of the foldable blade. As shown, the area of the folding blade is 50 mm, a total of foldable blades is 25, and the width is 2 mm. A weight of the foldable blades is 50 kg, and a driving rate of the foldable blades is 50 mm/c. An experimental device was configured so that the foldable blade driving shaft is driven at a torque of 19.12 kN·m.

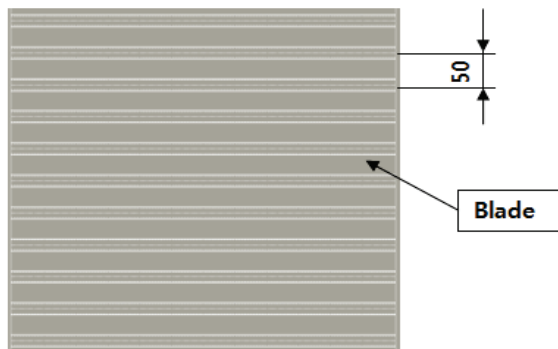


Figure 5 Size of foldable blade

2.2 Experimental Method

A slim foldable roll screen blade technology that will enable the application of dampers developed with new technologies with new concepts in cases where expensive products, high-function valves are used by installing slide dampers in narrow spaces in industrial facilities or the layout of industrial facilities are changed was experimentally studied. Whereas the existing dampers use individual blades or the integrated blade structure method like the slide dampers, in this study, an experimental device for a damper of a new concept in the foldable roll screen blade method was configured. In addition, according to study reports on the existing damper blades, it is hard to modify the continuous volume of the air that flows in the damper proportionally to a motionless weight and the level of opening. Tab. 1 presents the experimental variables and experimental situations for the study of the air volume characteristics according to the temperature change of the air going inside a duct of a conveyor type damper. The degree of damper opening was one of the experimental variables together with the air temperature, and changes in the hydraulic diameter. The degree of damper opening was uniformly allocated into 10 areas in the range of 10 to 100 %, and the experiment was performed at air temperatures of 280 K, 300 K, and 320 K.

The hydraulic length was uniformly separated into five areas in the range of 0.07 to 1 m to conduct the experiment.

Table 1 Conditions and parameters for the experiment

Parameter	Value
The damper's opening degree	10-100 %
Temperature of air	280 K, 300 K, 320 K
Hydraulic diameter	0.18-0.95 m

3 RESULTS AND DISCUSSIONS

3.1 Mass and Thermal Energy Equilibrium of the Air Flowing in the Damper

Fig. 6 discussed the relationship of the theoretical air mass flow rate and the experimental hot air mass flow rate in the conveyor type damper. Eq. (1) represents the continuous equation for calculating the theoretical hot air mass flow rate.

$$m_{a,th} = \rho \cdot A \cdot V \quad (1)$$

In Eq. (1), ρ represents the density of hot air (kg/m^3), A represents the cross-sectional section of the conveyor type damper. The thickness of a conveyor type damper is 1 m and the length is 1m. Thus, the cross-sectional section of a conveyor type damper is 1 m^2 . V signifies the flow speed (m/s) of the hot air running in the conveyor type damper. The temperatures of the hot air go along in the conveyor type damper were 280 K, 300 K, and 320 K when the hot air mass flow rate change experiment was performed with changes in the hot air temperature. In addition, the experiment was conducted in 10 equal sections while increasing the degree of damper opening by 10% from 0-100%. As shown in Fig. 6, a theoretical hot air mass flow rate and an experimental hot air mass flow frequency in the conveyor type damper matched well within a range of $\pm 3\%$. Hence, the accurateness of the experimental results of the theoretical hot air mass flow rate and the experimental air mass go along are shown to be high. It is considered that the consistency of the experimental outcomes has been proved.

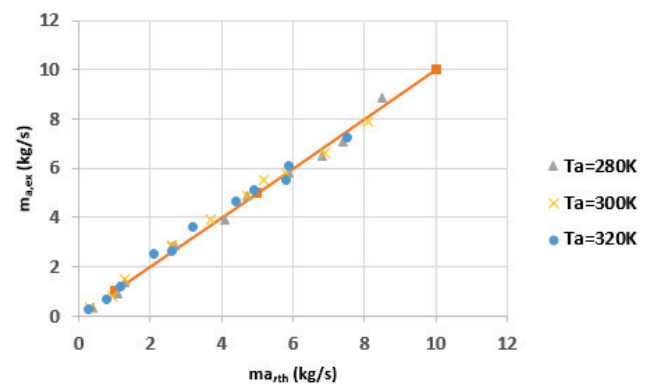


Figure 6 Comparison of theoretical hot air mass flow rate and experimental air mass flow rate

Fig. 7 represents the contrast of the theoretical hot air energy and experimental hot air energy of the air flowing in the conveyor type damper. Eq. (2) represents the theoretical thermal energy.

$$Q_{a,th} = m_{a,th} \cdot C_p \cdot (T_2 - T_1) \quad (2)$$

In Eq. (2), C_p of air represents the specific heat of air (kJ/kgK). T_1 represents the primary temperature (K) of an air flowing in a blade folding damper. A primary temperature of the hot air for a calculation was set to 0 K, and the hot air energy at 0 K was set to 0 kJ. T_2 represents the temperature of the flowing air when hot air energy was applied. Three temperatures: 280 K, 300 K, and 320 K of the air flowing in the conveyor type damper were set to experiment changes in the hot air energy in response to temperature changes. In addition, the experiment was conducted in 10 equal sections while increasing the degree of damper opening by 10 % from 0-100 %. Fig. 7 shows the theoretical hot air energy and the experimental hot air energy of the air go along in the conveyor type damper were in decent arrangement within the range of ± 3 %. As the hot air energy value rises, the accuracy of the experimental hot air energy develops. Therefore, the accuracy of the experimental hot air energy value of the air flowing in the conveyor type damper was high. It is considered that the consistency of the experimental outcomes has been confirmed.

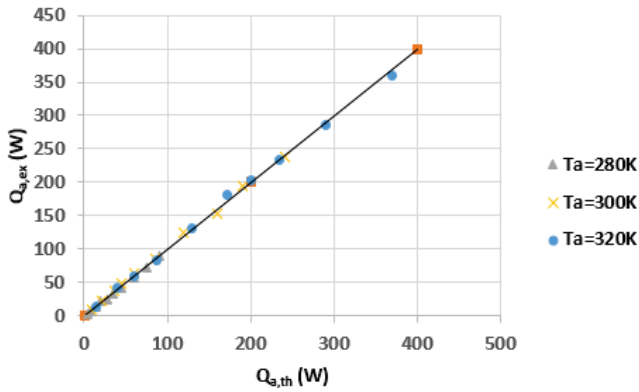


Figure 7 Comparison of theoretical hot air energy and experimental hot air energy of hot air flowing in the damper

3.2 Changes in the Temperature of the Air Flowing in the Damper and the Characteristics of the Air Volume according to Changes in Damper Opening

The variations in air mass flow rate about the conveyor type damper's damper opening level are shown in Fig. 8. In Fig. 8, D_o represents the degree of damper opening (%) of the blade folding damper. A degree of damper opening was controlled by configuring a conveyor type damper experimental device that can proportionally control the constant air volume. The experimental device was arranged so that the degree of damper opening could be adjusted, and the experiment was conducted in five equal sections while increasing the damper opening by 20 % from 0-100 %. In addition, three temperatures of the air flowing in the conveyor type damper: 280 K, 300 K, and 320 K were set to experiment changes in hot air energy in response to temperature changes. The mass flow rate of the air goes along in the conveyor type damper amplified in percentage to the increase in the degree of damper opening. It is believed that the mass flow rate of the hot air drops as the temperature of

an air rises because when the hot air temperature increases, the density of the air decreases.

Fig. 9 shows a change in the air volume with respect to the adjustment in a degree of the damper opening of a conveyor type damper. In Fig. 9, D_o represents the level of damper opening (%) of a conveyor type damper. The degree of damper opening was controlled by configuring a conveyor type damper experimental device that can proportionally control the constant air volume. The experimental device was arranged so that the degree of damper opening could be adjusted, and the experiment was conducted in five equal sections while increasing the damper opening by 20 % from 0-100 %. In addition, three temperatures of the hot air go along in the conveyor type damper: 280 K, 300 K, and 320 K were set to experiment changes in the hot air energy in response to temperature changes. Furthermore, the volume of the hot air go along in the conveyor type damper amplified in percentage to a rise in a level of damper opening, and the air volume increases as the temperature of the air increases. It is believed that the air volume rises as the temperature of the air rises since as the temperature of the air rises, the density of the air drops. The hot air energy of the hot air rises proportionally as the volume of air flow increases following the increase in the degree of the damper opening. Also, it is considered that the hot air energy increases as the amount of heat retained in the air rises as the hot air temperature rises.

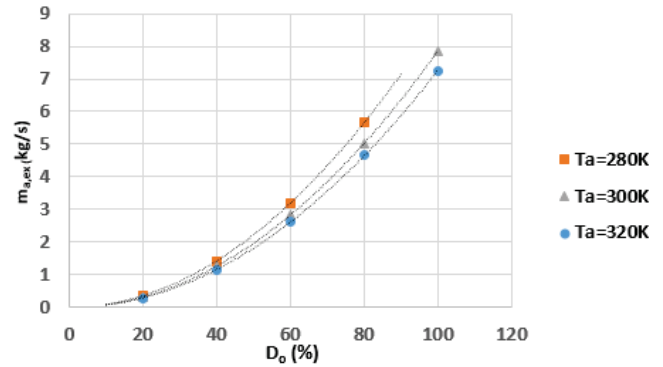


Figure 8 Modification of the air mass flow rate to adjust the damper opening

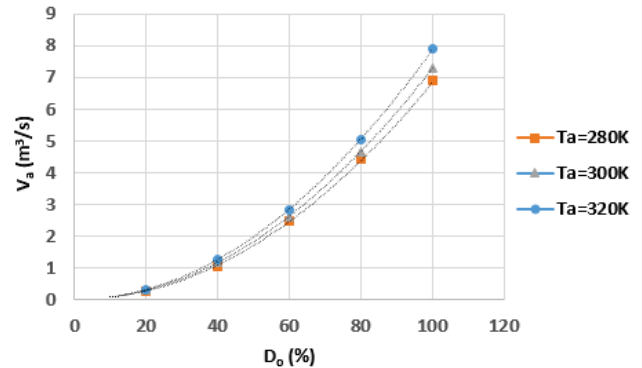


Figure 9 Change in hot air mass flow rate for change in damper opening

Fig. 10 appears a change in the hot air energy of the hot air for the adjustment in the degree of damper opening of the conveyor type blade folding damper. In Fig. 10, D_o represents the damper opening level (%) of the conveyor type damper. A damper opening was controlled by configuring a conveyor

type damper experimental device that can proportionally control the constant air volume. The experimental device was arranged so that the degree of damper opening could be adjusted, and the experiment was conducted in five equal sections while increasing the damper opening by 20 % from 0-100 %. In addition, three temperatures of the hot air flowing in the conveyor type damper: 280 K, 300 K, and 320 K were set to experiment changes in the hot air energy in response to temperature changes. It is thought that the mass flow rate of the hot air drops as the temperature of the air rises because as the air temperature increases, the density of the hot air decreases. Fig. 10 shows hot air energy of a hot air flowing in the conveyor type damper augmented in ratio to the increase in the degree of damper opening and increases as the temperature of the hot air rises. It is considered that the hot air energy of the hot air rises proportionally as the mass flow rate of hot air increases as the degree of damper opening increases. Also, the hot air energy rises as the amount of heat retained in the air increases as the air temperature rises.

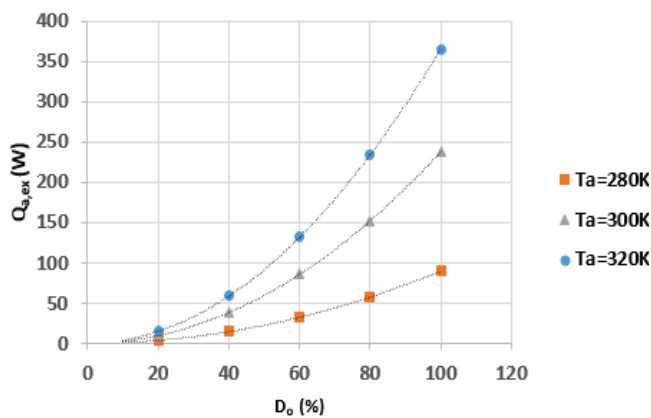


Figure 10 Modification of the hot air mass flow rate to adjust the damper opening

Fig. 11 represents a transformation in the Reynolds quantity for the changes in the hydraulic length of the conveyor type damper. Eq. (4) represents a hydraulic diameter.

$$D_h = \frac{4A}{P} \quad (3)$$

where, P denotes the wetted perimeter of the conveyor type damper and Eq. (4) represents the Reynolds number.

$$Re = \frac{\rho \cdot V \cdot D_h}{\mu} \quad (4)$$

where μ represents the viscosity coefficient of air (N/ms). The hydraulic diameter was experimented in five sections of 20 %, 40 %, 60 %, 80 %, and 100 % of the flow cross-sectional section of the damper. Thereafter, the hydraulic diameter was calculated using Eq. (3) for a flow cross-sectional section of a 5 sections. In addition, the Reynolds numbers according to changes in the hydraulic diameter at three temperatures of the air go along in a conveyor type

damper: 280 K, 300 K, and 320 K. As shown in Fig. 11, following changes in the level of damper opening, the Reynolds number improved in percentage to the rise in hydraulic diameter. As an air temperature increased, the Reynolds number decreases. From these experimental results, it is considered that the Reynolds number of the air drops as the temperature of the air rises, because a density of an air decreases as a temperature of an air increases.

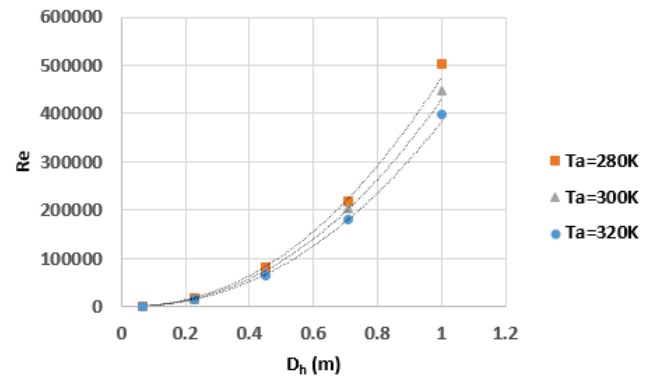


Figure 11 Change of Reynolds number of hot air with change of hydraulic diameter

Fig. 12 shows changes in hot air energy with respect to changes in the Reynolds number of the conveyor type damper. The Reynolds number was experimented in the range of 1000 to 400,000. Changes in the hot air energy in response to temperature changes were experimented at three temperatures of the air go along in the conveyor type damper: 280 K, 300 K, and 320 K. Fig. 12 shows hot air energy of the air flowing in the conveyor type damper augmented in percentage to the rise in the Reynolds number. Furthermore, the increment of hot air energy increased greatly in proportion to the increase in the air temperature. Therefore, a thermal energy of a hot air flowing in the conveyor type damper is a variable greatly affected by the rise in the Reynolds quantity and the rise in the air temperature. Therefore, the results shows that the space occupied by the damper is reduced by 50 % thus the energy saving effect of the conveyor type damper were large because it proportionally controls the continuous air volume and effectively control the air volume of the damper even when changes in the external conditions are severe.

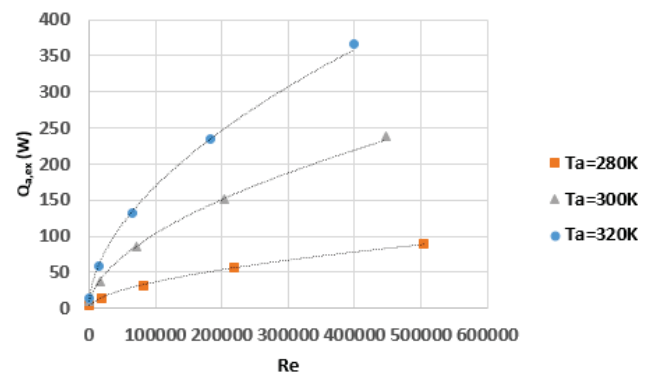


Figure 12 Changes in thermal energy concerning changes in the Reynolds number of the conveyor type damper number

4 CONCLUSION

An experimental study was conducted to find the adjustment in the mass flow rate of air and the adjustment in the hot air energy for the modifications in the temperature of the air passing through the conveyor-style damper varies together with the Reynolds number and damper opening degree. The following study results were derived. Within a ± 3 % range, there was a good match between the conveyor type damper's theoretical and experimental air mass flow rates. There was a ± 3 % discrepancy between the observed and predicted hot air energy of the air. As a result, it was demonstrated that the experimental effect values for the conveyor type damper's temperature changes and variations in damper opening level were highly accurate. Consequently, it was established that the experimental results of this investigation were consistent. The blade folding damper's mass flow rate of hot air is proportionally enhanced to an increase in the degree of damper opening and decreases as the temperature of the hot air increases.

The hot air energy of the hot air flowing in the conveyor type damper augmented in percentage to an increase in the degree of damper opening and increased as the temperature of the hot air increased. The hot air energy of the hot air flowing in the conveyor type damper augmented in percentage to an increase in the Reynolds number and the increment of the hot air energy increased greatly in proportion to the increase in the hot air temperature. The hot air energy of the hot air flowing in the conveyor type damper was greatly affected by the rise in the Reynolds number and the rise in the air temperature. From these research results, the space occupied by the conveyor type damper is reduced by 50 %, and that the energy saving outcome of a conveyor type damper is large because it proportionally controls the constant air volume and effectively control the air volume of the damper even when changes in the external conditions are severe.

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Assessing Adsorption and Desorption Performance in the Recovery of Volatile Organic Compounds: A Carbon Fiber Filter Design Perspective

Dong-Hwan Jeon, Hoon-Min Park, Hyun-Min Jung, Dal-Hwan Yoon*

Abstract: In this study, the activated carbon fiber filter design and VOC adsorption and desorption performance were evaluated based on the development of a filter regeneration device to treat VOCs in high efficiency and low cost. Activated carbon fiber (ACF) has the advantage of fast adsorption speed and high adsorption capacity because micropores are formed on the surface and a large specific surface area. However, the specific gravity is about 25 times lower than that of activated carbon (AC), so the amount of adsorbent that can fill the same volume is small. In order to solve this problem, the regeneration device is implemented by repeating adsorption and regeneration for a short time, and a cylindrical adsorption filter made of activated carbon fiber is designed according to the operating conditions of the regeneration device. At this time, the pollutant gas and regenerated air are uniformly distributed over the entire adsorbent, and the flow characteristics according to the supply of the pollutant gas and the regeneration gas are analyzed. When the size of the lower part of the cylindrical adsorption filter is smaller than the size of the upper part under the condition that the pollutant gas flows downward, a uniform distribution of the pollutant gas is possible. In addition, as the space velocity decreases, the adsorption capacity decreases, and the differential pressure increases rapidly. Through the regeneration experiment, it was confirmed that the desorption concentration of MEK was higher and the desorption concentration was higher. In addition, the regenerated air is uniformly dispersed throughout the adsorption filter, toluene, o-xylene, and methyl ethyl ketone, which are representative substances of volatile organic compounds (VOCs), are injected with 400 ppm, and then regenerated air is supplied at 150 °C to analyze adsorption characteristics and regeneration concentrations. As a result of the experiment, the adsorption capacity ratio to 1 g of regeneration air according to the type of VOCs was 0.48, 0.36, and 0.25 g in the order of o-xylene, toluene, and methyl ethyl ketone. In addition, as the space velocity decreases, the adsorption capacity decreases, and the differential pressure increases rapidly. Through the regeneration experiment, it was confirmed that the desorption concentration of MEK was higher and the desorption concentration of o-xylene was discharged at a relatively low concentration. Moreover, even if the adsorption concentration changes, there was no difference in the regeneration concentration change. Therefore, the filter was designed based on the spatial speed of the regeneration device of 51,000 -h or less, and the adsorption capacity ratio to 1 g of the regeneration air amount was 0.1 g, thereby enhancing the filter's recycling performance and VOCs emission effect.

Keywords: activated carbon fiber; adsorption; flow analysis; regeneration system; volatile organic compounds

1 INTRODUCTION

Efforts to reduce greenhouse gases are being made in various fields as global warming caused by greenhouse gases has reached a serious level worldwide. Volatile organic compounds (VOCs), known as representative greenhouse gases, can be efficiently and safely recovered and recycled at VOC emission sites, thereby minimizing environmental pollution and maximizing greenhouse gas reduction when generating desorption heat energy using renewable energy [1-10]. VOCs are selectively discharged from the discharge system through adsorption, oxidation, absorption, and condensation, depending on their material properties and concentration. Until now, most of the poorly soluble VOCs discharged below 800 ppm using activated carbon have been treated with adsorption technology. Activated carbon has been used for a long time for gas separation and purification because it has the advantage of having pore structures of various sizes. It has been used as an adsorbent for gas purification in a new field through chemical treatment [11].

Activated carbon fibers have developed micropores on the fiber surface, are capable of rapid adsorption due to their large specific surface area, and are known to have superior adsorption rate and selective gas adsorption than activated carbon [12, 13]. The activated carbon fiber can control a specific surface area through heat treatment and formation processes in the manufacturing process and is used for gas separation purification or water treatment in various fields [14-18]. However, since activated carbon fiber have a specific gravity of about 25 times lower than activated

carbon, the same volume can be filled with adsorbents. Therefore, there is a problem that the adsorption efficiency is better than that of activated carbon, but the adsorption time needs to be longer. In order to solve this problem and utilize high-performance adsorption properties, adsorption and regeneration must be repeated for a short period.

In addition, the pressure drop characteristics for process gas and the airflow characteristics for the uniform distribution of process gas and regeneration gas throughout the filter should be considered [19, 20]. These characteristics are essential factors in device design, and pollutant gas purification characteristics may vary depending on the filter shape and structure [21]. Computational flow analysis can confirm the airflow characteristics and the optimal shape can be obtained [22, 23].

Table 1 Comparison of design specifications of activated carbon fiber and activated carbon adsorbent in VOCs treatment equipment.

Adsorbent type		Activated carbon fiber	Activated carbon
Adsorbent	Fill amount	56 kg × 2 = 112 kg	1400 kg × 2 = 2800 kg
	Layer thickness	120 mm	600 mm
Change time	Adsorption	6 min/col	120 min/col
	Escape	6 min/col	30 min/col
Adsorbent container	$L \times W \times H$	1600×1100×1500	2600×1500
	Volume	2.64 m ³	7.96 m ³
Recall consumption	Vapor	350 kg/h	1660 kg/h
	Cooling water	10 t/h	25 t, 48 t/h
	Power	15 kW	15 kW

Tab. 1 compares the design specifications of activated carbon fibers and activated carbon adsorbents in VOCs

treatment units. In the case of activated carbon, it consists of a macro-pore with a pore diameter of 50 nm, a meso-pore with a pore diameter of 2-50 nm, and a micro-pore with a pore size of 2 nm or less deep inside. It is possible to adsorb various substances and is inexpensive, but the adsorption and desorption rate is slow and requires a lot of renewable energy. Activated carbon fibers mainly have micro-pores formed on the surface, so fast adsorption and desorption, less renewable energy is required, and the device can be miniaturized due to excellent adsorption efficiency. Therefore, when an activated carbon fiber adsorbent is used in comparing the performance of activated carbon and activated carbon fiber, the amount of desorption steam supplied is only 20% compared to activated carbon, the size of the device is 33%, the operating cost can be reduced by 4.8 times, and the size of the facility can be reduced.

In this study, activated carbon fibers are designed in the shape of a filter to develop a system to process VOCs with high efficiency and low cost, and a computational flow analysis and VOC adsorption and desorption characteristics were conducted to derive primary design conditions for adsorption filters.

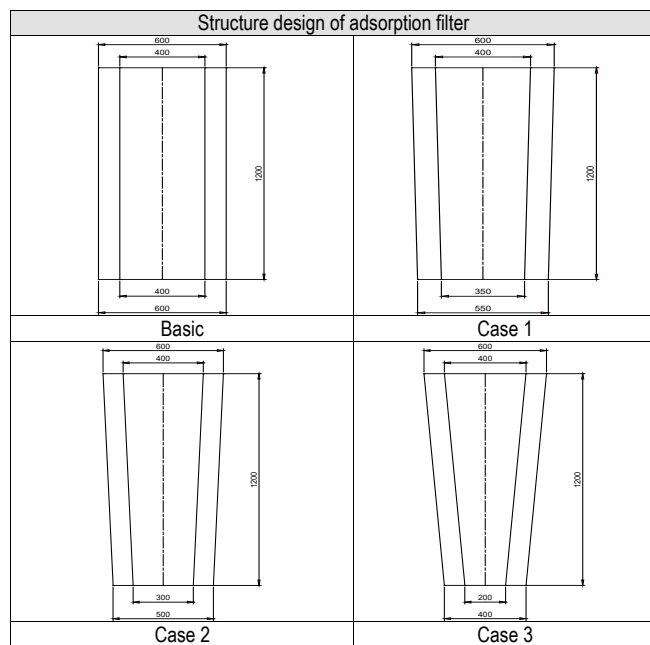


Figure 1 Adsorption filter design for flow analysis

2 IMPLEMENTATION OF OPTIMAL ACTIVATED CARBON FIBER FOR ADSORPTION

Using the high adsorption properties of ACF and designing a filter shape that can adsorb and regenerate quickly, the optimal fluid flow was confirmed using computational flow analysis. The program used for the flow analysis was Solid Edge 2022 Classic version. The adsorption filter shape is cylindrical, generally used in filters, and the grid size for the analysis area was 0.002 m. A matrix consisting of 24,934 cells was applied. The sagging gas supplied to the adsorption filter flows into the lower part of the filter, and the flow rate is 50 Nm³/min. Recycled air

flowed into the top of the adsorption filter and steam controls at a pressure of 2 bar. Gage was supplied at 0.83 kg/min.

Fig. 1 shows the basic filter size designs with an external diameter of 600 mm, an internal diameter of 400 mm, and a height of 1500 mm. In addition, the size of the lower filter was adjusted to 350 mm, 300 mm, and 200 mm to derive a shape in which pollution gas and regenerated air can be dispersed evenly throughout the adsorption filter.

Fig. 2 shows the flow analysis results under adsorption conditions according to the filter shape change. The basic configuration confirmed that gas flow concentrates at about 1 m/c at all eight corners. In addition, as the size of the lower part of the filter decreases, the concentration of the gas flow decreases, confirming that the gas flow distributes throughout the filter.

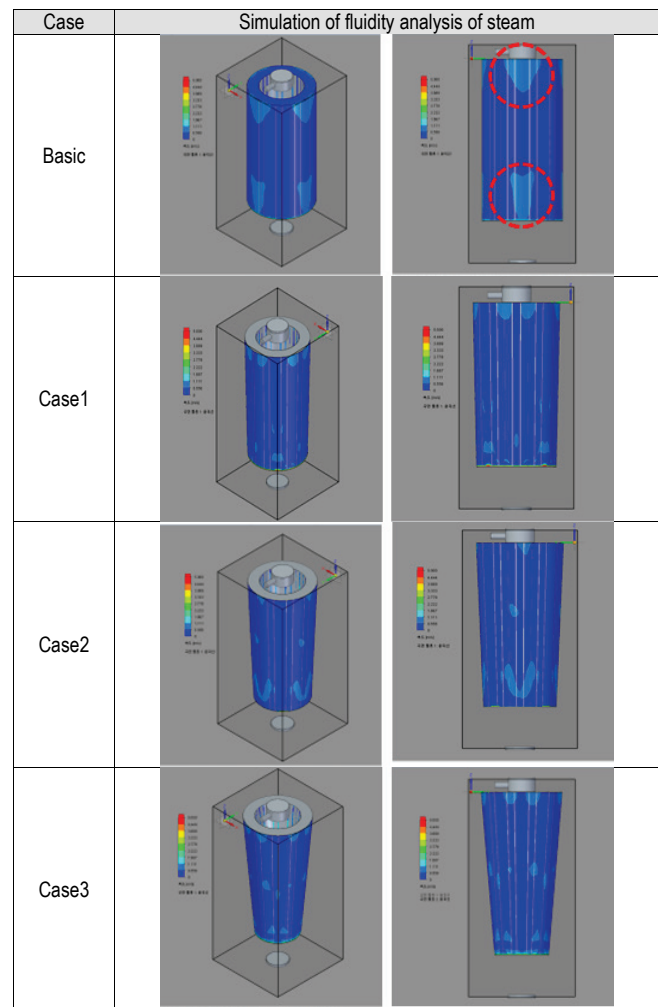


Figure 2 Results of confirmation of gas flow characteristics under adsorption conditions

Fig. 3 shows the results of flow analysis under regeneration conditions. In the case of the Case 1 shape filter, steam is distributed relatively evenly than the primary filter, but it shows that strong steam flow is generated locally at the bottom. In the case of Case 2 shape filters, steam is distributed and supplied to the entire filter compared to Case 1. However, steam flow concentrates around the corner of the

upper chamber of the filter, and it shows that there are areas where steam is not supplied intermittently to the middle and lower ends of the filter. The Case 3 shape filter also shows the supplied steam concentration under the filter, but the steam is evenly distributed and supplied compared to the primary Case 1 and 2 shape filters. Therefore, it judges that the Case 3-shaped filter is the most efficient for regenerating the adsorption filter using a steam supply.

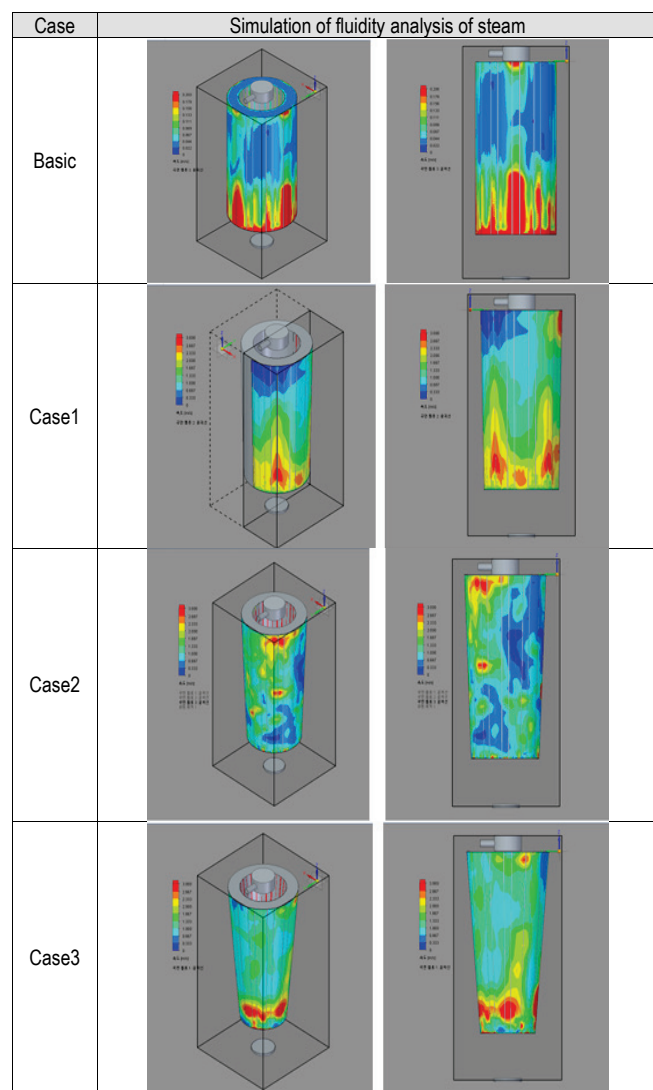


Figure 3 Results of confirmation of gas flow characteristics under desorption conditions

Fig. 4 designs and manufactures a wrinkle filter using activated carbon fiber, which is a filter adsorption material, based on the gas flow analysis in Fig. 3. A wrinkle pattern is designed in consideration of a 5 CMM-class regenerator, and the adsorption filter has an outer diameter of 200 mm and an inner diameter of 100 mm. At this time, the wrinkle height is 30 mm and the number of wrinkles is 30. And after calculating the area required for the adsorbent according to the processing gas flow rate, the filter height is set to 500 mm by applying a margin of 10 %. During the filter manufacturing process, a SUS mesh is attached to support the wrinkle shape of the activated carbon fiber adsorbent.

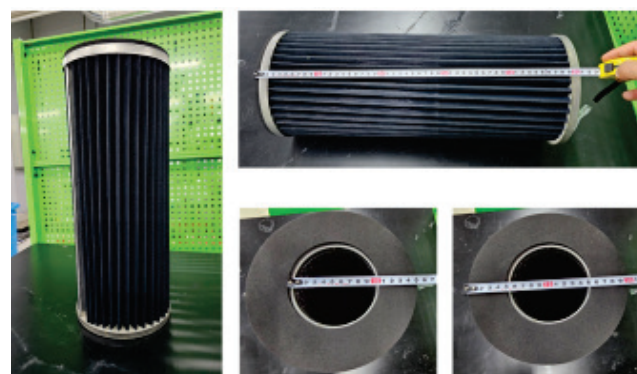


Figure 4 Wrinkle filter of 5 CMM grade

3 ADSORPTION CHARACTERISTICS OF VOCs IN ACTIVATED CARBON FIBER

Fig. 5 shows the configuration of the test device for checking the adsorption performance of activated carbon fibers. The activated carbon fiber used in this study was a product with a thickness of 3 mm and a specific surface area of 1,700 m²/g sold by the Korea Active Carbon Fiber Company to recover organic solvents. The test gas supplies gas flow rate using a mass flow controller manufactured by Brooks. For the adsorption, Toluene, o-xylene, and methyl ethyl ketone reagents, which are representative materials of volatile organic compounds, were used. The vaporized liquid adsorbate in the test gas controls the desired concentration and is used in adsorption experiments. The liquid adsorbate vaporizer was controlled at 150 °C using a PID-type temperature controller after installing a heating wire on the outer surface of the cylindrical reactor. The liquid adsorbate uses a micro syringe to precisely supply the control at 2-12 mL/hr. After mixing the adsorbed material vaporized into a gaseous state with the test gas, the concentration of the adsorbed gas confirms the use of an FID-type portable THC analyzer manufactured by Polaris. The research conducts the adsorption experiment by converting the test gas to be supplied to the adsorption reactor using a valve once it confirms the test gas concentration.

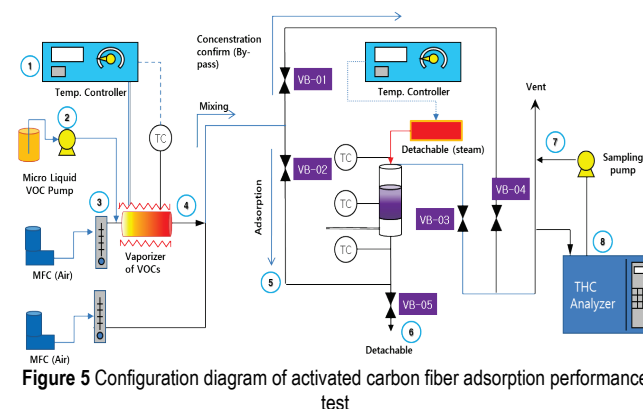


Figure 5 Configuration diagram of activated carbon fiber adsorption performance test

For the stable performance of the development facility and smooth operation, an integrated control system (Timer and Integrated Control System) operation method is

proposed based on the adsorbent performance evaluation test results. This control method is a method in which each chamber operation is controlled by a timer, and the operation of another chamber is sequentially performed based on the operation state of the chamber in which adsorption is performed. The blower operation operates to maintain a constant discharge gas flow rate by varying and controlling the blower rotation speed according to the filter differential pressure. If the inverter proceeds in real time, a change in the discharge gas flow rate may occur temporarily due to an error in the measuring instrument or the influence of production facilities. Therefore, it is controlled with a sequential control program so that it is variably operated according to the difference between the average filter differential pressure value measured for 2 to 5 minutes and the standard differential pressure value. Fig. 6 shows a net self-control flowchart.

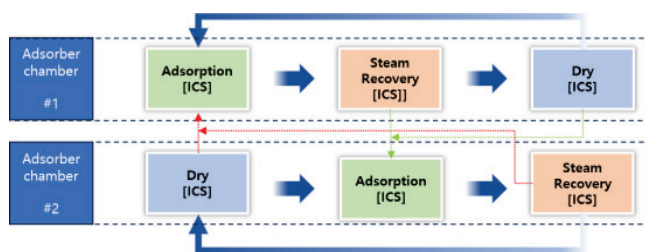


Figure 6 Net self-control flowchart

Tab. 2 shows the evaluation conditions for the adsorption performance of activated carbon fibers. The adsorption characteristics according to spatial speed change confirm the adsorption characteristics under spatial speed (10,000 ~254,000 m³/hour) conditions by installing activated carbon fibers in the adsorption reactor and adjusting the adsorbent filling height in the range of 3 to 75 mm under the test gas supply flow rate of 100 L/min and VOCs concentration of 400 ppm.

Table 2 The adsorption and regeneration test conditions

Category		Contents
Column size		100 mm × 400 mm H
VOCs	Supply method	Micro syringe pump
	Adsorbate	Toluene, o-xylene, MEK
	Test gas	Air (50, 100 L/min)
Operation Condition	Temperature/Concentration	26-28 °C/100-400 ppm
	Height of ACF	3, 6, 9, 15, 25, 75 mm

4 EXPERIMENTAL RESULTS

The adsorption characteristics according to spatial speed change confirm the adsorption characteristics under spatial speed conditions by installing activated carbon fibers in the adsorption reactor and adjusting the adsorbent filling height in the range from 3 to 75 mm under the test gas supply flow rate of 100 L/min and VOCs concentration of 400 ppm. As the spatial speed increased, the adsorption capacity for 1 g of regenerated air capacity tended to increase from 0.36 g to 0.40 g, but the adsorption capacity tended to decrease based on the breakthrough point. And the breakthrough time is maintained at 9 minutes and 15 seconds, likely to the

operating time of commercial facilities at a spatial speed of 51,000 m³/hour. Fig. 7 shows the adsorption characteristics and breakthrough time results according to the change in the conditions of Tab. 3.

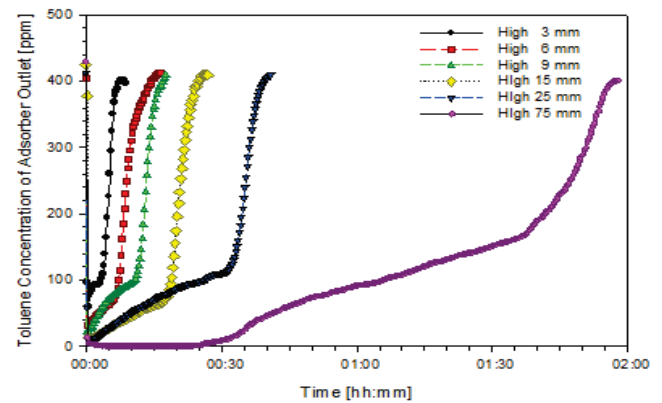


Figure 7 The toluene adsorption concentration of the adsorption outlet

Fig. 8 show the changes in the adsorption layer thickness and differential pressure with respect to the spatial velocity.

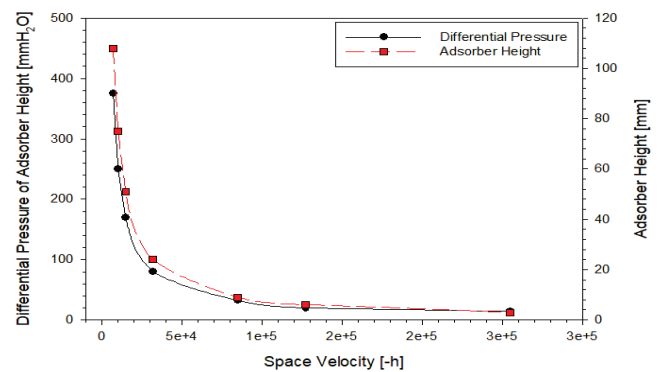


Figure 8 Variation of adsorption height and differential pressure with respect to spatial velocity

Table 3 Comparison of the space velocity and the differential pressure characteristics in the adsorption thickness

Adsorption thickness (mm)	Space velocity (SV) (m ³ /hour)	Differential pressure (mmH ₂ O)
24	32,000	80
9	85,000	32
6	127,000	20
3	254,000	14

Table 4 Variable adsorption performance according to concentration change

Concentration (ppm)	Adsorption weight (g)	Total adsorption (g)	Adsorption quantity (g/g)	THC 100 ppm (g)	Effective adsorption (42 ppm)
200	40.37	13.55	0.34	0.14	71' 15"
300	40.37	14.18	0.35	0.14	46' 45"
400	40.37	14.37	0.36	0.14	34' 30"

Tab. 3 presents the comparison results of space velocity and differential pressure characteristics according to the adsorption height and the adsorption thicknesses 3, 6, 9 and 24 mm of the activated carbon filter. When the adsorption

thickness decreases, the space velocity increases, while the differential pressure decreases.

Tab. 4 confirms the variable adsorption performance according to the change in concentration while supplying toluene concentration at 200, 300, and 400 ppm.

Fig. 9 show the ACF adsorption amount characteristics according to changes in the toluene concentration.

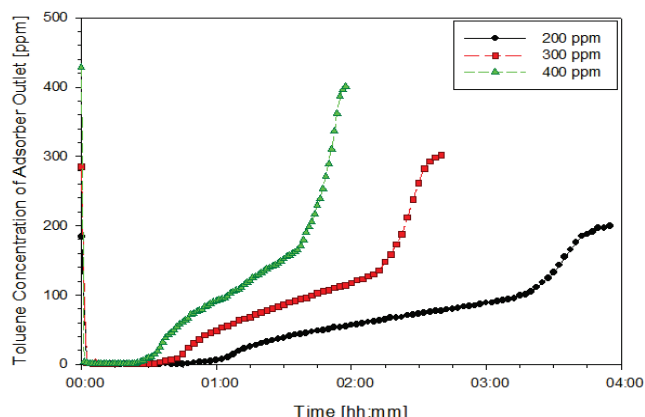


Figure 9 Adsorption curve according to changes in toluene concentration

Fig. 10 shows the desorption characteristics curve of the activated carbon filter according to the adsorption concentration. We can confirm the maximum desorption time.

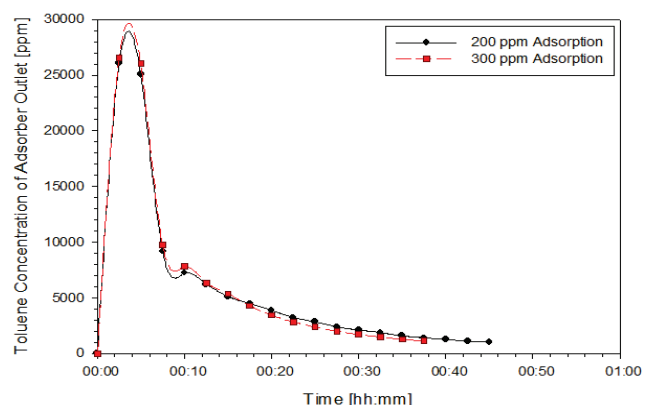


Figure 10 Desorption characteristics according to adsorption concentration

As the concentration of the adsorbed material increased, the amount of adsorption and the time required for the breakthrough point increased. However, the adsorption capacity for effective breakthrough point was 0.14 g/g. The difference between the total adsorption amount according to the concentration change and the adsorption capacity at the breakthrough point was not significant because adsorption from activated carbon fibers takes place on the surface of the adsorbent.

Tab. 5 is to estimate the experimental adsorption performance according to the Toluene, o-xylene, and MEK as representative materials to confirm the adsorption characteristic.

Fig. 11 compares the adsorption characteristics according to three gas types of VOCs. The adsorption

characteristic experiment according to the change in the simulated gas of Toluene, the adsorption amount and the breakthrough time tended to be longer as the concentration increased, but the adsorption capacity up to the effective breakthrough time was the same at 0.14 g.

Table 5 Adsorption experiment data by volatile organic compounds type

Material	Adsorption weight (g)	Total adsorption (g)	Adsorption quantity (g/g)	THC 100 ppm (g)	Effective adsorption (42 ppm)
Toluene	40.37	14.37	0.36	0.14	34' 30"
O-xylene	40.37	19.21	0.48	0.19	41' 15"
MEK	40.37	10.05	0.25	0.09	29' 45"

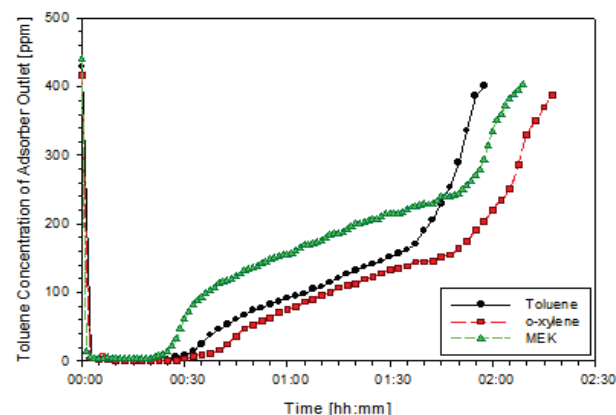


Figure 11 Adsorption curve according to adsorbate type

Fig. 12 confirms the regeneration characteristics according to the type of volatile organic compound and the maximum regeneration concentration of MEK, which has the lowest boiling temperature of the material, was the highest at 89,146 ppm, and desorption completes within about 5 minutes.

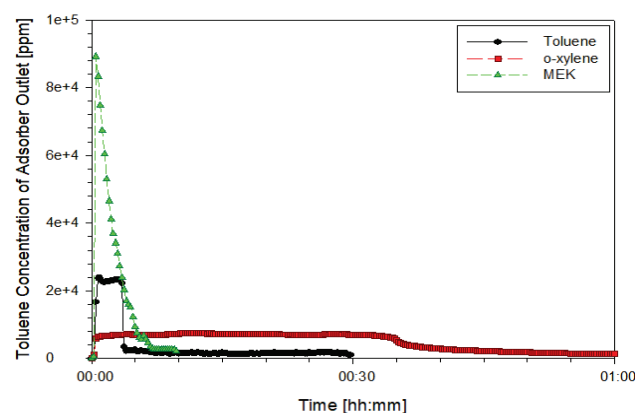


Figure 12 Desorption concentrations according to adsorbate type

On the other hand, o-xylene, with the highest boiling temperature, had the lowest desorption concentration of 7,528 ppm. After the desorption operation started, it was discharged at a specific concentration for about 35 minutes and gradually decreased. The desorption air temperature was 150 °C under the same conditions. However, it is necessary

to maintain 30 °C higher than the adsorbent material's boiling temperature to complete the adsorbent's regeneration quickly.

Fig. 13 shows the adsorbent regeneration characteristics according to the change in the amount of dry air. When the amount of air increases by 1 L/min based on the amount of dry air 16.8 L/min, the adsorption efficiency increases by about 0.06 %, and when the amount of dry air is supplied at 42 L/min, the adsorption performance is maintained up to 96.4 % of the initial adsorption performance.

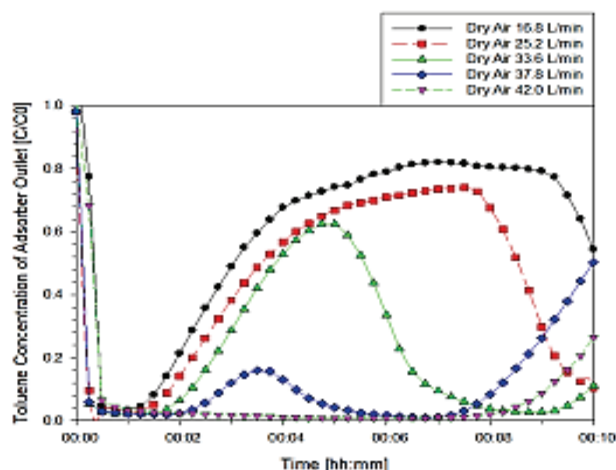


Figure 13 Regeneration characteristics according to the change in dry air amount

Fig. 14 compares the regeneration characteristics according to the supply location of dry air. When the amount of dry air was 42 L/min, the supply location of dry air was adjusted to the upper part of the reactor, the lower part of the reactor, and the lower part of the heat exchanger, and the regeneration characteristics were compared according to each condition.

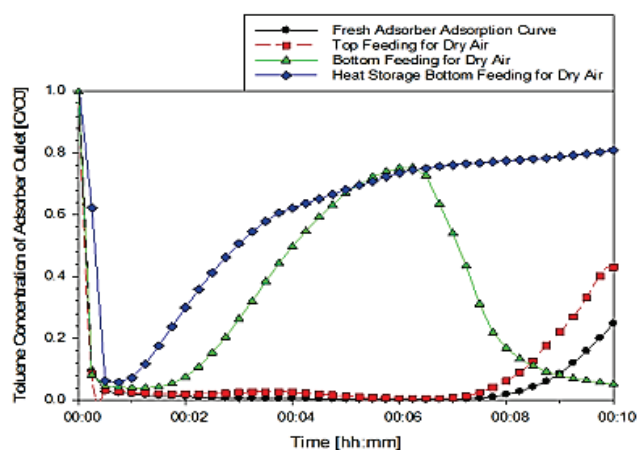


Figure 14 Comparison of the regenerative characteristics according to the supply location of dry air

When supplied to the upper part of the reactor, similar performance was shown at about 96.4 % of the initial adsorption performance. As a result of testing in the order of the lower part of the reactor and the lower part of the heat exchanger, the regeneration efficiency decreased by 69.8%

and 42.2 %, respectively. When dry air is supplied to the lower part of the heat exchanger, it is judged that the drying performance decreases due to the residual moisture inside the heat exchanger, and the regeneration performance of the adsorbent decreases.

As a result of the hot air regeneration experiment, according to the adsorption concentration of Toluene, the maximum regeneration concentration was about 26,000 ppm and 64 % of the desorption after about 10 minutes of completion. The discharge time of 5,000 ppm or more, which can condense at low temperatures, was about 15 minutes, and continuous operation was determined if the adsorbent fills twice the total adsorption amount of the adsorbent for continuous operation facility application.

5 CONCLUSION

In this study, the flow characteristics according to the shape of the adsorption filter were checked to design an adsorption filter to efficiently process volatile organic compounds using activated carbon fibers, and a shape in which pollution gas can disperse evenly throughout the filter was derived. In addition, excellent adsorption efficiency and fast adsorption properties of activated carbon fibers confirm the adsorption and desorption experiments using Toluene, o-xylene, and methyl ethyl ketone. In order to use activated carbon fiber as an adsorption filter material, the adsorption and desorption time must be kept short, so it is necessary to control the regeneration air temperature 20 °C higher than the vaporization temperature of the adsorbent, and it is appropriate to maintain the acceptable adsorbent filling height above 32,000 m³/hour. As a follow-up study, based on the design data obtained through the experiment, it plans to manufacture commercial facilities with a 100 Nm³/min scale and link the production process. Once planned testing is complete, which expects the commercial facility to secure the design and operational technology.

Acknowledgments

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Fostering Tech Innovation: Exploring TRIZ and ChatGPT Integration for Developer and Entrepreneur Challenges

Won-Shik Shin, Soo-Hyun Lee*, Hae-Jin Sue

Abstract: This study aimed to interpret the value of integration of TRIZ (Teoriya Resheniya Izobretatelskikh Zadach; Theory of Inventive Problem Solving) and ChatGPT (Chat Generative Pre-trained Transformer) to enhance technological and entrepreneurial problem-solving and decision-making. TRIZ offers a structured approach to innovation, while ChatGPT excels in generating diverse and innovative responses through advanced natural language processing. From the combination of them, we tried to discover synergies that promote innovation in highly competitive business areas. Through the analysis of case studies, including "Imperfect Waterproof Zipper" and "Drilling a Hole in a Thin-Walled Tube", we discovered that this integration not only aligns with actual problem-solving outcomes but also enhances the quality of solutions, particularly benefiting developers with limited TRIZ knowledge. We identified that leveraging ChatGPT enables developers and entrepreneurs to approach challenges with enhanced creativity, yielding practical and innovative solutions through these case studies. Our approach, focusing on real-world applications, demonstrates the study's contribution by providing a novel strategy for combining structured problem-solving with AI capabilities. The primary motivation behind this research was to ascertain whether AI can amplify the problem-solving framework of TRIZ, thereby extending its utility beyond traditional domains. The findings underline the importance of AI in creative problem-solving, suggesting that even those unfamiliar with TRIZ can apply its principles effectively with the aid of ChatGPT. This research adds to the existing knowledge by showcasing how AI can be a powerful ally in the creative process, offering new avenues for problem-solving and strategic decision-making. In conclusion, our study demonstrates that the collaboration between TRIZ and ChatGPT not only elevates creativity but also equips developers and entrepreneurs with competitive strategies, emphasizing the role of AI in driving forward human innovation and creativity.

Keywords: AI-driven insights; ChatGPT; decision-making; entrepreneurial strategy; problem-solving; technological innovation; TRIZ

1 INTRODUCTION

In today's dynamic and highly competitive business environment, creativity is paramount to a company's survival and growth [1]. With the growing need for proactive innovation, organizations are investing heavily in fostering creativity in their workforce. Historically, creativity was once considered a trait of genius, but modern perspectives, influenced by pioneers like cognitive psychologist Guilford, recognize it as an intrinsic aspect of human intelligence.

Among the myriad methods developed for idea generation and problem solving, TRIZ (Teoriya Resheniya Izobretatelskikh Zadach; Theory of Inventive Problem Solving) is one that stands out. Developed by Altshuler and his team through extensive patent analysis, TRIZ provides a systematic approach to creative problem solving and is used by many developers to solve their problems [2].

The field of artificial intelligence (AI) has grown exponentially in recent years, and ChatGPT (OpenAI's language model), a pre-trained generative transformer, has gained traction due to its machine learning algorithms based on large language models combined with a conversational interface. ChatGPT goes beyond the ability to generate human-like text responses to provide personalized interactions for users. It is being utilized in a variety of fields, including customer service, education, and healthcare, and as a versatile tool for complex problem solving and research and development efforts [3].

Entrepreneurs who need to navigate shifting market trends and manage multi-faceted business operations are faced with the challenge of mastering diverse domains and making decisions. Recognizing this, there is a growing demand for tools and methodologies that simplify and enhance the innovation process [4].

While TRIZ, entrepreneurship, and AI models are theoretically consistent, there is not enough empirical evidence of their effectiveness, and there is a need for research that examines the impact of their integrated application. This study aims to elucidate the synergistic potential of integrating TRIZ with ChatGPT to augment problem-solving and decision-making paradigms in the technological and entrepreneurial domains.

2 LITERATURE REVIEW

2.1 Creativity and Innovation in TRIZ and Entrepreneurship

Numerous studies across diverse domains have delved into the nexus between creativity and TRIZ. Studies have evaluated the effectiveness of TRIZ-based creativity training programs in enhancing employee innovativeness [5] and have demonstrated the efficacy of TRIZ training in fostering creativity across different educational contexts, including university students, secondary school students, and elementary school students [6]. The growing importance of creativity and innovation in science and engineering further emphasizes the significance of these findings [7].

Yong Won Song emphasizes that TRIZ aids in solving technical problems, particularly noting that the laws of technological development effectively predict the future and enhance creativity and technological innovation [8]. Yong Mun Jeon generated ideas using the technological evolution laws of TRIZ to derive a solution capable of minimizing the temperature effects on the probe card, a crucial device for inspecting semiconductor operation [9]. Hong Kyun Shim utilized the 40 inventive principles of TRIZ to resolve quality issues in the Equipment Front-End Module (EFEM) in the Fab etching process used for manufacturing semiconductor devices [10]. However, for those unacquainted with this distinctive methodology, which involves translating real-

world problems into general problem models and identifying corresponding solutions, TRIZ can be perceived as both complex and elusive [2].

For entrepreneurs, creativity is a crucial attribute that they must possess [11]. TRIZ, which is now being applied beyond technical domains, serves not only as a problem-solving tool that enables entrepreneurs to approach their endeavors systematically and scientifically, reducing the risks associated with intuitive decision-making, but also as a catalyst for unleashing their creative potential [12].

2.2 AI and Creativity

Over the years, various definitions of AI have emerged [13]. In essence, AI is a branch of computer science that aims to develop systems capable of performing tasks that typically require human intelligence, such as learning from experience, understanding natural language, pattern recognition, problem-solving, and decision-making. While creativity has long been considered a distinct human trait, the study of AI's creativity has gained attention.

In the field of computational creativity, Colton posited that the discipline had reached maturity, providing an overview of its development over time [14]. Boden also delved into the intersection between computational models and human creativity, discussing the application of computational models in understanding and simulating the creative process, as well as the limitations and ethical considerations associated with these models [15]. Studies have explored the application of AI techniques to evaluate human-made creative designs [16] and have shown the potential for AI to contribute to hybrid intelligence, where AI autonomously generates ideas using modern algorithms while fostering human creativity to solve creative tasks [17]. Besold explores different approaches and techniques in computational creativity, including rule-based systems, evolutionary algorithms, machine learning, and neural networks. He demonstrates how these methods can generate novel ideas, solve problems, and produce creative outputs in fields like art, music, and writing [18].

2.3 Collaboration with AI

The topic of AI and human collaboration has garnered significant attention, alongside discussions on AI creativity. Colton highlights that, rather than diminishing human thinking abilities, AI actually creates experts such as automated writers and scientists, inspiring humans to think [14].

Brynjolfsson and McAfee stress the importance of viewing AI as a complement to human capabilities rather than a replacement. They argue that successful businesses effectively integrate AI into their operations, leverage data, and adapt their strategies to changing circumstances [19]. Surveys and interviews with business executives further support this view, as AI leaders anticipate positive impacts on economic growth through revenue-generating opportunities and increased investments resulting from AI adoption [20]. The concept of Human-AI collaboration, as

proposed by Wingström, positions AI as a tool to generate ideas, support creativity, and push the boundaries of scientists' and artists' creative endeavors, rather than replacing human creativity [21]. Copley emphasizes the benefits of integrating human and artificial creativity, highlighting the significance of interdisciplinary collaboration and harnessing the unique strengths of both humans and AI to tackle complex and creative problems [22].

Considering these factors, AI manifests as a potent instrument for collaboration. Utilizing the actionable insights offered by AI enables developers to embrace a comprehensive approach to problem-solving, fostering innovation and optimizing product development. Concurrently, entrepreneurs can enhance creativity and innovation by integrating AI in promotional marketing, project management, and overarching business strategies.

3 RESEARCH METHODOLOGY

ChatGPT, developed by OpenAI, is renowned for its expansive language model and interactive interface. Its adeptness in natural language processing and ability to facilitate personalized interactions have made it a valuable tool in diverse fields, including customer service and health [26]. Previous studies have evaluated the performance of ChatGPT by scoring answers to questions extracted from test questions [3, 27].

Given the exploratory nature of the study and the need to delve deeper into the real-world application of ChatGPT, a case study design was deemed appropriate for this research, as it allowed the comparison of answers elicited from conversations with ChatGPT to real-world problems and solutions without relying solely on questionnaire-based assessments. For the purposes of this study, two patent cases authorized for experimentation with ChatGPT were handpicked: the first being a Korean patent and the second, a US patent.

This study's methodology encompasses two primary dimensions: problem-solving analyzed through a TRIZ perspective from the vantage point of a developer, and entrepreneurial strategy approached with an enterpriser's mindset. The potential of ChatGPT in aiding developers engaged in new product development and entrepreneurs striving for work efficiency were investigated in this study.

3.1 Problem-Solving from a TRIZ Perspective

This research was conducted in five steps, described below, to understand how ChatGPT approaches problem solving from a TRIZ perspective.

- a) Stating a real-world problem
- b) Analyzing the case from a TRIZ perspective and examining ways to solve the problem
- c) Identifying potential TRIZ solutions and compare them with actual problem solution
- d) Design and implement ChatGPT prompt engineering from a TRIZ perspective
- e) Evaluating the results of ChatGPT and compare them to real-world problem-solving methods.

In this study, advanced engineering techniques were employed, including the persona pattern and the flipped interaction pattern, to enhance the precision and efficiency of results derived from ChatGPT [28]. The persona patterns specify the role of ChatGPT, such as problem solver, scientist, entrepreneur, consultant, etc. The flipped interaction pattern empowers ChatGPT to initiate questions, ensuring the acquisition of accurate and fact-based responses. If the flipped interaction pattern does not yield satisfactory results, ChatGPT can be prompt to ask relevant questions by providing the ChatGPT's task in the prompt insert box and adding the statement, "Do you have any questions you would like to ask to effectively solve this problem?" This prompt instructs ChatGPT to provide the best solution or advice from a TRIZ perspective, allowing for repetition of the question if needed.

3.2 Business Strategy from an Entrepreneurial Perspective

This research was conducted in two phases as outlined below to understand how ChatGPT goes about its business strategy from an entrepreneurial perspective.

- Designing ChatGPT prompt engineering from entrepreneur's perspective
- Selecting the best viable offer.

To derive business strategies from ChatGPT using an entrepreneurial perspective, the persona pattern and the flipped interaction pattern were applied, reflecting the methodology utilized in the preceding TRIZ perspective. The persona pattern provides ChatGPT's role, incorporating a broad range of personas such as an economist, a marketer, a market analyst etc. Following this process, users then can select the option that most effectively corresponds with practical circumstances, confirms feasibility, and cost-effectiveness.

In this study, the above process was performed using ChatGPT plus (GPT4).

4 CASE STUDIES

4.1 Problem of Imperfect Waterproof Zipper

In the first case study, the potential solutions for the issue of incomplete waterproof zippers using the TRIZ methodology were investigated while also examining business strategies from an entrepreneurial perspective.

4.1.1 Problem-Solving from a TRIZ Perspective

4.1.1.1 Statement of Real-World Problem

The first case addressed the problem of 'imperfect waterproof zippers' that does not provide a perfect seal.

4.1.1.2 Analyzing the Case from a TRIZ Perspective and Examining Ways to Solve the Problem

The problem with imperfect waterproof zipper can be described as follows:

- The enclosure secured by the zipper is not hermetically sealed, leading to the permeation of fluids.
- The zipper fails to maintain a seal when subjected to bending, and external forces can induce its loosening.
- Applying lateral force to a zipper disrupts its seal, facilitating the release of any contained fluid or air.

A zipper is basic, consisting of side-to-side interlocking teeth, a slider mechanism, and an attachment tape. These teeth interlock with each other via the slider to create a chain-like structure that acts as a barrier to the movement of fluids. However, if the inherent mutual support of the teeth is weakened, the integrity of this chain structure can be compromised, causing the zipper to fail to contain gas or fluid leaks. However, the ease of opening and closing a zipper requires that the zipper be easily disengaged.

4.1.1.3 Identifying Potential TRIZ Solutions and Compare them with Actual Problem Solution

If this case is analyzed from a TRIZ perspective, a contradiction exists: the teeth need to have a strong engagement force for an effective seal, but the engagement force needs to be weak for easy operation during the opening and closing process. The TRIZ approach to resolving this contradiction is based on the principle of time separation, which means that if the zipper is strong when it is engaged and weak when it is opening and closing, the problem of this case can be solved. Alternatively, the principle of space separation can also be a viable solution by dividing the zipper into regions of varying strength to establish both strong and weak regions.

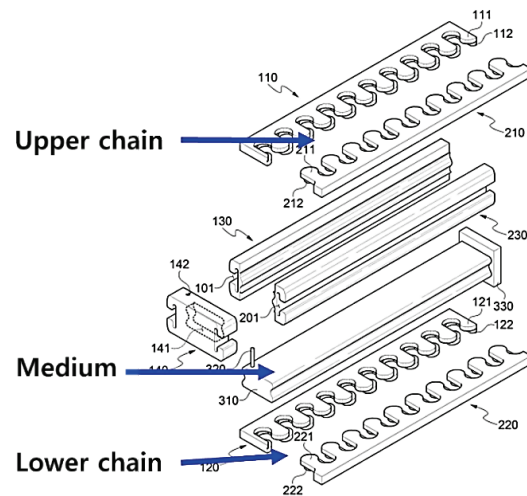


Figure 1 Korean Patent 10-2261012 (source: <http://kportal.kipris.or.kr>)

Possible TRIZ 40 Principles to solve this problem include:

- Principle 11. Preliminary Compensation: Implement measures to prevent the weakening of the fastening force.
- Principle 16, Partial or Excessive Actions, can be employed by incorporating two vertically aligned chains — one positioned at the upper and the other at the lower

end — to enhance the fastening force exerted by the zipper.

- Principle 24, Intermediate, recommends the introduction of an intermediary medium between the upper and lower chains. This medium serves to preserve the sealing efficacy during fastening operations.

Korean patent 10-2261012 solves this problem by designing a top and bottom interlocking teeth and inserting an intermediate mediator between them shown in Fig. 1.

4.1.1.4 Design and Implement ChatGPT Prompt Engineering from a TRIZ Perspective

From a TRIZ perspective, prompt engineering has meticulously crafted the persona pattern encompassing roles such as a TRIZ master, scientist, inventor, and consultants, thereby facilitating ChatGPT in offering the possible solutions or advices grounded in TRIZ principles. Moreover, the flipped interaction pattern has been instituted to permit the iterative posing of questions until the suitable responses are procured. Owing to spatial constraints, only a fragmentary view of the ChatGPT session utilized in this stage is showcased here; the comprehensive details are accessible via the following link: 'https://chat.openai.com/share/79bc817d-f387-4d39-b047-bbbdbfa03d22' Fig. 2.

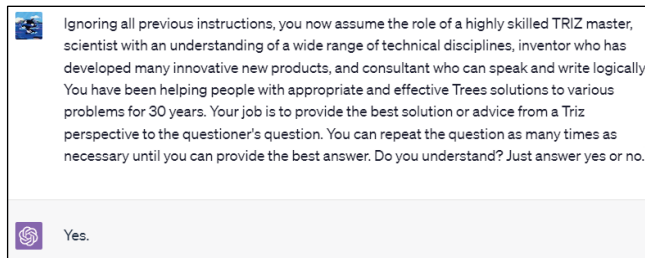


Figure 2 Prompt Engineering of a TRIZ Perspective

The problem presented to ChatGPT is the imperfect waterproof zipper, which lacks complete waterproofing. The issues related to waterproof zipper include incomplete sealing of the container, difficulty in sealing when bent, and vulnerability to external pressure. The zipper consists of left and right teeth, sliders, and tape, with the teeth engaging through the slider. The engagement force of the teeth plays a vital role in preventing fluid leakage. However, it needs to strike a balance between being strong enough to provide a good barrier and weak enough for easy opening and closing. The objective is to identify the most optimal solutions to tackle these challenges in Fig. 3.

ChatGPT proposed several solutions from a TRIZ perspective, including separation in time, separation in space, parameter changes, and the utilization of fields in Fig. 4.

In response to inquiries about the utilization of fields, ChatGPT had suggested various solutions, including mechanical fields, thermal fields, shape memory materials, hydraulic or pneumatic fields, chemical fields, and the piezoelectric effect. By further questioning ChatGPT's

provided responses, a more comprehensive investigation can be conducted, exploring specific and specialized domains. In this case study, ChatGPT recommended additional fields in addition to the MACHEM framework derived from TRIZ, thereby expanding the user's cognitive perspectives shown in Fig. 5.

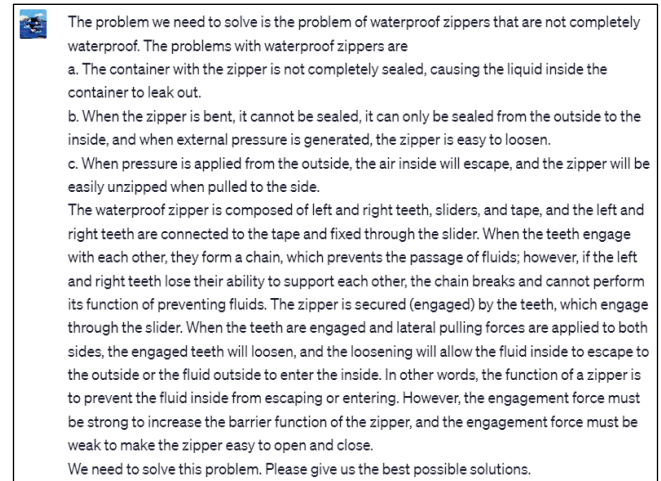
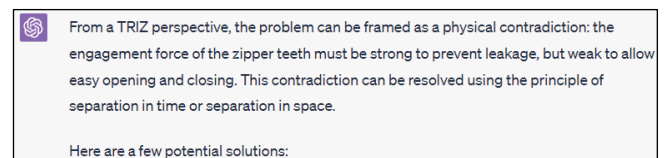
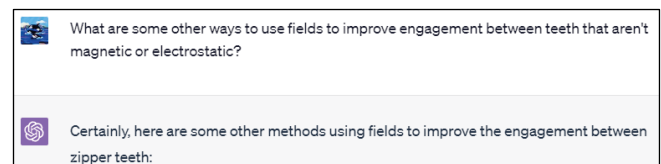


Figure 3 Type the Problem to be Solved at Prompt



****Use of fields**** - Apply an external field or force to assist in engagement when waterproofing is necessary and reduce it when easy opening/closing is required. This could be achieved by implementing a magnetic or electrostatic mechanism that enhances the engagement force between teeth when activated.

Figure 4 ChatGPT's Answer



1. ****Mechanical fields:**** This could involve adding a spring mechanism or elastic material to the zipper teeth to increase the force with which they engage.
2. ****Thermal fields:**** Utilize materials for the zipper teeth that expand or contract with changes in temperature to alter the level of engagement. For instance, a thermally responsive material could be used that causes the teeth to engage more firmly in cooler conditions (such as when in contact with cold water), thus improving waterproofing.
3. ****Shape memory materials:**** These are materials (like certain alloys or polymers) that can "remember" their original shape and return to it when subjected to a specific stimulus, often heat. They could provide stronger engagement when needed and relax when not.

Figure 5 ChatGPT's Answer Additional Question about using 'Fields'

Given the intricate nature of 'Fields' utilization and the substantial costs concomitant with its implementation, ChatGPT was prompted to come up with an alternative that would be cost-effective and optimally effective presented in Fig. 6.

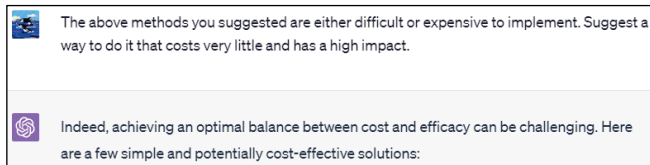


Figure 6 ChatGPT's Answer to Cost-Effective Solutions

3. ****Secondary Physical Barrier:**** Add a thin, flexible rubber or silicone strip along the length of the zipper. When the zipper is closed, this strip would be compressed between the teeth, creating an additional barrier to water. This is akin to the gaskets used in water-resistant watch cases or diving equipment.

4.1.1.5 Evaluating the Results of ChatGPT and Compare them to Real-World Problem-Solving Methods

ChatGPT had provided a series of cost-effective solutions, namely Hydrophilic Coating, Layered Fabric Seals, Secondary Physical Barrier, and Zipper Cover. Notably, the suggested Secondary Physical Barrier aligns with the approach described in the development of the Korean Patent 10-2261012.

4.1.2 Business Strategy from an Entrepreneurial Perspective

4.1.2.1 Design ChatGPT Prompt Engineering from an Entrepreneurial Perspective

A prompt engineering was designed to elicit insights from the entrepreneurial perspective. The persona patterns embodying roles such as economist, marketer, market analyst, etc. were incorporated to enhance the support provided to entrepreneurs. Concurrently, the flipped interaction patterns were used. Due to space constraints, only a portion of the ChatGPT sessions used in this phase was presented, which can be found at the following link: 'https://chat.openai.com/share/0b65edfd-672b-49a9-8447-8a3ff669eea0' in Fig. 7.

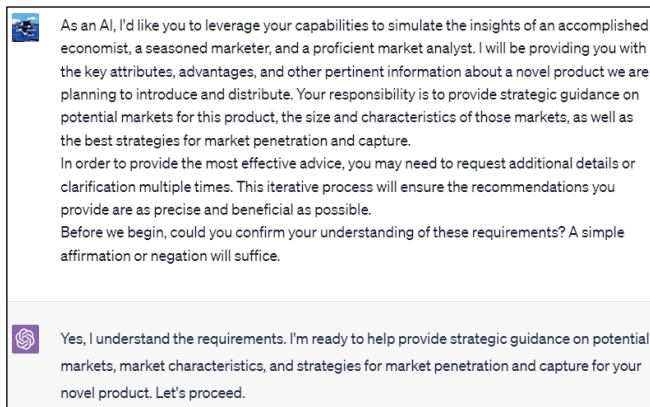


Figure 7 Prompt Engineering from an Entrepreneurial Perspective

Guidance from ChatGPT pertaining to a waterproof zipper as delineated in Korean patent 10-2261012 was solicited. To ensure an informed consultation from ChatGPT on this matter, it is imperative to furnish comprehensive details about this product shown in Fig. 8.

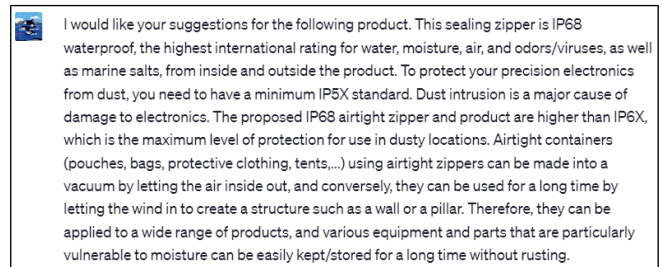
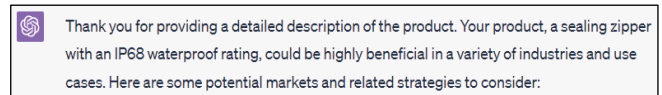


Figure 8 Type the Product Description at Prompt

ChatGPT provided a comprehensive analysis of potential markets and strategies associated with waterproof zippers, encompassing sectors such as Outdoor Gear and Equipment, Construction, and Military industry shown in Fig. 9.

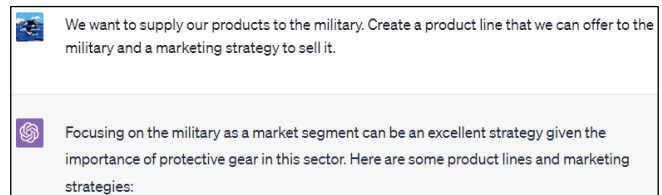


3. ****Industrial Applications**:** There are many industries where protective clothing and equipment are crucial, such as construction, healthcare, and the military. Approaching companies in these sectors and demonstrating the benefits of your product could be a successful strategy.

Figure 9 ChatGPT's Answers Customized to Support Entrepreneurs

4.1.2.2 Selecting the Best Viable Offer

Among ChatGPT's proposals, suggestions on product offerings that could be sold in the military market and effective business strategies were sought. ChatGPT provided a comprehensive product line that includes Protective Gear for Electronics, Storage Bags, Tents, and Temporary Shelter. Additionally, ChatGPT recommended implementing tailored strategies to effectively target the military market, taking into consideration their job nature and unique requirements in Fig. 10.



****Product Lines****

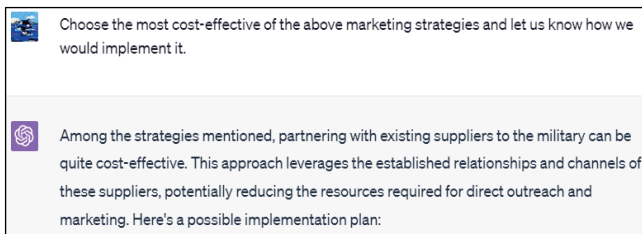
1. ****Protective Gear for Electronics**:** You can offer protective pouches or bags for various military electronics, such as radios, GPS devices, night vision goggles, and more. These pouches would utilize your IP68 sealing zippers, providing an unmatched level of protection against dust, water, and other harsh conditions often encountered in military operations.

****Business Strategies****

1. ****Direct B2B Approach**:** To effectively penetrate the military market, it's important to identify and reach out directly to military procurement officers and related decision-makers. Present the unique benefits of your product line and how it can enhance their operations. Attending military-focused trade shows or other industry events can also provide opportunities to establish these connections.

Figure 10 ChatGPT's suggestion for the Military Market

The next inquiry focused on identifying the most cost-effective business strategy and formulating an efficient execution plan (Fig. 11).



1. ****Identify Potential Partners****: Conduct thorough research to identify companies that currently supply products similar or complementary to those used by the military, specifically focusing on companies that offer protective gear, storage solutions, tents, or clothing.
2. ****Develop a Value Proposition****: When approaching these companies, clearly articulate the unique advantages that your zipper technology can bring to their product line. Highlight benefits such as enhanced durability, superior protection against environmental elements, and prolonged product lifespan. It is crucial to prepare evidence or demonstrations to support these claims and showcase the effectiveness of your zipper technology. This can include test results, case studies, or samples of products featuring your zippers. By effectively communicating the value proposition of your zipper technology and providing concrete evidence of its benefits, you can establish credibility and increase the likelihood of collaboration with these companies.

Figure 11 Chat GPT's response to the cost-effective business strategy and its execution strategy

In addressing this query, ChatGPT pinpointed "Partnerships with Existing Suppliers" as a cost-effective business strategy and has provided detailed recommendations for its implementation.

4.2 Drilling a Hole in a Thin-Walled Tube [26]

The objective of the second case study is to explore a feasible solution for effectively drilling a hole in a thin-walled tube without compromising its structural integrity, guided by ChatGPT. Additionally, the study aims to analyze business strategies from an entrepreneurial perspective to discover effective approaches for promoting a product or service in the marketplace.

4.2.1 Problem-solving from a TRIZ Perspective

4.2.1.1 Statement of Real-World Problem

The concern with drilling holes in thin-walled tubes is the potential deformation of the tube's structure or the infliction of damage to its walls.

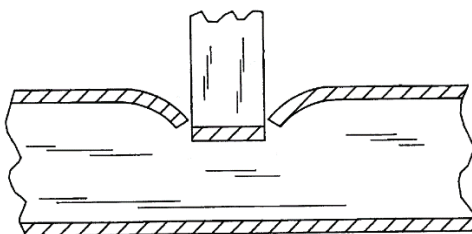


Figure 12 Dents in the Tube Wall [26]

4.2.1.2 Analyzing the Case from a TRIZ Perspective and Examining Ways to Solve the Problem

Outlined below are some ideas for solving the problem of drilling holes in thin-walled tubes, along with their potential limitations:

- One feasible solution is to place a solid material within the tube to effectively support the tube walls. While this approach could potentially prevent the tube from being crushed, complications arise when dealing with curved tube shapes, making it difficult to insert the solid material properly.
- Another possible solution is drilling the hole before bending the tube. However, this approach has a significant drawback, as subsequent bending of the tube would distort the previously round hole. To address this, a viable solution requires a support structure that is both solid enough to uphold the integrity of the tube walls and flexible enough to be conveniently inserted into the tube.

4.2.1.3 Identifying Potential TRIZ Solutions and Compare them with Actual Problem Solution

Solving the problem of drilling a hole thin-walled tube presents a contradiction: the process necessitates both a solid material inside the tube to support the drilling and a material in a soft state that can be easily inserted or ejected. This contradiction can potentially be resolved through the application of the 40 principles of TRIZ.

Principle 24, Intermediate, suggests the introduction of supports within the tube. These supports serve to stabilize and reinforce the tube walls during operations.

Principle 36, Phase Transformation, suggests altering the state of the support material—whether to a solid, liquid, or gas—based on specific conditions encountered during the drilling process.

As delineated in US Patent No. 5,974,846 [27], a specific solution to address this problem involves filling the tube with a liquid medium, such as water. Prior to the drilling process, this liquid is frozen, thereby providing solid support to the tube walls during drilling. Following the completion of the drilling, the solid medium can be reverted to its liquid state through melting, facilitating easy removal from the tube.

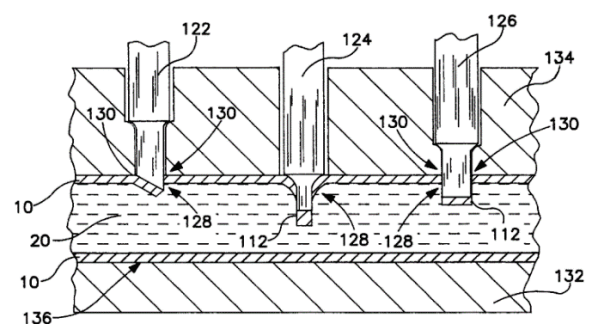


Figure 13 Ice Supports Tube Walls to Prevent Dents [27]

4.2.1.4 Design and Implement ChatGPT Prompt Engineering from a TRIZ Perspective

The identical Prompt Engineering methodology was employed to address this issue as was utilized in the 'problem of imperfect waterproof zipper' case study. Due to spatial constraints, only a fragmentary representation of the ChatGPT session utilized in this phase is presented herein; comprehensive details can be accessed through the following

link: 'https://chat.openai.com/share/1f9d174a-07cc-45cd-abf9-424ce6753dc6'.

To conduct this research, the problem, 'drilling a hole in a thin-walled tube', was described in a ChatGPT prompt.

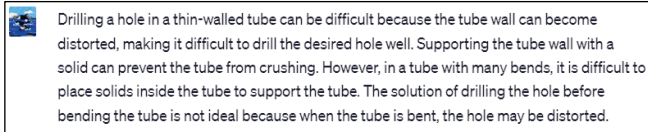
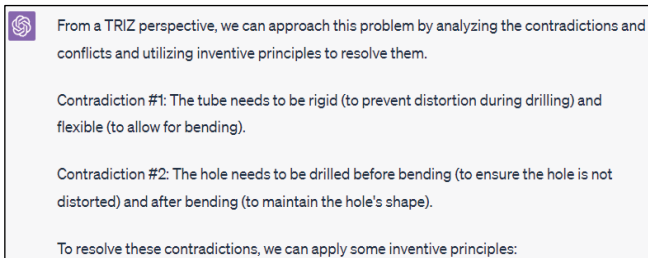


Figure 14 Type the Problem to be solved at Prompt

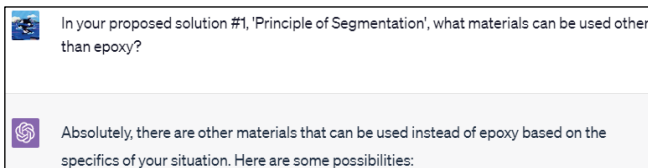
The preliminary step in tackling the issue involved a meticulous analysis of the intrinsic contradictions tied to the task at hand. Following this analysis, ChatGPT preceded to identifying relevant invention principles from 40 Principles. Among the principles considered applicable, 'Principle 1: Segmentation', 'Principle 10: Prior Action', 'Principle 15: Cushion in Advance', 'Principle 17: Another Dimension', 'Principle 26: Copying', and others were proposed as potential solutions to the problem.



1. **Principle of Segmentation (1)**:** One potential solution is to utilize a flexible, yet rigid material that can be easily inserted and removed, providing support to the tube during the drilling process. This material should have the ability to accommodate bending without compromising the structural integrity of the tube. An example of such a material could be a two-part epoxy or a similar substance that hardens into a solid state but can be softened or dissolved when no longer required.

Figure 15 ChatGPT's suggestion

In response to ChatGPT's initial suggestion, further insights regarding the feasibility of employing alternative materials as opposed to the epoxy referenced in 'Principle 1: Segmentation' was further inquired.



1. **Thermoplastic materials**:** These materials, such as polyethylene or polypropylene, can be heated to soften and reshape, and then cooled to solidify. This property enables easy insertion when the material is soft and provides necessary support when it solidifies.

2. **Low melting point metals or alloys**:** Alternatively, metals like Gallium or alloys such as Wood's metal or Field's metal, which have low melting points, can be melted and used to fill the tube. Once solidified, they provide support during the drilling process. These metals can be remelted and removed after the drilling is complete.

3. **Water or other fluids**:** In certain scenarios, the tube can be filled with a fluid, such as water, which is then frozen to provide support during drilling. After the drilling process, the ice can be melted and removed from the tube.

Figure 16 ChatGPT's Answer Additional Question about using Materials other than Epoxy

4.2.1.5 Evaluating the Results of ChatGPT and Compare them to Real-World Problem-Solving Methods

ChatGPT proffered an array of practical solutions, including thermoplastic materials, low melting point metals or alloys, water or other fluids, inflatable bladders or balloons, and soft solid materials. Notably, the suggestion to use water or other fluids aligns with the approach outlined in the development of US Patent No. 5,974,846. The outcomes of this case serve as a compelling testament to ChatGPT's capacity to augment practical problem-solving capabilities.

4.2.2 Business Strategy from an Entrepreneurial Perspective

4.2.2.1 Design ChatGPT Prompt Engineering from an Entrepreneurial Perspective

The identical prompt engineering methodology was employed as was utilized in the preceding case study. The complete ChatGPT session relevant to this phase can be accessed via the following link: 'https://chat.openai.com/share/58332325-6c29-475b-b20c-b7dc07a3e439'.

The specifics of U.S. Patent No. 5,974,846, titled "Method of forming and piercing a tube," was delineated and suggestions from ChatGPT were solicited.

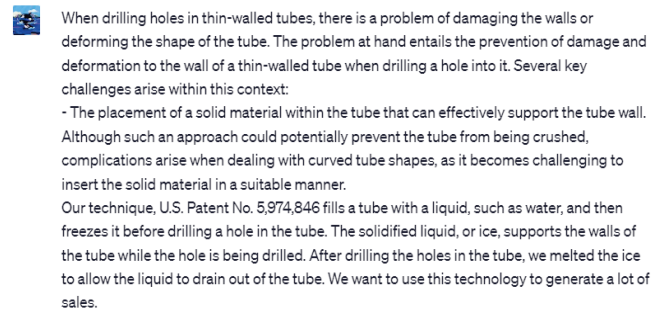
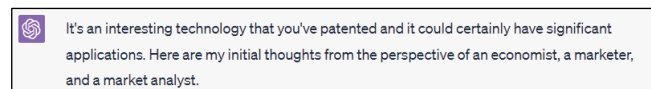


Figure 17 Type the Patent Description at Prompt

ChatGPT offered some advice from the perspectives of an economist, a marketer, and a market analyst.



Economist: From an economic perspective, potential market segments can be categorized based on industries that frequently engage in operations involving thin-walled tubing. These industries may include construction, aerospace, plumbing, medical device manufacturing, and various types of machinery manufacturing. These sectors offer substantial market opportunities, particularly if the patented technology significantly reduces the risk of damaging or deforming tubes during the drilling process. This can potentially result in significant cost savings for companies by minimizing material waste and reducing time spent on rework.

Marketer: To effectively penetrate these markets, it is crucial to effectively communicate the benefits of your product in a manner that resonates with potential customers. Understanding the pain points that these industries face with current methods of drilling holes in thin-walled tubes is essential. By positioning your product as the solution to these challenges, you can demonstrate how it addresses their specific needs and provides a more efficient and reliable drilling process.

Market Analyst: Market size and segmentation will be key to your success. You will need to conduct market research to understand the size of the potential markets, the number of companies that could benefit from your product, and the amount they currently spend on similar operations. This

research will allow you to forecast potential revenues, which will be crucial for business planning and investor presentations.

Figure 18 ChatGPT's Answer as a Relevant Expert with a View to Helping Entrepreneurs

4.2.2.2 Selecting the Best Viable Offer

Analogous to the initial case, users have the option to solicit further elucidation on specific facets of the preceding response or to request an alternative viewpoint from ChatGPT. Moreover, in instances where a user finds the furnished response unsatisfactory or wishes to explore a divergent line of thought, they have the recourse to employ the 'Regenerate response' feature situated beneath the ChatGPT response field. This tool grants ChatGPT the capability to craft a novel response, distinct from its predecessor, thereby facilitating a more exhaustive exploration of the topic at hand.

5 RESULTS AND DISCUSSION

In this study, which explored the integration of TRIZ and ChatGPT, strong synergies that strengthened both problem-solving and decision-making processes were found. These synergies have substantial implications for technical and entrepreneurial domains, and were illustrated through case studies. The specific findings of this study are as follows:

a) ChatGPT's Problem-Solving Capabilities from a TRIZ Perspective

In the domain of inventive problem-solving, TRIZ has emerged as a preeminent methodology. Yet, its integration with ChatGPT heralds a novel frontier for bolstered creative solutions. Viewed through a TRIZ perspective, the problem-solving capability of ChatGPT becomes manifest.

The cases in this study, namely 'Imperfect Waterproof Zipper' and 'Drilling a Hole in a Thin-Walled Tube', revealed that ChatGPT not only provided solutions that were actually applied, but also suggested solutions that could be sufficient for practical applications.

Furthermore, this synergy facilitates developers in harnessing TRIZ via AI models, independent of their prior knowledge or expertise.

b) Business Strategy Insights

From an entrepreneurial perspective, ChatGPT has proven its competence in offering market analyses from various angles and providing strategic insights. In the cases of Korean patent 10-2261012 and U.S. patent 5,974,846, ChatGPT demonstrated its ability to furnish comprehensive market analyses and strategies. It went beyond merely offering a thorough market analysis; it also proposed actionable strategies, thereby highlighting its applicability in real-world entrepreneurial scenarios.

This prompt engineering design thus unveils a rich vein of opportunities for entrepreneurs. It enables them to harness insights from various standpoints, facilitating informed decision-making and strategic planning.

c) Mutual understanding between developers and entrepreneurs

The collaboration of ChatGPT affords developers the prospect of crafting more successful products by delving into the non-technical facets from an entrepreneurial standpoint, encompassing an understanding of market trends, and consumer demands. Concurrently, entrepreneurs stand to benefit by navigating their enterprises and sales more efficiently, armed with an awareness of the spectrum of viable technologies and an insight into the developmental methodologies employed by developers.

The integration of TRIZ's structured problem-solving with ChatGPT's capability offers a novel approach to tech innovation, as demonstrated by the above results. For developers, this means a dynamic shift in problem-solving techniques, while entrepreneurs can harness this fusion for enhanced market analysis and product innovation. The AI's competence to provide diverse market strategies, combined with TRIZ's systematic methodology, can revolutionize both technical problem-solving and entrepreneurial strategy formulation. As technology evolves, this collaborative approach sets new directions and domains for innovation, highlighting the potential of combining human ingenuity with AI capabilities.

In conclusion, this case study stands as a testament to ChatGPT's prowess in fostering multifaceted and efficacious problem-solving initiatives, particularly when viewed through the prism of the TRIZ methodology. Furthermore, it endeavors to equip entrepreneurs with invaluable business acumen and strategic insights.

6 CONCLUSION

Numerous studies have raised inquiries regarding the extent of creativity exhibited by AI and acknowledged its presence in general [28]. Prognostications by both laypersons and experts indicate that AI will not solely augment human work efficiency but also pose a potential threat to human capabilities [29]. Nonetheless, AI is progressively permeating various aspects of our lives, and its integration is projected to escalate substantially in the future.

This engagement with AI extends beyond mere utilization; it entails collaborative synergy. A mounting body of research attests to the remarkable outcomes derived from such collaborative endeavours [30].

Aligned with this prevailing trajectory, this study explored problem-solving approaches from a perspective of TRIZ and elucidated business management considerations from an entrepreneurial standpoint through the employment of ChatGPT.

Despite the individual strengths of TRIZ and ChatGPT, their combined application remains rarely explored in existing literature. This study bridges that gap, demonstrating how the integration of TRIZ methodologies with ChatGPT's AI capabilities can address contemporary technological and business challenges more effectively. This bridging of theoretical methodologies with practical AI applications offers a novel strategy for leveraging technology to foster creativity and innovation.

The practical applications demonstrated through the "Imperfect Waterproof Zipper" and "Drilling a Hole in a

Thin-Walled Tube" case studies serve as concrete examples of how integrating TRIZ and AI can lead to innovative solutions that closely mirror real-world outcomes. Our research revealed that the confluence of TRIZ and ChatGPT not only aligns with actual problem-solving outcomes but also significantly augments the quality of solutions. This is particularly beneficial for developers with limited exposure to TRIZ, indicating that the complex methodology of TRIZ can be made accessible through AI facilitation. Moreover, the study underscores the versatility of ChatGPT as a tool not just for developers but also for entrepreneurs, providing strategic insights for market entry and product success. By highlighting the collaborative synergy between human creativity and artificial intelligence, this research contributes to the broader discourse on the role of AI in amplifying human problem-solving capabilities. This study highlights that AI not only reaffirms its potential to improve human efficiency, but also can provide a competitive advantage in a rapidly evolving industrial environment as a catalyst for innovative problem solving and strategic planning and proposes to adopt and integrate AI tools such as ChatGPT more widely in creative and strategic thinking processes to expand AI-human collaboration in different domains.

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Understanding the Drivers of Adoption for Blockchain-enabled Intelligent Transportation Systems

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Abstract: This study tended to present a model for examining the effective factors on adoption of blockchain-based intelligent transportation systems (ITS). The methodology employed was correlational descriptive approach using structural equation modeling. The research involved collecting data through a survey, which was completed by 368 individuals residing in prominent cities across Iran. The findings of the study suggest that perceived quality of digital services significantly impacts perceived ease of use, perceived usefulness, and trust in a positive manner. Additionally, the positive influence of information technology infrastructure and social influence on perceived ease of use and perceived usefulness is evident. Moreover, perceived ease of use and perceived usefulness play pivotal roles in building trust and fostering adoption of blockchain-based ITS. The study also highlights the positive and significant impact of transparent governance on trust and adoption. Furthermore, policies and regulations are identified as key drivers of perceived usefulness and adoption of such systems. Lastly, perceived trust and security are found to positively influence adoption. These findings underscore the potential of the examined variables to serve as robust predictors for the adoption of blockchain-based ITS by citizens.

Keywords: adoption of blockchain-based intelligent transportation system; perceived quality of digital services; policies and regulations; technology acceptance; trust; transparent governance

1 INTRODUCTION

Despite considerable progress in infrastructure development, the surge in vehicle numbers over the last twenty years has made the transportation strategies previously developed and put into action insufficient for tackling the growing issues of traffic congestion. There is an increasing importance placed on the integration of intelligent transportation systems (ITS). These systems play a key role in alleviating traffic issues, enhancing traffic flow, and fostering the development of smart road infrastructure. Users benefit from valuable updates on seat availability and real-time traffic conditions, leading to improved safety, enhanced comfort, and reduced travel times [1, 36]. ITS have evolved through the incorporation of integrated information and communication technologies within transportation networks. These systems facilitate the seamless integration of vehicles, road infrastructure, and individuals by leveraging advanced technologies like Radio Frequency Identification (RFID) scanners and Global Positioning System (GPS) for effective traffic data collection. Additionally, Advanced Traveller Information Systems (ATIS) aid travellers in making informed decisions, while advanced management systems oversee transportation operations. The integration of electric vehicles and intelligent traffic systems further contribute to the efficiency and effectiveness of modern transportation systems [2, 39]. By optimizing energy consumption efficiency in transportation systems, we can reduce overall carbon emissions and promote sustainability for future generations [48].

Fostering a trustworthy collaboration and developing a secure, reliable and decentralized architecture is crucial for maintaining a profitable, sustainable, efficient, and safe ecosystem of ITS. In response to this requirement, blockchain technology presents outstanding solutions. With the advent of Bitcoin, blockchain technology has revolutionized the landscape of digital currencies. This

emerging decentralized technology embodies a distributed ledger that possesses the capability to uphold an indelible log of transactions executed within a network. While initial research predominantly concentrated on the implementation of blockchain within the financial domain, scientific communities have recently redirected their efforts towards exploring its application in the context of the Internet of Things (IoT) [3], leveraging its decentralized, trustworthy, and secure environment. Recognizing its enormous potential, blockchain technology has garnered substantial attention from both industry and academia in recent times. As per a report by Deloitte in 2019, blockchain is projected to emerge as one of the top five strategic priorities over the upcoming two years [4]. Some of the advantages of blockchain technology may include anonymity, transparency, accountability, collaboration, financial efficiency, cooperation, agility, privacy, security, and scalability. These advantages of blockchain-based ITS have garnered significant attention from academics and experts, leading to development of several applications and prototypes in this field. Successful implementations of blockchain-based ITS encompass shared initiatives, systems for traffic control and management, as well as ad-hoc vehicle networks [2]. Considering the importance of blockchain technology in transportation systems, this study tends to present a model for examining the effective factors on adoption of blockchain-based ITS.

2 RESEARCH HYPOTHESES

2.1 Trust and Adoption of Blockchain-based ITS

Throughout the history of business, trust has served as a foundational concept for facilitating transactions and exchanges. It plays a crucial role in establishing and enhancing the quality of relationships through the process of making and fulfilling commitments [38]. Trust means customer tendency to have confidence in abilities and

capabilities of a trademark in performing assigned tasks [5]. According to Morgan and Hunt [6], trust is characterized as the perception of confidence in exchanges, dependency, partner reliability, and they argue that trust forms the cornerstone of a dedicated relationship. Belief in the reliability and trustworthiness of the other party fosters a robust, genuine, equitable, and advantageous collaboration. In instances where unexpected product issues arise, the brand's trustworthiness becomes a dependable factor for customers, contributing to the growth, sales, and promotion of products or services [7, 8].

The configuration of trust holds significant importance in cultivating interest in relationship marketing. Several researchers have recognized trust as a vital element in establishing and nurturing fruitful customer relationships and fostering customer loyalty [9, 10]. In particular, trust is more important in the electronic environment due to complexity and diversity of electronic interactions, and thus insecurity and unpredictable behaviors [11, 12]. Various studies also indicate the role of trust in behavioral intentions and use of services. Therefore, it is assumed that:

H1: Citizen trust is effective on adoption of blockchain-based ITS.

2.2 Perceived Security and Adoption of Blockchain-based ITS

Security, which involves protection and support of personal information of customers, transactions, and secure events to prevent misuse, is crucial for growth of any online business. Security includes secure and reliable exchanges and transactions, as well as robust systems and reliable support [13]. Information security refers to protection of information and minimized risk of information disclosure in unauthorized areas. Information security is a set of tools used to prevent theft, attacks, crimes, espionage, sabotage, and to study methods of data protection in computers and communication systems against unauthorized access and changes. By definitions, security refers to a set of measures, methods, and tools used to prevent unauthorized access and changes in computer and communication systems [14-16]. With rapid growth of e-commerce, government and private institutions perceive greater risk associated with protecting their information security. Developing electronic security as a field enables organizations to better understand a wider range of similarities between attacks occurring in their secure environment and take appropriate countermeasures. Protecting the privacy of confidential information has become a benchmark for success in the business world, as it enhances the reputation of organizations and gain the trust of individuals. Studies have also emphasized the role of perceived security in ITS [2]. Therefore, it is assumed that:

H2: Perceived security is effective on adoption of blockchain-based ITS.

2.3 Transparent Governance and Adoption of Blockchain-based ITS

Transparent governance entails the practice of open communication and disclosure of information among citizens, organizations, or governments, while also taking

into account privacy limitations [2]. Blockchain technology offers a reliable and transparent mechanism that ensures the permanence of all information. Transparent governance involves implementing a government system characterized by openness, clearly defined processes and procedures, and seamless access to public information for citizens. Enhanced transparency fosters ethical consciousness in public services by promoting information sharing, thereby ensuring accountability for the performance of individuals and organizations responsible for managing resources or holding governmental roles. Increasing transparency by providing users with the ability to track all system functions helps build trust in the organization and its programs [2]. Similarly, it positively influences the success of blockchain-based intelligent transportation initiatives. Hence, the success of blockchain-based ITS heavily relies on the implementation of transparent governance as a pivotal factor [2]. Thus, it is assumed that:

H3: Transparent governance is effective on adoption of blockchain-based ITS.

H4: Transparent governance is effective on citizen trust in adopting blockchain-based ITS.

2.4 Policies, Regulations and Adoption of Blockchain-based ITS

Policies and regulations refer to the guidelines and rules established by the government to oversee and regulate industries in their adoption of new technologies [2]. They are considered as a fundamental and influential factor in fostering innovation [17, 40]. Given that blockchain is a recently emerged technology, the introduction of new regulations presents challenges, including the definition of digital ownership and access rights, without established laws and regulations in place as of yet [18]. This can either promote or hinder the acceptance of technology, especially the success of blockchain-based ITS projects. Therefore, policies and regulations are defined as one of the key contributors to success in blockchain-based ITS projects [2]. Therefore, it is assumed that:

H5: Policies and regulations are effective on adoption of blockchain-based ITS.

H6: Policies and regulations are effective on the perceived usefulness of blockchain-based ITS.

2.5 The Perceived Usefulness and Ease of Use

The growth and increasing development of communication technology has led to a revolution in various aspects of human life and performance of businesses. Technology has led to changes in performance and attitude of people, companies, and governments, resulting in establishment of new industries, new jobs, and innovation in organizational processes [27, 40]. Various theoretical frameworks have been formulated and tested to assess the level of technology acceptance by users, the most important of which is Technology Acceptance Model (TAM) [12, 19, 43]. Davis [19] introduced the TAM to elucidate technology usage patterns and the factors associated with technology adoption. The TAM model is rooted in the Theory of Reasoned Action. It has been suggested that the TAM is the

most reliable predictor of behavioral intention towards usage. The TAM rests on two core elements, namely "perceived usefulness" and "perceived ease of use." Perceived ease of use pertains to an individual's conviction that minimal physical and mental exertion is needed to operate a given technology [12, 19]. Perceived usefulness denotes an individual's conviction that the utilization of technology will enhance their job performance [19]. Studies show that perceived usefulness and ease of use are effective on attitude (positive or negative personal feelings resulting from evaluation of certain behavior) while using a technology, which lead to decision to use that technology and ultimately manifest in actual usage. Moreover, the research conducted suggests that trust plays a mediating role in the impact of perceived usefulness and perceived ease of use on behavioral intentions. Therefore, it is assumed that:

H7: Perceived ease of use is effective on perceived usefulness.

H8: Perceived ease of use is effective on citizen trust on adoption of blockchain-based ITS.

H9: Perceived ease of use is effective is effective on adoption of blockchain-based ITS.

H10: Perceived usefulness is effective on citizen trust on adoption of blockchain-based ITS.

H11: Perceived usefulness is effective on adoption of blockchain-based ITS.

2.6 Social Influence

Social influence refers to how one perceives the importance of others' opinions in adopting new technologies. The intention of users to adopt a specific technology is influenced by social pressure from peers, family, and media [20, 41, 46]. According to Venkatesh et al. [21], social influence pertains to how much an individual perceives that others endorse their adoption of the new system. Prior research has demonstrated the effectiveness of social influence on users' perceived ease of use, perceived usefulness, and behavioral intentions. Therefore, it is assumed that:

H12: social influence is effective on perceived usefulness.

H13: social influence is effective on perceived ease of use.

2.7 Perceived Quality of Digital Services

According to most experts, the surest way to succeed is to remain in the minds of customers, and this can only be achieved through producing high-quality products and services. The quality of services has become a key marketing tool for achieving competitive differentiation and promoting customer loyalty. Awareness of the concept of service quality and striving to improve it has led to provision of high-quality services; customer satisfaction can be increased by improving the level of service quality [22, 37]. In various industries and sectors, companies tend to differentiate themselves and retain customers by providing better services. Zeithaml et al. [23] define electronic services as web-based services that are delivered to customers via the internet. Exceptional service quality is regarded as a pivotal element for achieving success in a competitive service market [44].

Numerous studies have highlighted that the perceived service quality has a direct impact on customer trust. Electronic service quality encompasses all interactive stages that consumers experience through websites, including the extent to which websites facilitate efficient and effective purchasing and delivery processes. In general terms, electronic service quality can be described as customer-oriented online services facilitated by consumers, integrated with technology and systems provided by service providers, with the aim of enhancing the relationship between customers and service providers [24, 25]. Past research indicates that the perceived quality of public transportation services has a notable positive influence on the perceived ease of use and utility. Therefore, it is assumed that:

H14: Perceived digital service quality is effective on perceived usefulness.

H15: Perceived digital service quality is effective on perceived ease of use.

H16: Perceived digital service quality is effective on citizen trust on adoption of blockchain-based ITS.

2.8 Information Technology Infrastructure

Information technology, as a new infrastructure, has attracted much attention to its impact on organizations. This infrastructure, generally defined as collective utilization of electronic devices, remote communication, software, decentralized computer stations, and integrated media, has had a profound effect on organizing spatial distances and consequently on other systems. Information technology infrastructure represents physical capital (i.e., computers, network equipment, and databases) that provides information sharing and accessibility for the company [26]. Currently, information technology is an incentive for globalization of productions and markets, increasing the dynamism and flexibility of services and financial flows, often setting the stage for increased performance and efficiency. Comprehensive information and information technology used at the right time can increase creativity and technology while preventing the waste of resources, unnecessary and unintended rework, and above all, fruitless decision-making. Therefore, it is assumed that:

H17: Information technology infrastructure is effective on perceived usefulness.

H18: Information technology infrastructure is effective on perceived ease of use.

Overall, as noted, the role of the variables mentioned in this study in ITS has been emphasized throughout the theoretical literature. However, review of empirical literature shows that few studies have provided a model to examine the effective factors on adoption of blockchain-based ITS. Therefore, the main problem of this study is to present a model to examine the effective factors on adoption of blockchain-based ITS. Drawing upon the theoretical literature and a conceptual framework derived from previous studies, Figure 1 illustrates the conceptual model for this research. In this model, perceived digital service quality, information technology infrastructure, social influence, transparent governance, policies and regulations, and perceived security are considered as independent variables, perceived ease of use, perceived usefulness, and trust as

mediating variables, and adoption of blockchain-based ITS as dependent variable.

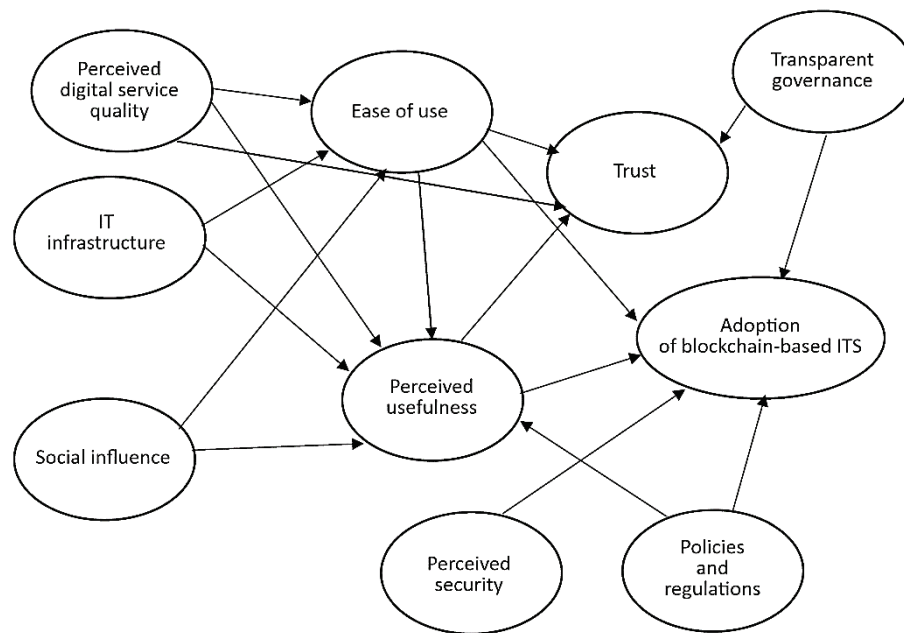


Figure 1 Conceptual model

3 RESEARCH METHODOLOGY

This section will detail the research methodology employed in our study.

3.1 Population and Sample

The participants of this study were residents of major cities in Iran. For this purpose, 450 questionnaires were distributed among citizens of these metropolises, out of which 392 questionnaires were returned, and 24 questionnaires were excluded from analysis process due to incomplete responses, ultimately leaving 368 questionnaires for analysis. Additionally, 61% of the study's participants were male, while 29% were female. Among the participants, 39% were aged between 20 and 30 years, 36% were between 31 and 40 years old, 19% were between 41 and 50 years old, and 6% were over 50 years of age.

3.2 Data Collection Instruments

To measure the variables, a questionnaire was used. The questionnaire consisted of 56 items. The perceived usefulness was measured using Chen and Chao's [28] questionnaire, which consists of 5 items. The ease of use was measured using Chen and Chao's [28] questionnaire, which consists of 5 items. Social influence was measured using Venkatesh et al.'s [21] questionnaire, which consists of 4 items. Transparent governance was measured using Ofochebe's [29] questionnaire, consisting of 5 items. Policies and regulations were measured using Zhu et al.'s [17] questionnaire, which consists of 3 items. Trust was measured using Shankar et al.'s [30] questionnaire, which consists of 6 items. Perceived security was measured using Gao et al.'s [20] questionnaire, which consists of 5 items. The quality of

digital services was measured using a 15-item questionnaire, assessing tangibility [31] with 5 items, convenience [31] with 6 items, and customer satisfaction [9, 32, 33] with 4 items. Infrastructure technology was measured using Ravichandran et al.'s [34] questionnaire, which consists of 5 items. Adoption of blockchain-based ITS was measured using Chen et al.'s [35] questionnaire, which consists of 3 items.

4 RESULTS

4.1 Validity and Reliability of Instruments

The evaluation of the measurement model involves examining the reliability (internal consistency) and validity (discriminant validity) of constructs and instruments. Three criteria for evaluating construct reliability are applied: 1) the reliability of individual items, 2) the composite reliability of each construct, and 3) the average variance extracted (AVE). For the reliability of individual items, a factor loading of 0.6 or higher in confirmatory factor analysis indicates the adequacy of each item within that construct. Additionally, the factor loadings of items should be statistically significant at the 0.01 level [12]. The significance of factor loadings was determined by calculating the T-value through bootstrap testing with 500 subsamples. The composite reliability of each construct was evaluated using Dillon-Goldstein's rho method (ρ_c). Acceptable ρ_c values should be 0.7 or higher. The third measure for evaluating reliability AVE. They suggest AVE values of 0.50 or greater, signifying that the construct accounts for approximately 50 percent or more of the variance in its indicators [27]. Tab. 1 displays the factor loadings, composite reliability, and AVE of the variables. The values presented in these tables demonstrate sufficient and satisfactory reliability of the constructs.

Table 1 The results of measurement model

Variable		Item	Factor loading	Cronbach's alpha	CR	AVE
Perceived digital service quality	Tangibility	1	0.853	0.874	0.909	0.668
		2	0.883			
		3	0.830			
		4	0.743			
		5	0.769			
	Convenience	1	0.779	0.806	0.861	0.509
		2	0.722			
		3	0.725			
		4	0.706			
		5	0.666			
	Customer satisfaction	6	0.676	0.795	0.867	0.619
		1	0.80			
		2	0.814			
		3	0.747			
IT infrastructure		4	0.785	0.864	0.901	0.647
		1	0.721			
		2	0.764			
		3	0.826			
		4	0.812			
Social influence		5	0.888	0.782	0.858	0.603
		1	0.828			
		2	0.844			
		3	0.747			
		4	0.676			
Perceived usefulness		1	0.669	0.855	0.840	0.514
		2	0.799			
		3	0.704			
		4	0.651			
		5	0.751			
Perceived ease of use		1	0.861	0.855	0.895	0.631
		2	0.739			
		3	0.718			
		4	0.848			
		5	0.796			
Trust		1	0.818	0.920	0.938	0.715
		2	0.850			
		3	0.874			
		4	0.855			
		5	0.869			
		6	0.804			
Transparent governance		1	0.827	0.864	0.900	0.645
		2	0.861			
		3	0.848			
		4	0.713			
		5	0.761			
Policies and regulations		1	0.737	0.756	0.807	0.583
		2	0.721			
		3	0.828			
Perceived security		1	0.827	0.895	0.923	0.706
		2	0.875			
		3	0.822			
		4	0.756			
		5	0.912			
Adoption of blockchain-based ITS		1	0.862	0.842	0.905	0.760
		2	0.899			
		3	0.854			

In evaluating construct validity or discriminant validity, Nazari-Shirkouhi et al. [12] proposes two criteria: 1) Items within a construct should exhibit the highest factor loading on their own construct, indicating minimal cross-loading on other constructs. Alipour et al. [27] recommended that the factor loading of each item on its designated construct should be at least 0.1 higher than its loading on any alternative construct. The second criterion states that the square root of

the AVE for a construct should exceed its correlation with other constructs. This signifies that the construct's correlation with its own indicators is stronger than its correlation with other constructs [42].

As per the data in Tab. 2, the square root of AVE exceeds the correlations with other variables for all variables. This confirms that the variables meet the second criterion for discriminant validity. Furthermore, the values below the diagonal in the correlation matrix are analyzed to investigate the interrelationships among variables.

4.2 Structural Model Testing

To forecast the adoption of blockchain-based ITS, the conceptual model under scrutiny was analyzed through Structural Equation Modeling (SEM). The Partial Least Squares (PLS) approach was applied to estimate the model in line with the hypotheses. Furthermore, the bootstrap technique (utilizing 700 subsamples) was utilized to compute *t*-values for assessing the significance of path coefficients [42]. Fig. 2 depicts the tested model, illustrating the connections among the variables. The figures within the circles indicate the variance explained by the variables.

Tab. 3 reports the estimated path coefficients and the explained variances of the variables.

As indicated in Tab. 3, the perceived quality of digital services exerts a significant and positive influence on perceived ease of use, perceived usefulness, and trust. Furthermore, the impact of information technology infrastructure and social influence is both significant and positive on perceived ease of use and perceived usefulness. Perceived ease of use and perceived usefulness demonstrate a positive and significant effect on trust and the adoption of intelligent blockchain-based transportation systems. Transparent governance exhibits a positive and significant effect on trust and the adoption of intelligent blockchain-based transportation systems. Moreover, policies and regulations have a positive and significant effect on perceived usefulness and the adoption of blockchain-based ITS. Additionally, perceived trust and security yield a positive and significant impact on the adoption of blockchain-based ITS. Furthermore, the model explains 67% of the variance in the adoption of blockchain-based ITS, 56% of the variance in trust, 28% of the variance in perceived ease of use, and 56% of the variance in perceived usefulness. The indirect coefficients are presented in Tab. 4.

Tab. 4 reveals that the perceived ease of use plays a significant and positive mediating role in the impact of perceived digital service quality, social influence, and IT infrastructure on the adoption of blockchain-based ITS. The perceived usefulness also has a positive and significant mediating role in the effect of the perceived digital service quality, social influence, policies and regulations, and IT infrastructure on adoption of blockchain-based ITS. In the adoption of blockchain-based ITS, trust acts as a positive and significant mediator in the impact of perceived digital service quality, perceived ease of use, perceived usefulness, and transparent governance.

In this study, the absolute GOF index for the tested model was computed as 0.597, indicating a satisfactory fit of

the model. Values exceeding 0.36 signify acceptable and adequate model quality.

Table 2 Matrix of correlation and square root of AVE of variables

	ITS	Digital Service Quality	Perceived Ease of Use	Perceived Security	Perceived Usefulness	Policy & Regulations	Social Influence	Technology infrastructure	Transparent Governance	Trust
Blockchain-based ITS	0.872									
Digital Service Quality	0.528	0.815								
Perceived Ease of Use	0.448	0.509	0.794							
Perceived Security	0.481	0.618	0.376	0.840						
Perceived Usefulness	0.545	0.676	0.485	0.596	0.712					
Policy & Regulations	0.596	0.624	0.482	0.569	0.587	0.763				
Social Influence	0.516	0.596	0.409	0.537	0.427	0.577	0.776			
Technology infrastructure	0.386	0.524	0.234	0.573	0.528	0.477	0.526	0.804		
Transparent Governance	0.476	0.396	0.162	0.397	0.502	0.389	0.354	0.428	0.803	
Trust	0.567	0.558	0.428	0.610	0.571	0.591	0.482	0.483	0.502	0.846

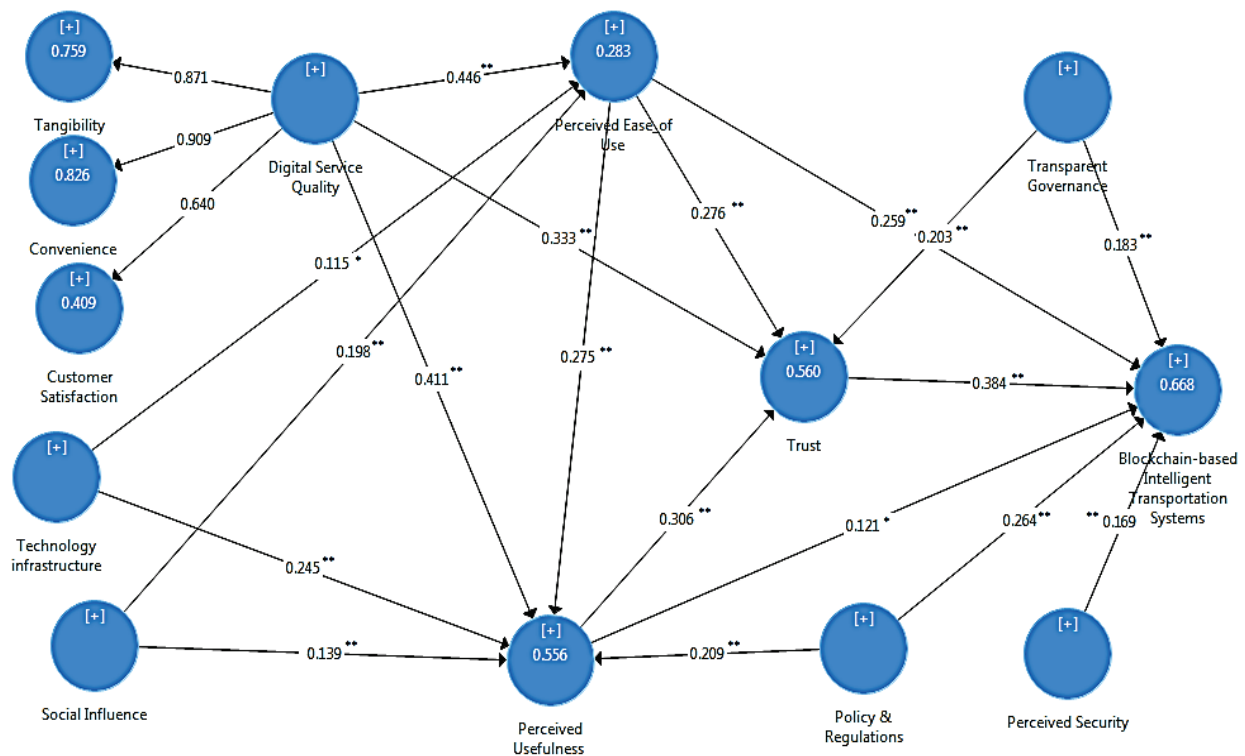


Figure 2 The tested model

5 DISCUSSION

This study tended to propose a model for examining the effective factors on adoption of blockchain-based ITS using the SEM method. The findings demonstrated that the proposed model exhibited a favorable fit with the collected data and successfully accounted for 67% of the variance in the adoption of blockchain-based ITS, 56% of the variance in perceived trust, 28% of the variance in perceived ease of use, and 56% of the variance in perceived usefulness.

The findings suggested that the perceived quality of digital services positively and significantly influences perceived ease of use, perceived usefulness, and trust, thereby enhancing the ease of use, perceived usefulness, and trust in blockchain-based ITS. In explaining this finding, if good services are provided and customer perceptions and beliefs about service quality are positively influenced, the level of trust in these services will significantly increase. In general, it can be concluded that service quality increases customer trust. Providing services as promised in a suitable, accurate, and reliable manner boosts customer trust.

Additionally, providing better digital services makes citizens perceive technology as easy to use and beneficial. Hence, it can be inferred that the quality of electronic services is closely associated with perceived usefulness, perceived ease

of use, and customer trust, thereby aiding citizens in their decision-making process and promoting the adoption of blockchain-based ITS.

Table 3 Path coefficients and explained variance

Variable	β	t-value	p-value	Explained variance
On adoption of blockchain-based smart transportation system via:				
Transparent governance	0.183**	3.014	0.01	0.668
Policies and regulations	0.264**	5.811	0.01	
Perceived security	0.169**	2.874	0.01	
Trust	0.384**	7.296	0.01	
Perceived usefulness	0.121*	2.508	0.05	
Perceived ease of use	0.259**	5.327	0.01	
On trust via:				
Transparent governance	0.203**	4.216	0.01	0.56
Perceived usefulness	0.306*	5.388	0.01	
Perceived ease of use	0.276**	5.926	0.01	
Perceived digital service quality	0.333**	5.776	0.01	
On perceived usefulness via:				
Perceived ease of use	0.275**	5.411	0.01	0.556
Perceived digital service quality	0.411**	7.065	0.01	
IT infrastructure	0.245**	5.722	0.01	
Social influence	0.139**	2.922	0.01	
On perceived ease of use via:				
Perceived digital service quality	0.446**	7.080	0.01	0.283
IT infrastructure	0.115*	2.409	0.01	
Social influence	0.198**	3.713	0.01	

* $p < 0.05$; ** $p < 0.01$

Table 4 Indirect coefficients

Indirect paths	Indirect effects	t-value	p-values
Digital Service Quality→Perceived Ease of Use→Blockchain-based ITS	0.115	4.256	0.000
Social Influence→Perceived Ease of Use→Blockchain-based ITS	0.051	3.046	0.000
Technology infrastructure→Perceived Ease of Use→Blockchain-based ITS	0.03	2.195	0.05
Digital Service Quality→Perceived Usefulness→Blockchain-based ITS	0.050	2.605	0.009
Perceived Ease of Use→Perceived Usefulness→Blockchain-based ITS	0.033	2.275	0.05
Policy & Regulations→Perceived Usefulness→Blockchain-based ITS	0.025	2.313	0.021
Social Influence→Perceived Usefulness→Blockchain-based ITS	0.017	2.189	0.029
Technology infrastructure→Perceived Usefulness→Blockchain-based ITS	0.030	2.600	0.010
Digital Service Quality→Trust→Blockchain-based ITS	0.128	4.531	0.000
Perceived Ease of Use→Trust→Blockchain-based ITS	0.106	4.599	0.000
Perceived Usefulness→Trust→Blockchain-based ITS	0.118	4.225	0.000
Transparent Governance→Trust→Blockchain-based ITS	0.078	3.664	0.000
Digital Service Quality→Perceived Usefulness→Trust	0.126	4.954	0.000
Perceived Ease of Use→Perceived Usefulness→Trust	0.084	3.818	0.001
Policy & Regulations→Perceived Usefulness→Trust	0.064	2.699	0.007
Social Influence→Perceived Usefulness→Trust	0.043	2.503	0.013
Technology infrastructure→Perceived Usefulness→Trust	0.075	3.925	0.000

The findings further revealed a positive and significant impact of information technology infrastructure on perceived ease of use and perceived usefulness, ultimately resulting in heightened perceptions of ease of use and usefulness regarding blockchain-based ITS. In explaining this finding, if a company has the necessary technological infrastructure to electronically connect units and has the technology infrastructure for intelligent transportation activities, and if capacity of ITS infrastructure meets current needs, it will lead to increased perceived ease of use and perceived usefulness of blockchain-based ITS and, consequently, an increase in their adoption.

The findings indicated that social influence has a notably positive impact on perceived ease of use and perceived usefulness, contributing to an enhancement in the perceived ease of use and perceived usefulness of blockchain-based ITS. In explaining this finding, if trustworthy friends or

family members recommend blockchain-based ITS, if a trusted agency (such as the police or a transportation authority) recommends it, and if a reputable source recommends and supports it, it leads to an increase in the perceived ease of use and perceived usefulness of blockchain-based ITS, thereby increasing the likelihood of their adoption.

Another finding of the study was that perceived usefulness and perceived ease of use have a significantly positive effect on trust and intention to use blockchain-based intelligent transportation systems, leading to an increased use of such systems. This result aligns with the Technology Acceptance Model (TAM), which underscores the significance of perceived usefulness and perceived ease of use in determining actual user behavior. In explaining this finding, if users perceive the adoption of blockchain-based ITS as easy, perceive it as easy to fulfill their needs, find it

easy to learn to use the system, feel that it enhances their effectiveness in daily activities, and believe that the system contributes positively to their performance, their intention to use the blockchain-based ITS will increase. As per the TAM, perceived ease of use and perceived usefulness stand out as key factors influencing technology acceptance, and if technology improves individual efficiency and performance, it fosters a positive attitude toward that technology, leading to a greater willingness to use it.

Another finding was that transparent governance and adoption of blockchain-based ITS have a positive and significant effect, leading to increased adoption of ITS based on blockchain technology. This finding is consistent with Çaldağ and Gökalp [2], who identified transparent governance as one of the determinants of adopting blockchain-based ITS. When elucidating this discovery, it is important for open communication and information disclosure to exist between citizens and organizations or governments in relation to blockchain-based ITS. The government should ensure that citizens have easy access to public information related to ITS through transparent processes and procedures. Additionally, a high level of transparency and ethical awareness in public services should be promoted through information sharing. These efforts will lead to enhanced trust and, consequently, greater adoption of blockchain-based ITS.

Another finding is that perceived usefulness and policies and regulations have a positive and significant effect on the perceived usefulness and adoption of blockchain-based ITS. This finding is consistent with Çaldağ and Gökalp [2], who emphasized the importance of policies and regulations as one of the success factors of blockchain-based ITS. In explaining this finding, policies and regulations related to how to use ITS and policies and regulations to address issues that may arise during the usage of these systems lead to increased adoption of blockchain-based ITS.

Another finding is that perceived security has a positive and significant effect on adoption blockchain-based ITS. This finding is consistent with Çaldağ and Gökalp [2]. In explaining this finding, if users are not concerned about their personal information while using the ITS, not worried about their personal information being shared without their consent, not concerned about their shared information being misused by the company, and feel secure when using the services of the company, it will lead to increased adoption of blockchain-based ITS.

Another finding was that trust has a positive and significant effect on adoption blockchain-based ITS, leading to increased use of these systems. In explaining this finding, if performance of the system meets user expectations and they feel that the company is true to its promises, their willingness to use the blockchain-based ITS will increase. The trustworthiness of a brand serves as a dependable factor for customer retention, guaranteeing the development, sale, and advertisement of a product or service. Once trust is established, it creates the potential for mutually beneficial relationships between customers and companies. Therefore, it can be inferred that trust plays a vital role in customer satisfaction when utilizing blockchain-based ITS.

6 MANAGERIAL IMPLICATIONS

Given the role of perceived digital service quality in adopting blockchain-based ITS, it is suggested that officials of ITS provide accurate information on how services are delivered to citizens, offer timely information to citizens, provide reliable services, offer professional services to citizens, and ensure that employees are responsive to citizen requests and address issues and problems that arise.

Considering the role of technology infrastructure in adopting blockchain-based ITS, it is suggested that companies responsible for technology infrastructure have the necessary electronic infrastructure to connect different units, have technology infrastructure for ITS, and that the capacity of technology infrastructure meets the current needs of citizens.

Given the role of trust in utilizing blockchain-based ITS, it is suggested that the company fulfill its commitments to citizens, provide reliable services, meet customer expectations with proposed services, and consider the interests of citizens. Numerous researchers have emphasized the importance of trust in establishing and nurturing successful customer relationships and loyalty. They argue that customers require a sense of security in their engagements with service providers and must feel assured that these interactions are dependable enough to engender trust. The reliability of a brand serves as a guarantee for customers, enabling the development, sale, and promotion of products or services. When trust is established, it opens up the potential for mutually advantageous relationships between customers and companies.

Considering the role of transparent governance and policies and regulations in adopting blockchain-based ITS, it is recommended that clear and explicit policies and regulations be developed in the field of blockchain-based ITS, and that open communications and transparent information exist between citizens and organizations or companies responsible for ITS. Transparency helps increase trust in organizations and programs.

Considering the role of perceived security in adopting blockchain-based ITS, it is suggested that citizens should not be concerned about their personal information during their exchanges and transactions when using ITS. They should not worry that their personal information will be shared without consent, that the information they provide on websites will be misused, that their personal information will be shared with the bank website, and that a sense of security for citizens should be ensured in using ITS.

7 CONCLUSION

In summary, the findings indicate that the model variables examined serve as robust predictors of the adoption of blockchain-based ITS. Additionally, perceived ease of use, perceived service quality, social influence, and technological infrastructure play a significant positive mediating role in the adoption of blockchain-based ITS. Perceived usefulness also plays a significant positive mediating role in the impact of perceived digital service quality, social influence, policies and regulations, and technological infrastructure on the adoption of blockchain-based ITS. Trust similarly plays a

significant positive mediating role in the impact of perceived service quality, perceived ease of use, perceived usefulness, and transparent governance on the adoption of blockchain-based ITS. Therefore, it is essential to take into account these model variables to enhance the adoption of blockchain-based ITS.

7.1 Limitations

This research involved a sample of citizens exclusively from key cities in Iran, hence limiting the generalizability of the results. Moreover, the findings rely on self-reported data. To enhance future investigations on the factors influencing the adoption of blockchain-based ITS, it is recommended that researchers employ qualitative analysis [41, 49], mixed methods, machine learning [44, 45] approaches, Fusion Models [47], artificial intelligence [50]. Furthermore, this study is correlational in nature, precluding the ability to draw causal conclusions about the relationships among the model variables.

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Impact of Illuminant Metamerism on Colour Fidelity in Graphic Reproduction of Artistic Images

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Abstract: The aim of the research was to evaluate the quality of illuminant metamerism by using Colour rendering index through similar paintings and half-tone reproduction images within the graphic industry. Employing the methodology of visual perception and testing conducted by standard observers, the study scrutinises how different colour techniques of paintings respond to diverse light sources under standardised conditions. This investigation is pivotal for understanding the chromatic fidelity and consistency of paintings and their reproduction with half-tone colours, by measuring the grey balance field, for all images. To find the most suitable light source and to complete the colour quality, the Osram LED light at 3000 K, 4000 K, and 6500 K is used. The resulting index could be deceptive in cases of significant disparities. The American IES TM-30-18 colour rendering index (CRI) metric, quantifies illumination metamerism's ability to faithfully depict natural colours. At every stage (R1–R15), the average colour reproduction CRI must be more than 90.

Keywords: CCT; colour quality; CRI; illuminant metamerism; visual perception

1 INTRODUCTION

The assessment of colour rendition in various contexts, particularly within the graphic industry, has long been a subject of keen scientific inquiry. Over the decades, researchers have endeavoured to understand the intricacies of illuminant metamerism and its implications for the faithful reproduction of colour [1]. The accurate reproduction of artistic images is a critical concern in the field of graphic reproduction, where color fidelity is paramount.

This research aims to investigate the impact of illuminant metamerism on colour fidelity in the graphic reproduction of artistic images, focusing on works created with acrylic and oil painting techniques. This can significantly affect the perceived colour accuracy of reproduced artwork, leading to discrepancies between the original piece and its printed version. Understanding how different light sources influence colour fidelity is essential for improving reproduction techniques and ensuring that printed images closely resemble the originals. Acrylic paints dry quickly and maintain colour vibrancy, while oil paints dry more slowly, allowing for blending and creating rich textures. These differences influence the way each medium interacts with various illuminants, affecting the colour fidelity of the reproduced image. By understanding these differences, we can improve the accuracy and quality of reproduction industry, lighting engineering, benefiting artists, printers, and the art reproduction. This research will provide valuable insights into the best practices for replicating artworks, ensuring that the printed reproductions remain true to the original pieces.

Efforts to assess the colour rendering abilities of light sources commenced during the 1930s with the emergence of fluorescent lamps, which presented a spectral composition distinct from the prevalent incandescent lamps of that era. Initially, a method known as the spectral bands approach was proposed [CIE 1948], paving the way for standardisation efforts by the International Commission on Illumination (CIE) [1, 2].

Understanding and assessing metamerism requires utilizing colourimetric measurements to evaluate the spectral characteristics of colour methods and inks [3-5].

In the realm of illuminant metamerism and reproduction technology, the accurate portrayal of colour is of paramount importance [2, 3]. As artists strive to convey their intended messages through paintings, and as reproduction technologies advance, understanding the quality of colour reproduction becomes increasingly crucial [6]. Research on metamerism has a long history; however, its application in the context of industry, art, and reproduction on half tone images has been relatively limited [3, 4, 6, 7].

Modern approaches to museum lighting seek to create an optimal balance between two key concerns: limiting the potential negative impact of light on artworks and achieving the best visual appearance through light [4, 8-11].

Modern museum lighting strategies strive to achieve a delicate balance between two key objectives: minimising the potential harm of exposure to artwork and optimising visual perception through strategic lighting [9].

This endeavour enables the representation of predetermined shapes. In the realm of traditional colour painting, the inherent metamerism often leads to colour matches with the original artwork under testing light sources, as reproducing the full spectrum using only three or four inks is inherently challenging [12].

Colour accuracy and consistency are crucial aspects of graphic technology, particularly in fields such as printing and display manufacturing [13]. Hence, the manipulation of light sources, including the adjustment of their chromatic attributes and the precise control of beam orientation, gives the ability to modify the visual characteristics of artworks to align with the specific desired effects [3].

The outcomes of these investigations affirm the viability of light-emitting diodes (LED) as an apt choice for illuminating museum spaces [10, 11]. LED lights are pivotal in various aspects of modern life because of their numerous advantages over traditional lighting technologies. They offer

energy efficiency, longer lifespan, durability, and environmental friendliness compared to incandescent and fluorescent bulbs [14]. This selection is supported by their commendable attributes such as efficient energy utilisation, environmental sustainability, protection of artworks from potential harm, and the versatility of the lighting arrangement in terms of rendering accurate colours [15].

Little is known, however, colour rendition, which refers to how a light source affects the colour perception of objects and surfaces, is a crucial aspect of lighting quality. It is influenced by the spectrum of light emitted, how it interacts with surfaces, and how the human visual system processes it [9, 16, 17].

The implementation and adoption of ANSI/IES TM-30-18, an established American National Standard for assessing the colour rendition of light sources, signify substantial progress in lighting technology. Endorsed by the Illuminating Engineering Society, this method has gained increasing traction among lighting manufacturers, different industries, specifiers, and researchers in the past five years. Its enhanced precision and comprehensive data offerings surpass those of its predecessors, making it the preferred choice for evaluating colour rendition across various industry contexts [16].

This study explores the quality of illuminant metamerism, focussing specifically on its manifestation in the reproduction of paintings. With advancements in lighting technology and the widespread use of digital reproduction methods and colourimetry, it is imperative to evaluate how well these systems preserve the colour accuracy and fidelity of the original artwork. To this end, we dive into the intricacies of the Colour Rendering Index (CRI) and its role in determining the quality of colour reproduction [17].

By examining the interplay between illuminant metamerism and the CRI, we aim to provide insights that can inform improvements in the reproduction process, thereby enhancing the fidelity and authenticity of reproduced paintings. This involves comparing colour variances across different lighting conditions to discern disparities.

Although our study aims to measure all images in appropriate meaner in the grey balance field. However, these domains endure challenges that stem from inadequate production comprehension and substandard quality. This method is very limited, since previous studies tend to measure spot parts and many scientists lack understanding of the industry of graphics and the quality of reproduction [6, 10].

Evaluating colour rendition under different lighting conditions is essential to ensure that printed or displayed colours match their intended appearance [9, 10, 16].

1.1 CMYK Reproductive Colours in the Colour of Photorealistic Images

In the field of graphic technology, the convergence of colour management practices and colourimetry is crucial [17]. Digital printing processes has inaugurated a new era

characterised by increased precision and fidelity in the reproduction of intricate visual compositions [5].

This symbiotic relationship between colour science and printing technology has paved the way for substantial advancements in the realm of colour accuracy [18, 19]. Moreover, the seamless integration of colour measurement instruments and spectrophotometers within the printing workflow facilitates real-time colour calibration and on-the-fly adjustments. This ensures that the colour output is precisely with specified standards, maintaining unwavering consistency throughout all production cycles [20].

1.2 Illuminant Metamerism

Central to this understanding is the concept of illuminant metamerism, which refers to the phenomenon where colours match under one light source but appear different under another [2, 3].

Metamerism, in which the colours of paintings and different light sources are known as a source of annoyance among painters and museums and among those in the apparel, visual perception and advertising industries [10].

For the average person, it is challenging to obtain paints that create metamerism under a particular light source [10].

In the context of graphic reproduction, metamerism can lead to inconsistencies in colour appearance when viewed under different illuminants. This is particularly crucial for artistic images where colour accuracy is paramount.

2 METHODOLOGIES

This research proposes a technology for realizing the artistic perception of two similar paintings, acrylic and oil, by comparing their reproduction in halftone images under different light sources such as Osram LED lights at 3000 K, 4000 K, and 6500 K, with the assessment by standard observers.

The colour techniques utilized were selected by Royal Talens – Art Creation, a longstanding entity in the art supply industry known for prioritizing quality in its diverse range of colour products. Red, blue, and yellow pigments, examples of subtractive colours, were applied in these paintings to correspond with the CMY colour reproduction, lighting, and viewers' vision, allowing for easy identification between them. The size of the artwork was 250 × 320 mm.

The original works were created under standardized conditions in natural light. The artworks were produced on Italian matte Fabriano I264 paper, compliant with the ISO 9706 long life standard.

This mixed media paper was chosen for its suitability for different colour techniques, comprising 25% cotton and 100% alpha cellulose, with a natural grain and cold press finish. With a weight of 300 g/m², it supports all artistic techniques and facilitates comparison with reproduced samples.

This study presents a detailed workflow for the photographic realization of visual subjects, crucial for high-quality image reproduction in research (Fig. 1).



Figure 1 Realization process flow for high-quality image printing

The process begins with capturing the subject using a high-resolution digital camera, the Canon EOS 5DS R, with manual settings to ensure accurate detail and colour.

The captured image data is stored on a secure digital storage medium, typically an SD card, allowing for easy transfer and subsequent processing. The image is then transferred to a computer for digital processing, including inside grey balance, colour correction and enhancements, to faithfully represent the original subject. The processed image is saved and verified on a high-resolution monitor before being printed. The printed image undergoes scientific analysis for accuracy and quality. The Xerox Colour C70 printer was used to reproduce the painting images under conventional operating procedures, with a high quality of 100%, the prints met our predetermined standards for precision and clarity. The colour mode was set to full colour, which provided the best balance between colour accuracy and print consistency.

Laser printers are known for their precision and ability to produce consistent, high-quality prints. The printer was set to its maximum resolution of 1200×1200 DPI to capture fine details. Print speed Colour: up to 60/70 ppm, we utilized Xerox Colotech + paper mat, which have a thickness of 300 g/m^2 , for the sample preparation.

To measure the grey balance, we used the spectrophotometric using the X-Rite eXact device, standard observer 2° , which is used to measure the $L^* a^* b^*$ values on grey balance field.

All equipment was calibrated before use according to the manufacturer's guidelines.

This workflow ensures precise reproduction of visual subjects in both digital and physical formats, maintaining the integrity required for experimental research. The techniques of oil- and acrylic-colour, which, although not often used in scientific research comparison, especially in technology of graphic, detecting differences through different light temperature and light sources, turned out to be a good choice.

The purpose of this research is the use of three subtractive colours of paints in different colour techniques to generate illuminant metamerism, thus enabling the representation of premeditated shapes. As an example, painting detection was illuminated by different light sources such as a LED, with matching CCT as 3000 K, 4000 K, 6500 K, luminance and visual perception and measuring the metamerism index to see similarities and differences between them.

2.1 Optical Colour Space Utilizing CMYK for Digital Recording

Using the software program, CMYK reproduction colours were employed for the perceptual analysis of digital records derived from photographic images. To address technical considerations, two distinct photographic images using various techniques were deliberately incorporated into the programme framework.

This arrangement allowed for their simultaneous and consistent operation when alterations were made to the curves. During the subsequent phase, a grey balance field was integrated into all photographic images.

The accurate percentages of this grey balance were established according to the ISO 12647-2 standard (50% Cyan, 40% Magenta, 40% Yellow). This grey balance field configuration facilitates the precise quantification of the half-tone variation across the entire image, obviating the need for part-specific measurements.

Referring to (Fig. 2), for an example of reproduction employing an oil-colour painting within a grey balance field. Similarly, (Fig. 3) illustrates the reproduction of an acrylic-colour painting using the same grey balance field.



Figure 2 Oil-colour painting reproduction with grey balance field



Figure 3 Acrylic-colour painting reproduction with grey balance field

Within this spatial framework, tonal adjustments were made within the Generic CMYK profile using the built-in tools available in the property's settings, from the starting point value of 50%.

Halftone images underwent alterations by incrementing and decrementing their values by $\pm 2\%$, $\pm 4\%$, and $\pm 6\%$.

For specific tones, adjustments were consistently applied in increments of three defined percentages: 52%, 54%, and 56%. This modulation procedure was mirrored across the Cyan, Yellow, Magenta, +CMYK - Process, and -CMYK - Process channels. For the -CMYK channel, adjustments are described as relative decrements from the original tone value. Therefore, the values 48%, 46%, and 44% indicate reductions from the original value, respectively.

An enumeration of the initial test samples is provided in (Tab. 1); wherein abbreviated identifiers were used as key markers to signify the tonality and proportion of halftone photographs that were scrutinised within the research.

Table 1 The percentage of halftone image values increment and decrement in the CMYK space.

Variations in the percentage of halftone picture values from the CMYK colour space	The identifiers
Cyan 52%	+2% C
Cyan 54%	+4% C
Cyan 56%	+6% C
Magenta 52%	+2% M
Magenta 54%	+4% M
Magenta 56%	+6% M
Yellow 52%	+2% Y
Yellow 54%	+4% Y
Yellow 56%	+6% Y
CMYK 52% - Process	+2% P
CMYK 54% - Process	+4% P
CMYK 56% - Process	+6% P
CMYK 48% - Process	-2% P
CMYK 46% - Process	-4% P
CMYK 44% - Process	-6% P

This achievement was realised through the application of two distinct methodologies: oil-colour painting and acrylic colour painting. Each methodology was subjected to a comprehensive analysis involving 15 distinct sample variations, all within the context of half-tone colour images.

Additionally, the manipulation of tonality was facilitated through the utilisation of the curve's histogram, affording control over the x-axis.

Due to the relatively minimal tonal disparities and subtle subjective distinctions, a judicious decision was made to exclusively employ the x-axis to effect output adjustments.

The light sources used for the purpose of this research are Osram LED lights with different CCT from 3000 K, 4000 K, and 6500 K as shown in (Tab. 2), the product specification.

Table 2 Technical specifications of Osram LED lights

Product specification	LED LIGHT 3000 K	LED LIGHT 4000 K	LED LIGHT 6500 K
Product datasheet	P MR16 35 36° 4.3 W/ GU5.3	PAR16 50 36° GU10	PAR16 50 36° GU10
Nominal wattage	4.3 W/50 W	4.3 W/50 W	2.6 W/35 W
Nominal voltage	220-240	220-240	220-240
Light colour (designation)	Warm white	Neutral white	Cool Daylight
Colour temperature	3000 K	4000 K	6500 K
Luminous flux	350 lm	350 lm	230 lm
Colour rendering index	$Ra \geq 90$	$Ra \geq 90$	$Ra \geq 90$
Beam angle (Ceiling)	30°	30°	30°

In this graphic technology research, a comprehensive visual analysis of the experimental phase was conducted involving nonspecialist surveyors based on the standard ASTM-D1729 [21]. These participants lacked professional knowledge in the field but engaged in the evaluation of photographic images using simultaneous comparisons with originals. Despite their unfamiliarity with metamerism, the 35-observers surveyor group expressed interest in visual perception, colours, communication, and memory compliance.

Participants, 18 women and 17 men, aged 18-60, were classified by age: 18-25 years (10), 25-45 years (15), and 45-65 years (10). Before the experiment, observers underwent binocular and Ishihara tests to ensure normal vision, with only those passing participating. Strict adherence to standardised circumstances was maintained throughout the graphic technology inspection experiment.

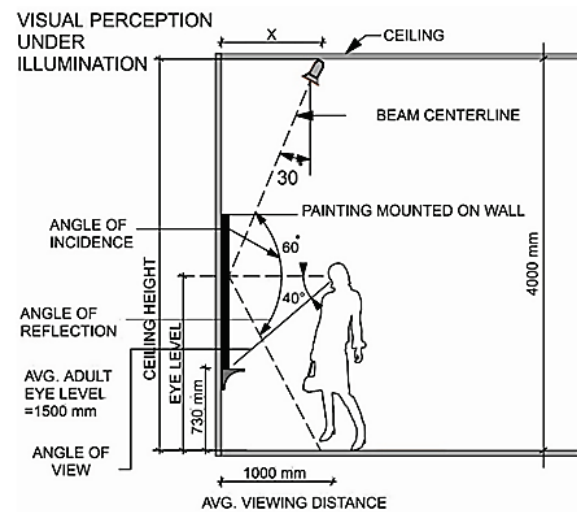


Figure 4 Subjective research

The experiment was conducted in a laboratory atelier with an area of 16 m². The interior walls were painted light grey, and external lighting was eliminated to ensure more accurate results.

This study investigates optimal viewing conditions for wall-mounted paintings under artificial illumination, focusing on geometric relationships between light incidence, reflection angles, and observer position in gallery settings.

The analysis considers a ceiling height of 4000 mm, an average adult eye level of 1500 mm.

The painting is located 730 mm from the floor, and a viewing distance of 1000 mm. The light source, mounted on the ceiling, directs the beam angle at a 30°, minimizing glare and harsh shadows, angle of incidence from the painting 60°. A reflection of 40° angle aligns with the standard observer enhancing visual comfort, finding the best matches of the samples and comparing with original paintings under different light source.

The 60° viewing angle ensures a comprehensive view of the artwork, with the observer positioned 1000 mm from the painting. The standard observers were asked to choose three of the best samples toward original painting under each light

sources. These conditions create an ideal viewing environment, enriching the viewer's experience by maximizing detail visibility and minimizing glare. This framework guides optimal light source positioning for the best visual perception, with potential future research exploring variations in painting sizes and room dimensions (Fig. 4).

3 RESULTS AND DISCUSSIONS

Colour evaluations were performed using original painting comparing with acryl and oil-based reproduced samples under three different LED light sources: 3000 K, 4000 K, and 6500 K. Each observer was asked to choose the three best matches to the original painting under each light source. These visual results were ranked, with the best match receiving 5 points, the second-best receiving 4 points, and the third-best receiving 3 points. Each light source represents a different colour temperature, which can significantly influence visual perception, as shown in (Fig. 5).

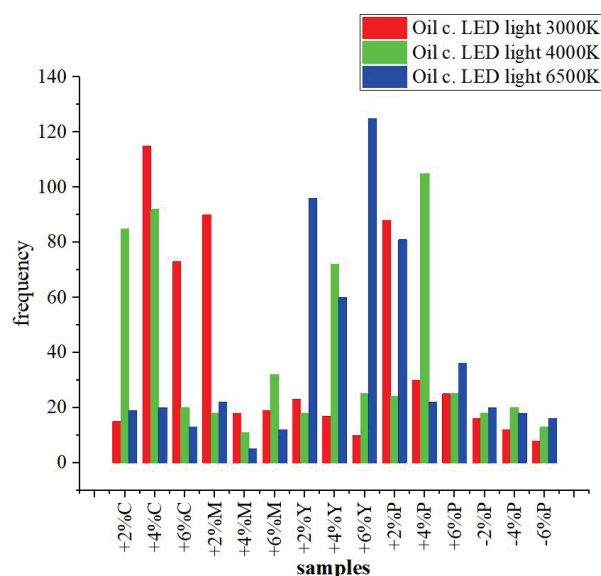


Figure 5 Subjective results of oil colour samples on Osram LED Light 3000 K, 4000K, 6500 K

The x-axis lists the samples, which are identified by specific chromaticity, density variations and the percentage of change. The height of each bar indicates how frequently that sample was chosen as one of the best matches during the evaluation. The y-axis represents the frequency with which each sample was selected during the visual evaluations under the different LED light conditions. The histogram allows for a comparison of how different light sources influence the visual evaluation of color samples.

Higher bars suggest a higher preference for that sample under the specific lighting condition, indicating how well the sample matches the original painting under that light.

The results reveal significant variations in the colour under different LED light sources and sample conditions. Colour perception appears to be influenced by the light

source's colour temperature, with differences observed in both chromaticity and density measurements.

For instance, in the +2% C samples, the LED Light 4000 K source yields notably higher readings than the other sources. Similarly, in the +6% Y samples, the LED Light 6500 K source leads to significantly higher measurements compared to the other sources.

Moreover, the density of the samples also contributes to variations in colour measurements. This is evident from the divergent results between different density levels within the same chromaticity category. For instance, in the +4% Y samples, there is a substantial difference between the Led Light 4000 K measurements for the +4% Y and +6% Y samples, indicating the impact of density on colour appearance. In the context of graphic technology, the presented results show the effects of different lighting conditions LED light at 3000 K, 4000 K, and 6500 K on the visual perception of various acryl samples containing different concentrations of colourants as shown in (Fig. 6).

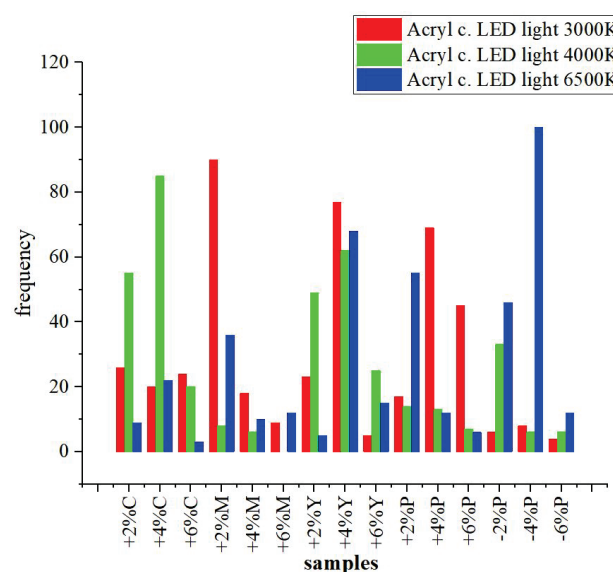


Figure 6 Subjective results of Acryl colour samples on Osram LED Light 3000 K, 4000 K, 6500 K

Varying concentrations of colourants result in significant differences in how the first best samples are perceived under different lighting conditions. This indicates that presence and concentration play a crucial role in the appearance of the colour. The different LED light temperatures (3000 K, 4000 K, and 6500 K) have different effects on the perception of colour.

For instance, higher colour temperatures (e.g., 6500 K) seem to enhance the visibility of certain colourant concentrations, while lower temperatures (e.g., 3000 K) might alter the perception. The interaction between colourants is evident in some cases. For example, at +2% C and +4% C concentrations, the samples appear significantly different at the three light temperatures. This suggests that the interplay between the Cyan colourant and the lighting temperature is intricate.

Negative lightness percentages (-2% P, -4% P, -6% P) demonstrate a pronounced effect of lightness on the

perception of the samples. The results indicate a considerable shift in how samples are perceived, especially under LED light with a colour temperature of 4000 K. Looking at specific colourant combinations, such as +2% M and +4% M, the differences in perception under different lighting conditions are notable. This could imply that lighting colourant's interaction with the lighting plays a significant role in colour appearance. The results are not linear in many cases.

For example, the +4% Y samples appear quite differently under the three lighting conditions.

This non-linear response could be attributed to complex colour interactions and human visual perception. The results of the colour analysis of $L^*a^*b^*$ values of first best match samples with metamerism index (MI) and ΔE (ΔE). Undertaken on both acrylic and oil colour samples, that were illuminated by various light sources with different colour temperatures, provide a comprehensive insight into the nuanced interaction between lighting conditions and colour perception (Tab. 3).

Table 3 The colourimetry measurements between the best sample reproductions of acrylic and oil colour samples.

Sample	LED 3000 K	LED 4000 K	LED 6500 K
1) Acryl s.	+2% M	+2% C	+2% M
2) Oil s.	+4% C	+4% D	+6% Y
1. L^*	53.60	58.46	53.61
1. a^*	-10.50	-7.12	-10.51
1. b^*	-20.45	-12.96	-20.45
2. L^*	56.72	43.13	57.79
2. a^*	-5.92	-5.31	-3.31
2. b^*	-16.85	-10.83	-14.15
ΔL	3.12	15.33	4.18
ΔC	5.99	3.64	9.33
ΔH	3.37	0.50	5.67
ΔE	4.68	15.46	7.40
Δab	5.83	3.15	9.56

Investigation of perceptual differences, as evidenced by the calculated parameters (ΔL), (ΔC), (ΔH), (MI), and Δab , provides a foundation for an in-depth understanding of the impacts of illuminant metamerism across the specified colour samples [22].

Under illumination of LED light with a colour temperature of 3000 K, the acryl colour sample denoted as +2% M and the oil colour sample typified by +4% C emerge as subjects of enquiry. On examination, the acryl colour sample manifests a distinct alteration in its perceptual attributes. Specifically, an increase in luminance (ΔL) by 3.12 units is accompanied by a concomitant elevation in chroma (ΔC) by 5.99 units and hue (ΔH) by 3.37 units.

This perceptual change corresponds to a metamerism index (MI) of 4.68, indicative of a moderate degree of perceptual variation. Similarly to this, the +4% C, at oil colour sample experiences alterations in luminance, chroma, and hue by 15.33, 3.64, and 0.50 units, respectively. This perceptual modulation is further reinforced by an MI of 15.46, which substantiates a notable divergence in colour perception under the specified lighting conditions.

Transitioning to the LED light source with a colour temperature of 4000 K, the acrylic colour sample of +2% C and the oil colour sample of +4% D emerge as test subjects.

Upon illumination, the acryl colour sample registers a reduction in luminance of 15.33 units, accompanied by marginal changes in chroma and hue of 3.64 and 0.50 units, respectively.

This perceptual deviation gives rise to an (MI) of 15.46, underscoring a discernible shift in colour perception. Parallely, the oil-colour sample experiences a decrease in luminance, chroma, and hue by 5.31, 5.31, and 10.38 units, respectively. This perceptual transformation is reflected in an (MI) of 3.15, which is indicative of a relatively lower degree of colour variation compared to the acryl sample.

Shifting the focus to the LED light source with a colour temperature of 6500 K, the acryl colour sample denoted as +2% M and the oil colour sample of +6% Y assume prominence. The acryl colour sample exhibits incremental shifts in luminance, chroma, and hue by 4.18, 9.93, and 5.67 units, respectively, contributing to an (MI) of 7.40.

These changes in perceptual attributes signify a moderate level of colour variation attributed to illuminant metamerism. Similarly, the oil-colour sample experiences a transition in luminance, chroma, and hue by 4.18, 9.93, and 5.67 units, respectively, which results in an (MI) of 9.56. This value suggests a discernible alteration in colour perception under the stipulated lighting conditions, albeit to a slightly higher degree than in the acryl sample.

In summary, the analysis of the presented results underscores the intricate relationship between illuminant metamerism and the distinct colour samples under varying LED light sources. The calculated parameters, (ΔL), (ΔC), (ΔH), (MI), and (Δab), collectively provide an empirical basis for understanding the impact of spectral changes inherent in different lighting conditions on colour perception. These findings illuminate the necessity for judicious lighting selection in the presentation and conservation of artworks, underscoring the significance of accounting for illuminant metamerism to ensure faithful colour representation and perception. Further research and adaptations of these insights in practical settings may facilitate enhanced visual experiences within the realm of art display and appreciation.

The technical memorandum TM-30-18 standard was used developed by Illuminating Engineering Society (IES), employing 99 colour samples and specific evaluation metrics tailored for LED sources. In this investigation, every light source tested demonstrated excellent colour fidelity based on the TM-30 standard. The software BabelColor CT&A utilized the ilPro / ilPro 2 (XRGa) device to measure the nanometers (nm) of light sources.

For example, LED Light 3000 K showed exemplary lighting quality with notable characteristics such as uniformity of radiant power throughout the spectrum (630 - 780 nm), minimal local chroma and hue changes, rendering fidelity (Rf-95), and preservation of the gamut (Rg-104) as it shown (Fig. 7).

However, slight deviations were observed, such as a marginal increase in CCT to 3102 K and a (Duv) value

indicating a minimal change in CCT from the black body (-0.0061). Additionally, while overall colour rendering fidelity was high (Rf 95), specific hue bins (R6, R7, R8, R10) fell slightly below this threshold.

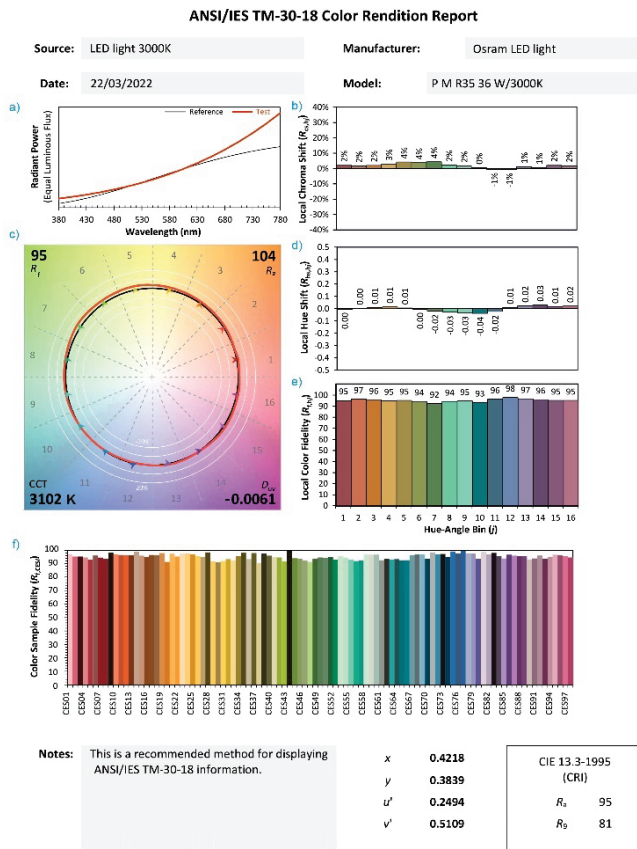


Figure 7 LED light measurement at 3000K using TM-30-18 color rendition.

High quality lighting may be observed using LED Light 4000 K in (Fig. 8). Specifically, (a) the radiant power increases considerably between 630 nm and 680 nm. In (b) and (d), there are minor fluctuations in the local hue and chroma shifts.

The colour vector graphics (CVGs) in (c) show a rendering gamut (Rg-100) and rendering fidelity (Rf-96), with a higher CCT of 4100 K than what is required technically.

Is visible in the Duv measure a small CCT variation from the black body (-0.0015).

Despite a high CRI (Rf 96) in (e), some hue bins (R10, R11, R12) remain slightly less than 95.

The characteristics of artificial light vary among different sources, exhibiting nuanced differences despite advances aimed at daylight emulation. In (Fig. 8), under LED light, 6500 K demonstrates fluctuations in radiant power (a) between 430 nm and 580 nm, accompanied by varying percentages of local hue and chroma shifts in (b, d).

In line with technical criteria, is shown by the colour vector graphics (CVG) in (c). High-quality illumination with rendering fidelity (Rf-93) and rendering gamut (Rg-100).

A change in the CCT value of 0.0050 from the black body is reflected in the Duv measurement.

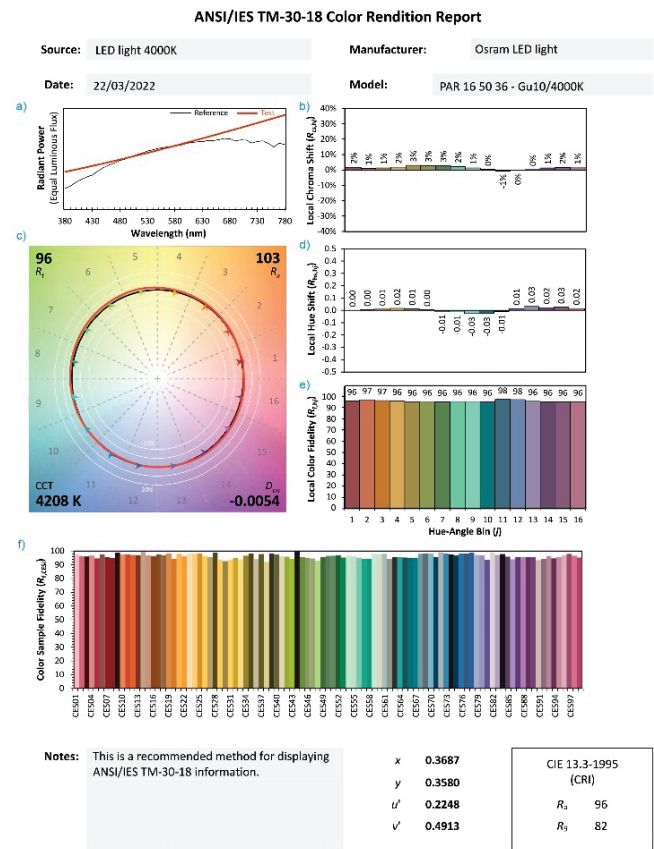


Figure 8 LED light measurement at 4000K using TM-30-18 color rendition.

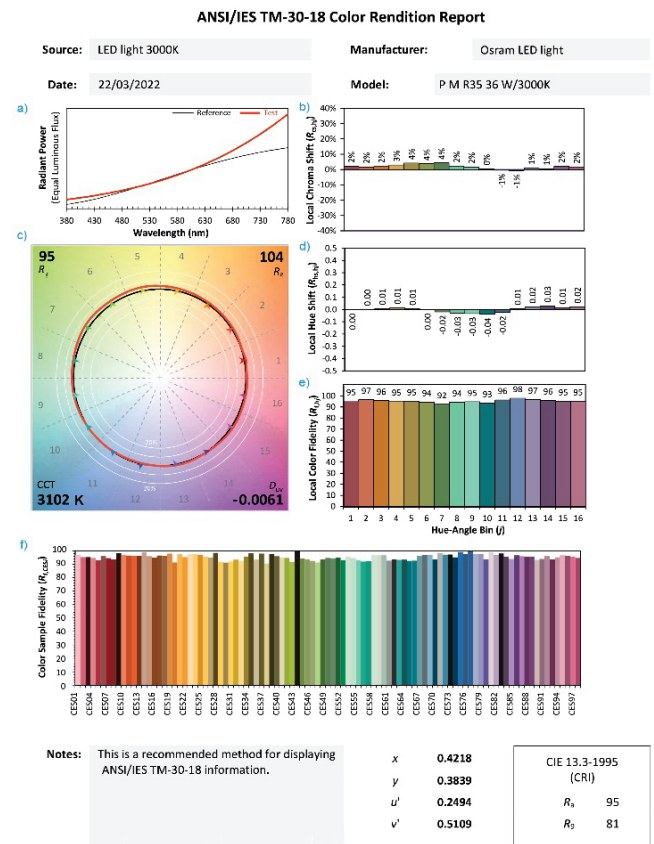


Figure 9 LED light measurement at 6500K using TM-30-18 color rendition.

While some hue bins (R5, R10, R11) fall below Rf 95 in (e), others surpass this threshold, notably R2, R7, and R16.

The data appears to be comprehensive and cover various aspects of colour rendition and illuminant properties. It seems to facilitate analysis of how different hues, chromatic shifts, and illuminant conditions impact colour rendition performance.

Across all colour temperatures, certain wavelengths exhibit notable differences in intensity.

At shorter wavelengths (e.g., 380 nm to 500 nm), the LED lights tend to have higher intensities, with variations depending on the colour temperature.

Longer wavelengths (above 500 nm) show decreasing intensities across the spectrum, again with differences between colour temperatures.

4 CONCLUSIONS

The utilisation of standardised LED lighting has been found to reduce the occurrence of illuminant metamerism, especially when accompanied by a clearly defined spectral power distribution. This finding emphasizes how well standardized LED light works to decrease the impacts of illuminant metamerism.

These results highlight the intricate relationship between colourants, lighting conditions, and human perception. The variations observed underscore the need to carefully consider lighting conditions and colourant concentrations in graphic technology applications to ensure accurate and consistent colour reproduction.

Based on the comparison of TM-30-18 results for LED lights at different colour temperatures (3000 K, 4000 K, and 6500 K), the preferable option depends on the specific requirements of the application and the pigments. Further exploration could delve into the underlying mechanisms of colour perception, aiding in the refinement of colour management strategies in practical applications.

In summary, the comprehensive analysis conducted in this study sheds light on various critical aspects of colour rendition and its response to differing illuminant properties. The findings offer valuable insights into the intricate relationship between illuminant characteristics and colour performance metrics. By identifying and visualising trends in colour fidelity, chroma, and hue shifts across different entries, this research provides a comprehensive understanding of the overall colour rendition performance. Furthermore, examination of how alterations in illuminant properties correspond to shifts in colour performance metrics uncovers the nuanced connections between these factors. Grouping entries based on illuminant properties serves as a robust approach to comparing colour rendition variations under distinct lighting conditions. Delving deeper, the investigation of outliers or extreme shifts in colour fidelity and other metrics offers a deeper comprehension of their connection to specific illuminant properties.

It is concluded that the absorbance of light by oil and acrylic colours depends on various factors such as the

composition of the pigment, the thickness of the paint layer, and the specific properties of the paint medium.

In summary, oil paints generally absorb more light than acrylic paints due to their higher pigment concentration and thicker consistency. Acrylic paints, on the other hand, are generally less absorbent than oil paints. Acrylic paints have a more translucent quality, allowing more amount of light to pass through the paint layer.

Natural daylight or full-spectrum lighting is often preferred for viewing both oil and acrylic paintings and their samples, although LED lights with lower colour temperatures, such as 3000 K and 4000 K with high CRI up to ≥ 90 can it be the most preferable for illuminating acrylic artworks.

These lights generally exhibit higher colour fidelity and a wider colour gamut compared to higher colour temperatures like 6500 K. The balanced spectrum of lower colour temperatures enhances the rendition of various hues, contributing to accurate colour representation and visual clarity.

This study, by untangling the complexities of colour rendition under varying illuminations, contributes to enhancing our knowledge of colour management and reproduction strategies, ultimately benefiting applications in graphic technology and related fields.

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Estimation of the Service Life of Approach Slabs of Road Bridges Based on the Statistical Modeling Method

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Abstract: The article discusses the durability and reliability of a separate element – bridge approach slab, which is justified by the need to maintain a satisfactory technical condition of Ukrainian bridges in general and traffic safety on public roads with limited funding during martial law. The scope of the research is forecasting the residual service life of bridge elements (on the example of approach slabs) using probabilistic methods. Approach slabs are designed to smoothly and safely connect the road approach embankment with the bridge to gradually equalize the elastic modulus of the carriageway from a less rigid asphalt pavement on an elastic base to a more rigid one on a reinforced concrete slab. The main defects in the destruction of approach slabs are: changes in the longitudinal profile of the road due to the collapse and subsidence of the soil under the approach slabs; longitudinal and transverse cracks in the asphalt concrete pavement on the bridge approaches; and potholes that lead to an increase in the additional dynamic load on the bridge deck.

Keywords: approach slab; bridge crossing; failure; motorway; residual life; service life

1 INTRODUCTION

In road construction, technological processes are characterized by the mutual combination and influence of random phenomena caused by the heterogeneity of soils and materials, the variety of operations (crushing, damping, mixing, compaction, etc.), and the impact of various meteorological factors. That is why the values of certain quality indicators often vary in a fairly wide range.

An objective assessment of such indicators is possible based on the application of mathematical statistics. Such methods have long been widely used in engineering to assess product quality. In road construction, the use of these methods is also of great importance.

When performing a statistical assessment of product quality indicators, it is necessary to

- Estimate measurement errors, identify possible errors
- Establish the laws of distribution of indicators
- Determine confidence limits and intervals for the distribution parameters of the quality indicator being assessed
- Compare sets of measurements to identify existing patterns
- Solve problems of tolerances
- Investigate the relationship between quality indicators.

1.1 Problem Statement

Regulatory documents related to the calculation of reinforced concrete bridge elements in Ukraine do not include mechanisms for durability management, do not contain theoretical dependencies that would allow for the calculation of the element's durability, and do not include regulations for quantifying the impact of physical and mechanical characteristics of materials on the element's durability, or quantifying the impact of the environment. As a result, it turns out that the service life of reinforced concrete span structures stated in the bridge design standards is 80-100 years for Ukraine, which is unrealistic and poses a real

threat to the safety of structures, as well as significant economic losses.

The problem of safe operation of bridges in Ukraine has been relevant since independence. Over the last decade of 2014-2024, the problem has become even more acute due to active hostilities and a number of other unfavorable reasons: the maintenance system does not meet modern technical standards and does not have the necessary resources for proper and timely maintenance of structures; the financing system of the road network of Ukraine does not allow the use of modern and innovative technologies for the operation and construction of bridges; Ukraine lacks a clear strategic plan for the improvement, maintenance and operation of road bridges.

The steady deterioration of bridges is the result of their complicated operation in modern conditions and not always sufficiently high quality of construction, as well as the lack of mechanisms for managing the durability of bridges, both at the design, construction and operation stages, currently under the influence of hostilities.

Today, the design life of reinforced concrete bridges is set by regulation, the design dependencies do not include the time variable, and the durability problem mainly depends on the experience and intuition of the designer.

The problem of durability of reinforced concrete elements is the subject of research by a large number of scientists, including Ukrainian ones. In modern conditions, there is a need to combine the scientific basis of research on the degradation of reinforced concrete with design requirements, construction and operation conditions, as well as to obtain a theoretical model for assessing the service life of reinforced concrete bridge elements, which would form the basis for developing a practical mechanism for managing the life cycle of bridges.

In these conditions of limited funding, it is advisable to consider the durability of individual bridge elements. The area where the approaches meet the bridge deck (Fig. 1), where the approach slabs are located, is often in an unsatisfactory technical condition.



Figure 1 Soil spillage under the approach slabs in the area where the bridge meets the approaches due to precipitation - View from the side of the bridge pillar



Figure 2 Soil spillage under the approach slabs in the area where the bridge meets the approaches due to precipitation - View from the road side

The technical condition of the bridge-approach junction directly affects traffic safety, if there is damage in the form of changes in the longitudinal profile of the road, then additional dynamic loads are also transferred to the bridge deck, which significantly reduce the durability of the bridge as a whole [1].

In this case, it is advisable to consider the reliability and durability of the road-bridge junction to ensure acceptable traffic safety and good technical condition of the bridge in conditions of limited funding.

1.2 Publications Overview

The application of the Markov chain method to assess the service life of bridge elements is described in a large number of research papers. The change in bridge states is a random process, so the service life of bridges is related to the probabilities of condition transitions. A bridge service life prediction model using a Markov chain was developed to reflect the stochastic nature of bridge condition and service life. The paper [2] includes a discussion of the Markov chain concept, the development and application of a Markov chain service life prediction model, and a comparison of service life predictions using a statistical approach (degradation curve constructed using regression analysis) and a Markov chain

approach. Markov chain service life prediction has an advantage over the statistical regression approach because it can be used not only to estimate the average service life of a number of bridges but also for each individual bridge. In addition, the Markov chain prediction is based on the current condition and age of the bridges, therefore it is simple and can be updated with new information on the condition assessment and age of the bridge. However, it should be noted that this study was based on a statistical analysis of condition ratings. Condition ratings are subjective judgements that can be biased and therefore can affect the results of service life predictions.

In order to reduce the bias of certain judgements, a mathematical model for assessing the condition of a bridge using fuzzy set theory was developed in [3]. The reliability and accuracy of service life predictions can be significantly increased by applying the bridge condition assessment model in the process of its inspection.

A method of predicting the condition of structures and facilities based on the use of machine learning and artificial intelligence is relevant and promising. In particular, the paper [4] proposes the concept of using machine learning (ML) algorithms for more accurate prediction of bridge pavement wear. The results showed that ensemble ML algorithms were able to predict the condition of the bridge deck significantly more accurately than individual models when “optimal” characteristics were used.

The results of this study will improve researchers' understanding of the most important parameters that can influence the deterioration of a bridge pavement. The study allows maintenance services to better understand the performance and life expectancy of bridges using machine learning. Such knowledge can help bridge owners to be proactive in planning maintenance and repair, developing capital maintenance programs to ensure that funds allocated for bridge maintenance, rehabilitation and repair are properly and efficiently allocated.

In the absence of extensive failure statistics, the paper [5] proposes to use a probabilistic-physical approach to assessing durability. The main parameters of the probabilistic model with DM-distribution of failures are the average rate of change of the determining parameter and the coefficient of variation of the generalized degradation process.

The probabilistic-physical method proposed in the article, based on the study of the dynamics of change in the determining parameter, allows calculating the residual service life of road bridge elements with consideration of the appearance of cracks and predicting the full service life.

The probabilistic-physical method based on the DM-distribution of failures takes into account the random nature of destruction (degradation) processes, which are irreversible, with monotonous realizations and develop at a constant rate. This method provides more adequate calculation results and, in some cases, reduces the operating costs of facilities.

High-quality collection of information on bridge failure parameters, bridge structures and a probabilistic-physical approach to assessing the actual technical condition of the facility provide more accurate calculation results and allow predicting when their maximum permissible value will be reached.

The paper [6] presents a detailed assessment of the remaining service life of a repaired bridge using the Joint Committee on Safety of Structures (JCSS) reliability analysis method based on the structural load-bearing capacity (LBC) of the bridge and the design load. Using finite element analysis (FEA), the bending moment on the control section of the bridge was determined under the most unfavorable loading conditions and the ultimate LBC of the bridge was verified. Subsequently, static and dynamic tests were carried out on the rehabilitated bridge, where the FEA analysis was used to determine the load and capacity for the control section. A time-dependent reliability index was developed for the rehabilitated bridge using probabilistic distributions of the capacity and design load variables and the remaining service life was determined. This study predicts the remaining service life of the bridge based on a large amount of data that is relevant for future maintenance and life cycle management of bridges.

The paper [7] presents a comparative study of two service life prediction models (Life-365 and NCHRP report 558). The service life prediction analysis was performed on corroded bridge piers. To assess the existing condition of the structure and obtain the parameters required for the analysis, a review of the existing bridge documentation, visual inspection and concrete damage survey, field sampling and testing, and laboratory tests were carried out. A good agreement was obtained between the results of the Life-365 and NCHRP report 558 analyses.

The residual service life of bridge structures is traditionally assessed using the AASHTO S-N curves in a deterministic manner. In this approach, the fact that a structural component has already undergone n_{cs} load cycles does not affect the expected fatigue life. However, the data obtained due to the fact that the structure has undergone n_{cs} cycles should theoretically change future estimates of survival and life expectancy based on conditional probability theory. To do this, it is necessary to develop conditional survival (reliability) functions for a specific stress range and fatigue part category. Survival analysis methods and conditional probability theory can provide the necessary computational tools to achieve this.

The paper [8] discusses the theoretical basis for probabilistic fatigue life estimation based on well-established survival analysis methods (and conditional survival models). The implications of incorporating conditional endurance into estimates of expected remaining fatigue life of bridges are discussed for the various AASHTO fatigue design categories. The results indicate that the inclusion of conditional survival has an important impact on the residual fatigue life of bridges.

The approach proposed in [8] based on endurance analysis can calculate the remaining fatigue design life even if n_{cs} exceeds the fatigue limit based on AASHTO S-N curves for a certain stress range and detail category.

In the study [9], the remaining service life expressions for different service conditions were established using the random process analysis method when the reinforcement rebar of a beam bridge began to corrode, the concrete cracked due to reinforcement corrosion and the bridge reached the limit state. The results show that the reinforcement of a concrete girder bridge begins to corrode after the bridge has served 10.07-10.97 years. When the corrosion depth of the

rebar is 0.047 mm, the concrete begins to crack, which consequently leads to an acceleration of the corrosion rate of the reinforcement, and when the corrosion depth is 1.591-1.595 mm, the girder bridge will reach the ultimate state of load-bearing capacity.

The paper [10] proposes a framework for predicting the remaining service life based on the reliability of existing deteriorated structures, separately taking into account random and epistemic uncertainties. A Bayesian probability box (p-box) is developed to model epistemic uncertainty by taking into account the limits of the distribution parameter, while random uncertainty is modelled as an exact distribution function. The method allows to automatically update the results and limits of the remaining service life (RSL) estimation by deploying the data of regular and repeated inspections of bridges, which are usually available in practice. For validation, the method is applied to a real reinforced concrete bridge with a corrosion defect in the steel reinforcement. The results show a significant variance in the RSL prediction given the imprecision of the data, which strongly emphasizes that epistemic uncertainty should be taken into account when making decisions related to existing bridges. In fact, for the given example, accounting for epistemic uncertainty in rebar corrosion can almost double the probability of failure.

The reviewed works mainly consider an integrated approach to assessing the condition of the bridge and its service life, without considering individual elements. Accordingly, the aim of this study is to assess the service life of approach slabs at bridge crossings based on the methods of mathematical statistics and probability theory.

2 RESEARCH METHODOLOGY

To statistically assess quality indicators and perform comparative analysis, it is necessary to know the law of distribution of random variables. In road construction, according to the research of the road quality research laboratories of the National Transport University, the law of normal distribution of variables is preferable.

In addition, the following distributions can be used.

The *Weibull distribution* is most commonly used for reliability indicators, for example, to describe the distribution of failures and service life of road pavements:

$$f(x) = n \cdot \mu^n \cdot x^{n-1} \cdot e^{-\mu^n \cdot x^n}, \quad (1)$$

where n, μ are the parameters of the distribution law; x – argument (usually time).

The *Poisson distribution* is used to analyse random discrete short-term events, for example, the analysis of road and utility vehicles, equipment operation at asphalt and cement plants, etc. The probability of occurrence of the number of events $x = 1, 2, 3, \dots$ per unit of time according to the Poisson law is:

$$P(x) = \frac{m^x}{x!} \cdot e^{-m} = \frac{(\lambda \cdot t)^x}{x!} \cdot e^{-\lambda \cdot t}, \quad (2)$$

where x is the number of events in a given time period t ; λ – density, i.e., the average number of events per unit of time; $(\lambda \cdot t) = m$ – average number of events in time t .

Based on the analysis of physical factors, a hypothesis about the type of distribution is put forward, which is tested according to statistical criteria.

The adequacy of the distribution function, i.e., the assessment of the consistency of the experimental and theoretical distributions, is established by the Fisher's, Pearson's χ^2 , and Kolmogorov's criteria.

Next, we will consider the law of *normal distribution*, as the most common in road construction. After obtaining the statistical series, the average values of the indicator \bar{x} , the range R , the standard deviation σ and the coefficient of variation c_v are calculated. The probability density of the normal distribution law is expressed by the following relationship:

$$f(x) = \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot e^{-\frac{1}{2} \left(\frac{x - \bar{x}}{\sigma} \right)^2}. \quad (3)$$

The empirical density function of the distribution is represented graphically by a histogram of frequencies – relative frequencies – a step graph consisting of rectangles with bases of partial variation intervals of length $h = x_k - x_{k-1}$ and heights n_k/h . Here k is the number of intervals of the variation series. For series close to the normal distribution, the approximate value of the number of intervals (an integer) is determined by the Stagers' formula:

$$k = 1 + 3,322 \cdot \lg(N), \quad (4)$$

where N is the size of the variation series (sample size).

To establish adequacy, during the construction of an experimental graph of the normal distribution, centering ($\bar{x} = 0$) and normalization ($\sigma = 1$) are performed. As a result, a tabular function is obtained, and the transition from it to the specified function is performed by decentering and deformatizing of the tabular function.

If it is needed to plot the integral function of a normal distribution law, the following expression is used:

$$F(x) = \int_{-\infty}^x \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot e^{-\frac{1}{2} \left(\frac{x - \bar{x}}{\sigma} \right)^2}. \quad (5)$$

If this function is centered by $(x - \bar{x})/\sigma = t$, then the centered and normalized normal distribution function will have the form:

$$F(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^t e^{-0,5t^2} dt. \quad (6)$$

where $t = (x - \bar{x})/\sigma$.

Here is a methodology for establishing the adequacy of the normal distribution law. The task is formulated as

follows: to establish the law to which the phenomenon under study is subject, and to test the plausibility of the statistical hypothesis at the accepted significance level α .

1) To solve this problem, the sample size N is divided into k intervals. For each interval, the lower M_l and upper M_u margins of values are set. One of the intervals is taken as a false zero M_0 .

The lower M_{l0} and upper M_{u0} margins of the intervals relative to false zero are calculated:

$$M_{l0} = M_l - M_0, \quad (7)$$

$$M_{u0} = M_u - M_0. \quad (8)$$

The midpoints of the intervals are determined:

$$x_{mi} = 0,5(M_{l0} + M_{u0}). \quad (9)$$

2) Next, the experimental (trial) frequencies of falling into each interval are calculated:

$$P_{ei} = \frac{m_{ei}}{N}, \quad (10)$$

where m_{ei} are the experimental frequencies (the number of times an event occurs).

Then the accumulated frequencies ΣP_{ei} are summed over the intervals.

3) The function under study is centered and normalized. To do this,

$$t_i = \frac{x_{mi} - \bar{x}}{\sigma}, \quad (11)$$

is calculated and tabulated probability densities $f(t)$ at $\sigma = 1$ are established:

$$f(t_i) = \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot e^{-\frac{1}{2}t_i^2} = \frac{1}{\sqrt{2\pi}} \cdot e^{-\frac{1}{2}t_i^2}. \quad (12)$$

4) Then the theoretical probabilities of falling into the intervals are calculated:

$$P_{mi} = \frac{f(t_i) \cdot \Delta x}{\sigma}, \quad (13)$$

where Δx is the length of the interval.

Theoretical frequencies are calculated next:

$$m_{mi} = P_{mi} \cdot N. \quad (14)$$

5) After that, the adequacy of the theoretical curve is determined. Adequacy is confirmed if

$$P(\chi^2, \nu) > \alpha, \quad (15)$$

where χ^2 is Pearson's criterion of coherence:

$$\chi^2 = \sum_{i=1}^n \frac{(m_{ei} - m_{mi})^2}{m_{mi}}, \quad (16)$$

where ν is the number of degrees of freedom:

$$\nu = k - S, \quad (17)$$

where k is the number of intervals (groups) of a large sample or the number of measurements in one interval in the analysis of a single-series experiment;

S is the number of relationships used, i.e., the number of available dependencies (parameters).

In Eq. (15), $\alpha = 0,01$ is usually assumed.

3 METHOD VERIFICATION

To verify the applicability of the normal distribution law to the failure of approach slabs at bridge crossings and to check the adequacy of the above methodology, a sample of 200 surveyed prematurely failed reinforced concrete approach slabs was used. For this purpose, it is necessary to find the law to which this phenomenon – slab failure – is subject, to establish its compliance with the law of normal distribution, as well as to determine the average service life of slabs (time between failures) and to build a residual life curve depending on the service life (the accepted normative service life of slabs before overhaul is $T_n = 20$ years).

Let's solve the problem according to the above methodology. The actual service life of the slabs T_a is taken as a random variable in the sample, with a range of R from 6 to 24 years.

1) The sample size is divided into k intervals according to Eq. (4)

$$k = 1 + 3,322 \cdot \lg(N) = 1 + 3,322 \cdot \lg(200) \approx 9, \quad (18)$$

in $\Delta x = 2$ years. We set the lower M_l and upper M_u margins of the intervals. For a false zero with a maximum of the experimental frequency, we take

$$M_0 = 0,5 \cdot (6 + 24) = 15 \text{ years}, \quad (19)$$

and calculate the intervals relative to the false zero using Eq. (7), (8) (data from Tab. 1). We establish the midpoints of the intervals x_{mi} according to Eq. (9) and the experimental frequencies m_{ei} (the number of times the actual service life of the approach slabs falls into each interval) (Tab. 1).

2) We calculate the experimental frequencies by intervals according to Eq. (10) (data from Tab. 1):

$$P_{e1} = 4/200 = 0,02, \quad (20)$$

$$P_{e2} = 6/200 = 0,03, \text{ etc.} \quad (21)$$

Then we find the sum ΣP_{ei} .

Fig. 1 shows a histogram of the experimental frequencies of failure of approach slabs, on the basis of which we make a preliminary conclusion that it follows the law of normal distribution. To test this hypothesis, it is necessary to build a theoretical curve and determine the Pearson's χ^2 criterion.

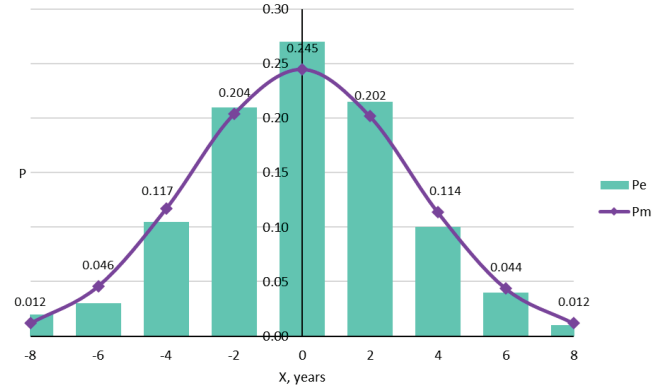


Figure 3 Experimental frequencies (P_e) and theoretical equalization curve (P_m) of the normal distribution law of the service life of approach slabs

3) To build the tabular function of the normal distribution law, we center the real function. To do this, we first calculate the mathematical expectation $m(x)$ and the standard deviation σ .

We calculate the experimental (trial) mathematical expectation of the deviation of T_a from false zero:

$$m(x) = \sum_x (x \cdot P(x)) = \sum_x (x_{mi} \cdot P_{ei}). \quad (22)$$

This implies that the center of the experimental distribution is shifted towards the bigger side from the assumed false zero by only 0,03 years. The average time between failures of approach slabs (time between failures) is $15 - 0,03 \approx 15$ years instead of the standard 20 years. Thus, there are objective reasons (insufficient quality of design, construction, and maintenance of the slabs) that caused premature wear of the approach slabs.

Next, the statistical variance is calculated as follows:

$$D = \sum_{i=1}^q (x_{mi} - m(x))^2 \cdot P_{ei}. \quad (23)$$

The unbiased estimate of the standard deviation:

$$\sigma = \sqrt{D \cdot \frac{k}{(k-1)}}. \quad (24)$$

In accordance with Eq. (3), the experimental distribution is expressed in terms of the law of normal distribution.

Next, the function is centered and normalized. Based on the data, tabular probability densities $f(t_i)$ (data from Tab. 1) are established according to $f(t_i)$ ($t_1 = -2,448$; $t_2 = -1,834$).

4) Next, we calculate the theoretical frequencies Eq. (13), (14). Fig. 1 shows a leveled theoretical curve (P_m)

of the normal distribution law of the service life of approach slabs.

5) To check the adequacy of the distribution, we calculate the χ^2 criterion using Eq. (16).

Using Eq. (17), we determine the number of degrees of freedom. Next, we determine the p -value (probability value, or asymptotic significance) of the distribution:

$$p = 1 - \text{CDF}(\chi^2, \nu), \quad (25)$$

where CDF is the cumulative distribution function of the probabilities of a normal distribution; it is determined by special tables, ready-made functions of software systems, or the following expression:

$$\text{CDF}_n(x, \nu) = \int_0^x \frac{t^{\frac{\nu-2}{2}} \cdot e^{-\frac{t}{2}}}{2^{\frac{\nu}{2}} \cdot \Gamma\left(\frac{\nu}{2}\right)} dt, \quad (26)$$

where Γ is the gamma function.

Since, according to condition Eq. (15), $0,618 > 0,010$, the adequacy is established, i.e., the experimental histogram follows the law of normal distribution.

Table 1 Statistical parameters of the intervals of the normal distribution of the service life of approach slabs

	Interval								
	1	2	3	4	5	6	7	8	9
M_l	6	8	10	12	14	16	18	20	22
M_u	8	10	12	14	16	18	20	22	24
M_{l0}	-9	-7	-5	-3	-1	1	3	5	7
M_{u0}	-7	-5	-3	-1	1	3	5	7	9
x_{mi}	-8	-6	-4	-2	0	2	4	6	8
m_{ei}	4	6	21	42	54	43	20	8	2
P_{ei}	0,020	0,030	0,105	0,210	0,270	0,215	0,100	0,040	0,010
ΣP_{ei}	0,020	0,050	0,155	0,365	0,635	0,850	0,950	0,990	1,000
t_i	-2,448	-1,834	-1,220	-0,605	0,009	0,624	1,238	1,852	2,467
$f(t_i)$	0,020	0,074	0,190	0,332	0,399	0,328	0,185	0,072	0,019
P_{mi}	0,012	0,046	0,117	0,204	0,245	0,202	0,114	0,044	0,012
m_{mi}	2	9	23	41	49	40	23	9	2
x_{exti}	-9	-7	-5	-3	1	3	5	7	9
t'_i	-2,756	-2,141	-1,527	-0,912	0,316	0,931	1,545	2,160	2,774
ΣP_{fail}	0,003	0,016	0,063	0,181	0,624	0,824	0,939	0,985	0,997
ΣP_{res}	0,997	0,984	0,937	0,819	0,376	0,176	0,061	0,015	0,003

6) Continuing the analysis of the experimental data, we build an integral function. To calculate the function of failure probabilities, we accept the extreme boundaries in the intervals x_{exti} (Tab. 1). The results of centering and normalizing of the deviation $t'_i = [x_{exti} - m(x)]/\sigma$ are also shown in Tab. 1. Based on these data and according to Eq. (12), the points of the integral function or probabilities of slabs failure P_{fail} are obtained.

Tab. 1 also shows the probability function of operative (working) condition of the approach slabs (curve of residual life):

$$P_{res} = 1 - P_{fail}. \quad (27)$$

The functions P_{fail} and P_{res} are shown in Fig. 3. As can be seen from the graph, 100% of the residual life corresponds to an actual service life of 6 years, 75% corresponds to 14,4 years, and 50% – to 15,4 years. For the law of normal distribution, the service life of the approach slabs equal to the mathematical expectation is characterized by equal values of the probability of failure and operative (working) condition.

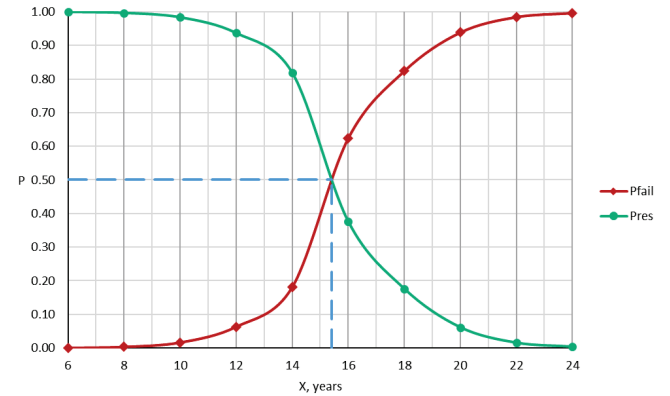


Figure 4 Functions of service life of approach slabs: P_{fail} – failures; P_{res} – residual life (working condition)

7) Next, we calculate the confidence interval for the probability $P_c = 95\%$:

$$CI = \bar{x} \pm \delta = \bar{x} \pm t_s \frac{\sigma}{\sqrt{k}}, \quad (28)$$

where t_s is the Student's criterion; it is used for small samples or a small number of intervals (usually up to 30 items) and is determined according to a special table depending on the accepted significance level (or confidence level) and the number of degrees of freedom calculated by the Student's density function, i.e.:

$$p(x) = \int_{-\infty}^x \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\sqrt{\pi \cdot \nu} \cdot \Gamma\left(\frac{\nu}{2}\right)} \left(1 + \frac{t^2}{\nu}\right)^{-\frac{\nu+1}{2}} dt. \quad (29)$$

For a confidence probability $P_c = 95\%$ (which corresponds to a significance level of $\alpha_2 = 0,05$ for a two-sided test or $\alpha_1 = 0,025$ for a one-sided test) and the number of degrees of freedom $\nu = 6$, the Student's criterion t_s is 2,447.

Thus:

$$CI = 15,4 \pm 2,45 \frac{3,26}{\sqrt{9}} = 15,4 \pm 2,7 \text{ years}. \quad (30)$$

This means that with a confidence level of 95%, it can be stated that the service life of precast approach slabs on bridges will be at least $15,4 - 2,7 = 12,7$ years and no more than $15,4 + 2,7 = 18,1$ years. As can be seen, for both values, the actual probable service life of the slabs is lower than the normative service life ($12,7 < 20$ years; $18,1 < 20$ years).

Let us determine the failure rate of approach slabs in classical formulations [11]:

$$\lambda(t) = \frac{f(t)}{1 - F(t)}, \quad (31)$$

where $f(t)$ is the density of the time distribution; $F(t)$ is an integral function of time on the interval $[0, t]$.

4 DISCUSSION

During the inspection of bridges in Ukraine, usually only the above-ground part of the bridge structures is inspected by means of instruments. Detection of defects and damage to underground elements is possible only in case of significant destruction (Fig. 1) or by indirect signs such as: soil subsidence in the areas of approach slabs; transverse and longitudinal cracks in the asphalt pavement above the approach slabs; change of the design position of the backwall of the bridge; destruction of the embankment of the bridge abutment cone, etc.

The current model of expert evaluation of bridges in Ukraine considers the bridge as a whole as a summation of the reliability of all groups of elements with an emphasis on load-bearing structures: span structure, piers, and foundations. This model does not allow to rank bridges by the need to repair minor bridge elements with limited funding when there is an urgent need to ensure traffic safety for users of public roads with acceptable reliability of the structure.

The proposed study estimates the residual service life of precast approach slabs. The predicted residual life and service life of monolithic approach slabs are expected to be longer than that of precast slabs. This is due to the technological efficiency of construction, i.e., the absence of longitudinal seams which are present in precast slabs. This is confirmed by the study proposed in the paper [12], where the statistical service life of monolithic bridges is 23% longer than precast bridges. However, in Ukraine, precast approach slabs are preferred as a cheaper and simpler technological solution.

Obviously, there is a need in Ukraine to develop a model for expert evaluation of bridges that will take into account the need and phasing of repairs of minor elements, such as approach slabs, with limited funding in the medium term.

When applying such an expert model of technical condition assessment to predict the service life and residual life of approach slabs, it becomes necessary to collect additional statistical input data, namely: the height of the approach embankment; width, length, thickness and number of approach slabs; the method of their connection; the presence and type of waterproofing of approach slabs; the presence of drainage structures; the type of soil of embankment; the average annual rainfall in the region, etc. All these statistical data can be used as initial parameters for further improvement of the service life prediction model based on mathematical statistics and probability theory.

5 CONCLUSIONS

1) The proposed study proves that the statistical sampling of the service life of approach slabs obeys the normal distribution law.

2) The obtained failure rate of approach slabs will be used in further studies to develop an expert model for assessing the technical condition of bridges, as well as to obtain an indicator of the need for maintenance measures for planning the life cycle cost of Ukrainian bridges.

3) An experimental study showed an average service life of transition approach of 15,4 years, while the average service life of bridges in Ukraine is 50 years [12]. In this case, during the life cycle of operation, the approach slabs on the approaches to the bridge require at least three repairs. This should be taken into account when developing an operation project and a financial plan for bridge maintenance by the balance holding organizations.

4) Probabilistic approaches to forecasting the residual service life of bridge elements are the most convenient in the absence of a centralized maintenance system and can be used in conditions of limited funding, while ensuring acceptable accuracy of the results with a confidence level of 95% – 2,7 years (for approach slabs).

5) The bridge as a whole can be considered as a group of elements. Approach slabs are an element of a bridge in the area where the road meets the bank pier. In case of defects and destruction of the approach slabs, the bridge as a whole continues to perform the functions laid down in the design, but the safety of traffic on the road, durability and reliability of the entire structure are significantly reduced.

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The Investigation on the Application of Digital Technologies for Logistics Business Competitiveness

Aurelija Burinskiene*, Diana Daskevici

Abstract: The logistics sector's performance is integral to nations' economic and industrial progress. The advent of digital technologies marks a monumental historical shift, impacting worldwide transformations in structural organization, business strategies, economic principles, and regulatory frameworks. The landscape of logistics management provides a fertile ground for integrating these digital advancements, as exemplified by the dynamic emergence of logistics 4.0. This study evaluates how implementing digital technology profoundly influences logistics management's competitiveness in the business context. The study investigates applying digital technologies within the logistics sector using multi-stage methodology, which integrated different methods: the formation of hierarchy of quantitative methods and the application of statistical data analysis methods. Statistical data analysis helps to collect knowledge about logistics business, the application of digital technologies and its performance within European Union (EU) countries. The application of hierarchy of quantitative methods allows to compare the applications of various technologies with digital technologies and the competitiveness of various sectors with logistics sector competitiveness. These findings accentuate the intricate interplay between technological advancement and competitiveness within the logistics sector. The study contributes to a deeper comprehension of how digital technologies reshape competitive dynamics and lays the foundation for refined logistics practices in an increasingly digital-driven world.

Keywords: applications; digital technologies; hierarchy of methods; logistics management

1 INTRODUCTION

The study explores how embracing digital technologies opens up added value business prospects for logistics companies, offering opportunities to optimize operations, enhance supply chain visibility, and boost overall efficiency. Propelled by emerging technology trends, a growing worldwide competitive environment, and rapidly evolving customer expectations, businesses are driven to look at how top management could leverage impending digitalization to enhance the management of their supply chain operations.

Contemporary Industrial Revolution, referred to as logistics 4.0, encapsulates the digital metamorphosis within the production and operations domain, driven by an array of ground-breaking digital technologies. The logistics 4.0 concept is described by progressive ideas, innovative assistant systematical solutions, and not a centralized decision-making approach. These inherent digital technologies greatly enhance the ability to respond to fluctuating demand cases and improve flexible needs management [1].

Specifically, digital technologies assume an active and pivotal function in providing vital logistics and transportation services. An example could be geographical information systems (GIS) or big data analytical approaches that have risen to prominence in harmonizing for managing product demand and supply. Among the business benefits of digital technologies are enhanced operational efficiency, cost reduction, fortified decision formulation, and stakeholder interaction management [2].

The technologies enable the separation of information streams from connected physical shipment flows, allowing for smooth digital data exchange among involved parties [3]. This encourages collaboration and forms the foundation for developing extensive logistics networks. Logistics service provider stands to have value from innovative solutions that could broaden the spectrum and the quality of ancillary service extended to trucks, enterprises, and individuals [4].

Indeed, integrating technologies and automated system approaches fosters the productivity increase, enhancement, amelioration of labor conditions, and refinement of strategic approaches among participants.

Prominent scholarly articles [2] concur that the most auspicious digital technologies for Munich Security Conferences (MSC) encompass advanced printing technologies, Human Machine Interface (HMI), augmented reality, Automated System approaches, Big data analytical applications, Blockchain Technologies, Cloud Computing solutions, Internet-of-Things, Location Detection technology, Mobile devices, Multi-level Customer Interactions, Customer Profiling, and Smart Sensor applications.

Tangible devices, like mobile phones, machinery, and intelligent sensors, remain constantly interconnected with humans and their operational surroundings, resulting in the augmentation of operational performance for logistics firms [5]. Enabling digital technologies has brought transformative changes to various operational aspects of logistics activities.

These digital advancements enhance operational efficiency, customer satisfaction, and competitiveness within logistics centers, fostering agile and responsive supply chains.

The paper consists of five chapters. The paper starts with introduction. The second chapter investigates the applications of digital technologies. The third chapter provides the an in-depth exploration of the application of digital technologies in logistics. The fourth chapter presents methodology, which is later on is applied in following sub-chapters. First su-chapter presents materials and methods used for researching the studies on technologies and business competitiveness. The second sub-chapter is dedicated to the statistical analysis of logistics and technology trends and findings. And finally, the fifth concluding remarks chapter is provided and further research directions are provided.

2 THE APPLICATION OF DIGITAL TECHNOLOGIES: LITERATURE REVIEW

Technologies like the Internet, artificial intelligence, and automation can penetrate different industries and sectors, fundamentally altering how businesses operate and people interact. The principal objective of technologies to elevate a company's effectiveness, with a particular emphasis on bolstering or maintaining competitive advantage. It impacts the ability to broaden markets, enhance product quality, and shift the demand curve for a company's product. It has the potential to reshape a company's cost curve. Another aspect pertains to the favorable transformation in a company's capacity to invest, nurturing the development of new knowledge and expertise.

Given the swift progression of digital technologies such as ubiquitous computing, digital convergence, Web 2.0, service-oriented architecture, cloud computing, and the open-source revolution, a crucial facet of enterprise activity lies in the competence and ability to harness digital technologies. The emergence of digital technology marks a

significant paradigm shift, reshaping both organizations and markets. Digital technologies can be categorized as "general-purpose technologies" [6]. Digital technology is closely tied to societal transformation driven by technological advancements, digital technologies are reshaping various aspects of our lives. Digital technologies influence how we communicate, access information, conduct trade, and navigate the world. This comprehensive influence recalls the transformative potential of general-purpose technologies. They can potentially restructure economies, redefine jobs, and even affect our daily concerns. This transformative potential aligns them with general-purpose technologies, historically responsible for profound changes in our ways of living and working.

The Swiss International Institute for Management Development characterizes digital transformation as a profound organizational change propelled by contemporary technologies to amplify business efficiency. This transformation entails utilizing various phenomena from modern information technology, including social media, mobile devices, the Internet of Things, cloud computing, and real-time analytical systems [7].

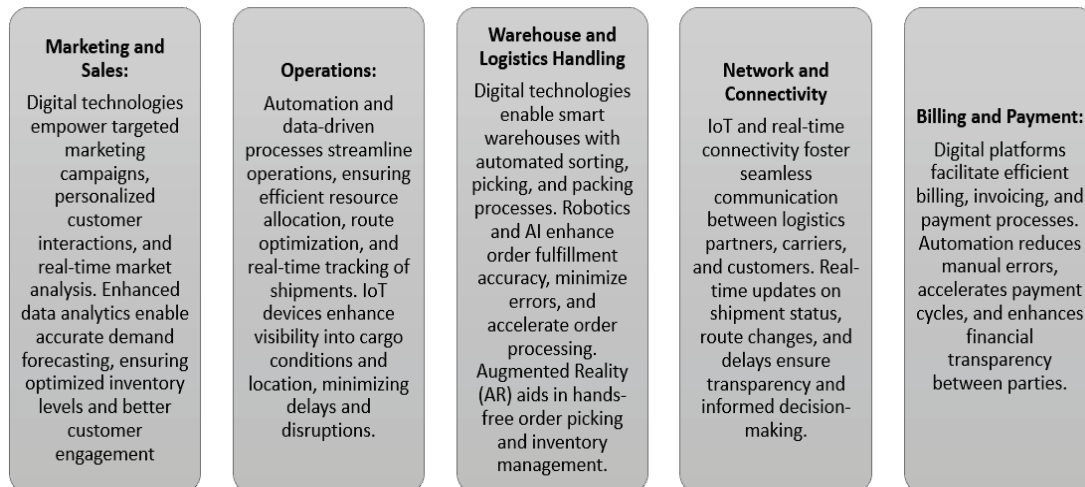


Figure 1 Overview of the primary applications of enabling digital technologies

Digital technologies, enabling the generation of new digitized formats. It goes beyond the simple technical process of converting analog information into a digital format (referred to as "digitization"). Instead, it entails reconfiguring socio-technical systems previously mediated by non-digital artifacts or relationships into systems mediated by digitized artifacts and relationships. This goes beyond mere technical encoding and includes the rearrangement of fresh socio-technical frameworks facilitated by digitized artifacts and alterations to the artifacts themselves. Alternative definitions of digital technology depict it as a technological metamorphosis within a product. We are characterizing digital technology as a result which influence the development of new products and services. With these perspectives in mind, it's evident that digital business is a catalyst for digital technologies, viewed from the perspective of digital technology utilization. Research conducted by the World Economic Forum, involving 14 business sectors, highlights that a higher return on investment in these technologies emerges only when various technologies are

thoughtfully integrated [8]. The convergence and synergy of technologies drive the emergence of digital business. A clear causative link suggests that digital technologies are the wellspring within companies, shaping the perception of digital business across diverse sectors. Companies are increasingly reliant on the digitization of the economy. As such, companies must navigate a more dynamically changing external and internal landscape, acknowledging that the company and its entire environment is becoming digitally oriented, ushering in new requirements for business operations [4]. The utilization of contemporary digital technologies, which involves establishing value chains through an innovative management model, shapes the perspective of digital technologies within management methodologies and tools, which foster higher competitive advantage. This aligns with the statement indicating a generational shift in management that requires the integration of digital technologies. To conclude, Fig. 1 provides a concise summary of the key uses of enabling digital technologies across various operational areas related to

logistics. These areas encompass marketing and pre-sales procedures, operations, storage and distribution management, networks and connectivities, invoicing, and paying.

The use of digital technologies in marketing and sales transforms logistics companies to reach a wider audience through online platforms and targeted digital marketing campaigns. Digital technologies make it easy to create easy-to-use websites and mobile apps that provide customers with intuitive and seamless interfaces to track packages, receive offers, and access information, improving the overall customer experience. Digital platforms allow logistics companies to expand their reach and enter new markets, providing a competitive advantage in a globalized and digitally connected business environment. Digital technologies simplify sales processes and help logistics companies manage productivity, track interactions, and analyze data to make informed decisions, increasing sales efficiency. Marketing logistics companies use social media tools to engage audiences, share industry insights, and answer customer questions in real-time, increasing brand visibility and customer satisfaction.

Digital technologies have changed the logistics industry by automating operations and data-driven processes. Digital technologies are changing the way the logistics industry operates by real-time monitoring, automating, optimizing logistics processes, and improving overall operational efficiency. Not only does this automation improve work efficiency, but it also provides real-time data analytics, ensuring informed decision-making and better operations. Digital solutions and data analytics tools enable logistics companies to analyze large amounts of data, gain valuable performance insights that can help you make strategic decisions, and help you continuously improve overall performance. The deployment of Internet of Things (IoT) devices, such as GPS trackers and sensors, will allow logistics companies to track the location, status, and status of shipments, providing greater visibility and control over logistics operations.

Digital technologies have changed the warehouse and logistics handling in the logistics business. Digital warehouse management systems (WMS) simplify inventory management, order fulfillment, and distribution, reduce errors, and improve overall warehouse and processing process efficiency. Inventory management and tracking accuracy have significantly improved the implementation of automated systems, such as barcode scanners and RFID tags. The integration of artificial intelligence and machine learning algorithms makes it possible to actively monitor, predict need, and make advanced decisions, further simplifying warehouse and logistics operations. Real-time tracking systems provide real-time information on inventory levels, shipment status, and shipment updates. Artificial intelligence and machine learning algorithms improve the optimization and planning of transport routes, enabling logistics companies to reduce costs, reduce fuel consumption, and reduce delivery times. Digital technologies will also help with preventative maintenance in the logistics sector, helping companies monitor the status of their vehicles and equipment, prevent breakdowns, and ensure a reliable and efficient fleet of vehicles.

Digital technologies have played an important role in improving the connectivity of manufacturers, suppliers, and customers. The connection of the logistics network has been improved, allowing companies to operate more efficiently. Cloud platforms enable seamless cooperation and data sharing between different stakeholders, including suppliers, manufacturers, and distributors, ensuring better coordination and efficiency. Digital technologies have facilitated connectivity between manufacturers, suppliers and customers, ensuring more efficient and personalized interaction throughout the value chain. They provide real-time information on inventory levels, production schedules, and delivery status, ensuring effective coordination between manufacturers and suppliers.

Digital technologies have fundamentally changed the billing and payment processes in the logistics sector and increased competitiveness. The introduction of online payment gateways and digital wallets allows for faster and more secure transactions, reducing reliance on traditional paper invoices and manual payment processing. Automated clearing systems simplify the clearing process, reduce the number of errors and delays, and improve liquidity management. Digital technologies can track and control payments in real-time, ensuring transparency and reducing the risk of fraud. Digital technologies make it possible to integrate billing and payment data with analytical tools, provide valuable insights, provide personalized payment and payment options, and thus increase customer loyalty through satisfaction, which is essential for the competitiveness of logistics companies.

Digital technologies facilitate enhanced accessibility and analysis of information, thereby promoting mobility. These tools govern logistics activities, which prompts a pertinent exploration of digital technologies in logistics management. This interaction gives rise to digital supply chains and hybrid digital manufacturing systems, both essential and traditional components of the logistics chain.

Research often scrutinizes innovative processes from a technological or a managerial mindset perspective but seldom considers both simultaneously. It is contended that technology and thought processes should be jointly analyzed since they fundamentally share common elements, albeit at distinct interaction levels.

The integration of digital technologies into logistics has led to the emergence of what is known as intelligent logistics or smart logistics. The term "intelligent" is used to describe contemporary technological advancements and further elaborates that anything streamlining human efforts and automating tasks can be characterized as "smart" [5].

In the industry, it is indicated that the transport and logistics (T&L) sector is at the forefront of embracing novel digital technologies, surpassing other industries with a participation rate of 90%, compared to 83% in other sectors. The expansion of the transportation and logistics sector is spurred by improved transport infrastructure and streamlined business processes. Improved infrastructure, in return, has a positive impact on logistics processes that are flexible and scalable. The integration and utilization of digital technologies within companies while concurrently prompting changes in logistics management aimed at securing or gaining a competitive advantage.

3 REVIEW OF THE APPLICATION OF DIGITAL TECHNOLOGIES IN LOGISTICS: AN IN-DEPTH EXPLORATION

The integration of digital technology into the logistics sector, often referred to as "intelligent logistics" or "smart logistics," has brought about a transformative revolution in the transportation, storage, and management of goods throughout the supply chain. This digital integration has significantly enhanced efficiency, transparency, and optimization across various aspects of logistics operations [4].

Here are some key areas presented in Fig. 2 where digital technology is being implemented in the logistics industry.

Regulatory compliance and documentation (i.e. compliance with laws and written documents) plays an important role in improving the competitiveness of logistics companies and ensuring compliance with legal and industry standards. Compliance with regulatory requirements helps build trust and reliability from customers, partners, and institutions, contributing to the logistics company's reputation in the market. Compliance certification can give

logistics companies a competitive advantage when it comes to offering contracts, as customers often prefer service providers with proven compliance expertise. Compliance with transportation, customs, or security regulations helps avoid supply chain disruptions and increases reliability and continuity of services. Active compliance management and reliable documentation procedures not only reduce risks, but also contribute to profitability by avoiding fines, penalties, and litigation costs, thereby supporting the overall competitiveness of logistics operations. Accurate and well-maintained records ensure smooth and efficient work, reduce the risk of errors, delays, and any legal issues that may negatively affect the company's competitiveness. Digital documentation replaces paper-based processes with electronic formats and platforms, improving efficiency, reducing waste, enhancing collaboration, and expediting document processing. Electronic documentation and digital signatures streamline regulatory compliance processes. Electronic Data Interchange (EDI) streamlines communication through standardized digital formats, facilitating seamless communication between systems and organizations.

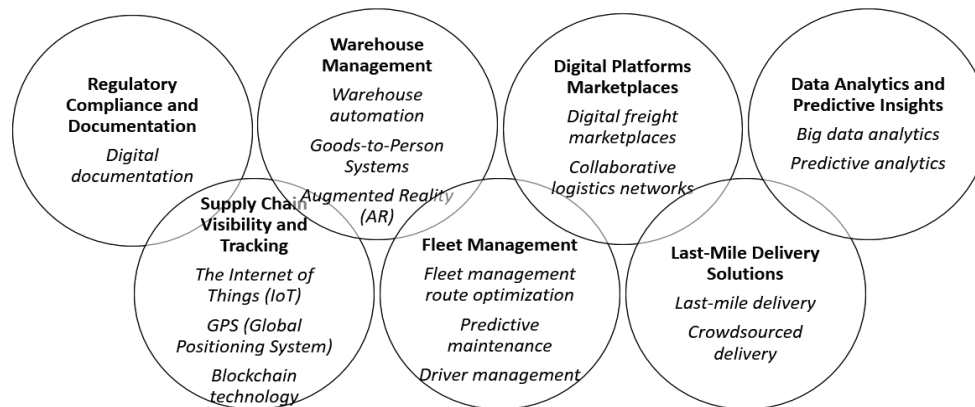


Figure 2 Selected solutions resulting from the implementation of digital technology in the area of logistics

Supply chain visibility and tracking is key to increasing the competitiveness of logistics companies by providing real-time information on the movement and status of goods in the supply chain. Better visibility enables better decision-making, allowing logistics managers to actively address potential issues, allocate resources efficiently, and reduce lead times, helping to increase customer satisfaction. Transparent supply chain transparency allows logistics companies to implement data-driven strategies such as demand forecasting and inventory management, cost reduction, and overall efficiency improvements. The ability to track shipments and inventory levels in real-time allows logistics companies to streamline operations, simplify processes, and respond quickly to any disruptions or changes in demand. Real-time monitoring not only helps avoid delays and roadblocks, but also improves communication and cooperation between stakeholders, fostering closer relationships with suppliers, carriers, and customers. In a competitive market, the ability to provide accurate and up-to-date information on the location and condition of goods builds trust and reliability by positioning the logistics company as the best partner for customers looking for

efficiency and visibility in their supply chain. There are several examples. The Internet of Things (IoT) represents a network of interconnected devices capable of autonomously collecting, exchanging, and analyzing data. These devices, equipped with sensors and software, operate without human intervention, collecting and transmitting real-time data about goods' location, temperature, humidity, and other conditions. This technology provides unprecedented visibility into the entire supply chain, impacting industries and everyday life through increased efficiency, automation, and convenience [2]. Global Positioning System (GPS) and telematics technologies are pivotal in real-time vehicle tracking and management. In industries like transportation and logistics, they enhance navigation, monitoring, and operational efficiency. GPS and telematics devices are deployed in vehicles, containers, and assets to facilitate real-time tracking, route optimization, and proactive issue resolution. These technologies empower organizations with immediate insights into asset locations, conditions, and performance, fostering informed decisions, safety improvements, and overall operational efficiency [3]. Blockchain technology introduces a secure, transparent, and tamper-resistant

platform for recording and sharing information, promising to revolutionize supply chain visibility and tracking. Addressing conventional supply chain challenges like transparency, and data consistency, blockchain ensures data integrity and transparency, making records difficult to alter and creating a trustworthy transaction ledger.

Warehouse management deploys technology and machinery to streamline various warehouse operations. Utilizing robotics, sensors, and software enhances efficiency, accuracy, and productivity in storage, picking, packing, and shipping tasks. Warehouse automation encompasses a range of aspects, including goods-to-person systems, picking and packing automation, sorting and conveying, Automated Guided Vehicles (AGVs), robotic palletizing and depalletizing, goods handling, inventory management, Automated Storage and Retrieval Systems (AS/RS), Warehouse Control Systems (WCS), and data analytics. These aspects collectively increase efficiency, accuracy, space optimization, labor savings, 24/7 operations, faster order fulfillment, and scalability.

However, successful implementation requires careful planning, system integration, technology investment, and considerations for maintenance and employee training [9].

Augmented Reality (AR) enriches users' interaction with their physical environment by superimposing digital information and objects onto the real world. AR can enhance worker productivity, accuracy, and efficiency in warehouse management. Benefits include increased productivity, reduced errors, faster onboarding, enhanced accuracy, improved safety, and real-time data access. Fleet management route optimization is crucial in ensuring cost-effective and efficient vehicle movements. It employs technology and data to plan, optimize, and adjust routes, reducing travel time, fuel consumption, and operational costs and improving delivery times. Algorithms utilize real-time data such as traffic conditions, weather, and delivery priorities for route optimization, leading to cost savings, time efficiency, improved customer satisfaction, reduced emissions, and enhanced asset utilization.

Predictive maintenance uses data analysis and technology to forecast equipment or asset failures, enabling timely maintenance and reducing downtime. In logistics, this approach is essential for ensuring smooth operations. Driver management involves coordinating, monitoring, and optimizing driver activities and performance, promoting safe, efficient, and compliant operations through digital tools.

Digital platforms marketplaces facilitate efficient digital connections between shippers and carriers, streamlining freight transactions and offering transparency, collaboration, and cost-effectiveness. Real-time updates in logistics provide stakeholders with timely, accurate information to make informed decisions and respond to changes quickly. Self-service tools empower customers, partners, and stakeholders to manage logistics-related tasks, independently enhancing efficiency and user experience. Optimized routing employs technology and algorithms to determine efficient and eco-friendly transportation routes, minimizing emissions while considering factors like traffic, delivery windows, and vehicle capacity. It contributes to sustainable transportation practices and operational efficiency. Collaborative logistics networks are strategic partnerships among logistics

stakeholders, aiming to enhance supply chain efficiency and performance through shared resources, information, and expertise. Both approaches leverage digital platforms to promote cooperation and cost savings, contributing to operational improvements and competitive advantages. Real-time communication and collaboration platforms enable instant information exchange and coordination among supply chain stakeholders, enhancing efficiency and responsiveness.

Last-mile delivery solutions, including delivery drones, robots, and crowdsourced delivery, are transforming the final step in logistics. These innovative approaches offer efficient, fast, and cost-effective last-mile delivery while addressing congestion, distance, and urbanization challenges.

Data analytics and predictive analytics are reshaping the logistics sector by providing valuable insights, optimizing operations, and enhancing decision-making. Big data analytics processes vast supply chain datasets to uncover patterns, trends, and correlations, while predictive analytics utilizes historical and real-time data for informed decisions and operational optimization.

Carbon footprint tracking measures, monitors, and manages greenhouse gas emissions across the supply chain to promote sustainability. Digital tools support sustainability goals by measuring and managing the environmental impact of logistics operations.

This transformation encompasses various facets of logistics operations, from supply chain visibility to last-mile delivery, predictive analytics, and environmental sustainability. Embracing digital transformation is key to achieving greater efficiency, reducing costs, enhancing customer experience, and staying competitive in the ever-evolving logistics landscape. Digital documentation is fundamental in streamlining processes, improving collaboration, and increasing overall supply chain efficiency.

4 METHODOLOGY

The study is based on multi-stage methodology, which aims to reach conceptual understanding about the phenomena. First, the knowledge has to be collected from the publications presented on the topic. Second, the knowledge has to be collected from the data describing logistics business.

Several methods were used to reach the goal. For the first stage, the authors used a hierarchy of quantitative methods and for the second stage -statistical data analysis method.

The authors examined the application of digital technologies within the logistics business. Over time, researchers have shown a keen interest in analyzing technologies. This exploration of technologies has given rise to entirely new concepts and methods, particularly within mathematics and science.

To refine methods beneficial for problem-solving, a hierarchical approach can be adopted to discern the model's type, technique, and specific methods within a category. The authors present the hierarchy of quantitative methods which is used for the investigation studies in the scholarly field.

During statistical analysis the authors identified the concentration of logistics business by countries; the application of various digital technologies (for inventory

management, fleet management, RFID, AI, etc.) in logistics sector across EU countries.

The authors presented the results of the study in two sub-chapters presented below. The first sub-chapter includes the formation of the hierarchy of quantitative methods in several directions, which specify a) the application of technologies compared with digital technologies; b) business competitiveness studies compared with logistics business competitiveness studies. Finally, the summary of various modeling techniques and their corresponding solution methods in the context of the logistics sector is provided. The second sub-chapter presents statistical analysis provided on the application of digital technologies in logistics business.

4.1 Materials and Methods on Researching the Studies on Technologies and Business Competitiveness

Five primary categories are employed, beginning with the mathematical programming category, progressing to

model-based methods, refining heuristic and hybrid models, and concluding with analytical models. Modeling methods vary in their nature and pertain to one or several objectives.

First, in this research, the authors analyzed the methods used for studies researching the application of technologies and digital technologies. To address these issues, various methods were employed and categorized in Tab. 1. Tab. 1 summarizes and provides a hierarchy of quantitative methods and models.

Among the methods, the most popular is the network model in studies dedicated to the differences in researching technologies and digital technologies. In ICT research, the application of such methods is in its early stages but holds significant potential for analyzing various aspects of cloud technology. In principle, the authors investigate the technologies that help to increase efficiency, save energy, and form suitable conditions for achieving optimal resource allocation to maximize output.

Table 1 The hierarchy of quantitative methods and models for investigating the application of technologies and digital technologies

Types	Modeling technique	Solution methods	Authors investigating technologies	Authors investigating digital technologies
Mathematical programming methods	Single-objective	Bi-level linear programming (LP)	[7]	[7-8]
	Multi-objective	Multi-objective mixed integer linear programming (MILP) Fuzzy-goal programming Polynomial dynamic programming Queuing model Non-linear programming		
Simulation methods	System dynamics (SD)		[9]	
	Discrete event (DES)			[10]
Heuristic methods	Simple heuristic	Simulated annealing heuristics (SAH)	[11]	
	Artificial intelligence (AI) techniques	Markov chains Object-oriented Petri nets Bayesian network modeling Fuzzy logic Artificial Neural network Grey system and rough sets	[12-13]	[14]
	Meta-heuristic	Genetic Algorithm (GA) Evolutionary Algorithm (EA) Differential evolution algorithm (DEA) Particle swarm optimization (PSO) Ant Colony Optimization Greedy Randomised Adaptive search procedure	[15-16]	[17-18]
Hybrid model	Hybrid simulation	SD-DES		[19]
Analytical model	Multi criteria decision making (MCDM)	Analytical hierarchy process (AHP)	[20]	

Source: Own elaboration

The authors identified that mathematical programming methods are rarely mentioned among above listed quantitative methods. Time series analysis could help to identify factors that support the activation of the application of digital technologies that is required.

Later, the authors presented the application of methods for studies analyzing competitiveness. By delivering investigations on applied techniques, the authors compared which quantitative methods in which studies were the most popular. Many studies on business competitiveness lack the application of mathematical programming methods, such as Bi-level linear programming (LP), Multi-objective mixed integer linear programming (MILP), and simple heuristic

simulated annealing heuristics (SAH) method, as specified in Tab. 2.

Many studies on logistics competitiveness focus on applying simple heuristic and meta-heuristic approaches. In addition, different methods have been used in logistics system competitiveness, such as simulated annealing heuristics (SAH), Genetic Algorithm (GA), Evolutionary Algorithm (EA), Differential evolution algorithm (DEA), Particle swarm optimization (PSO), Ant Colony Optimization, Greedy Randomised Adaptive search procedure, etc. However, we could also identify methods that have not yet been explored and applied in studies, i.e., three methods from artificial intelligence (AI) techniques: Object-

oriented Petri nets, Bayesian network modeling, and Fuzzy logic.

Subsequently, the authors devised a framework that could enhance the logistics sector's competitiveness for Descriptive Analysis in the context of investigating the application of technologies in the logistics sector, modeling techniques, and solution methods focused on summarizing and presenting data meaningfully without necessarily predicting outcomes or identifying causal relationships.

Descriptive analysis provides insights into trends, patterns, and distributions within the data [19]. Here's how

modeling techniques and solution methods can be applied at this level. Each level of the hierarchy builds upon the previous one, allowing for a more in-depth and comprehensive analysis of the impact of digital technologies on the logistics sector. Descriptive analysis in the logistics sector involves data and statistical techniques to summarize, visualize, and understand various aspects of logistical operations. This type of analysis aims to provide insights into patterns, trends, and characteristics of logistical processes, which can help organizations make informed decisions and improve their overall efficiency.

Table 2 The hierarchy of quantitative methods and models for investigating business and logistics competitiveness

Types	Modeling technique	Solution methods	Authors investigating business competitiveness	Authors investigating logistics business competitiveness
Mathematical programming methods	Single-objective	Bi-level linear programming (LP)	[21]	[22]
	Multi-objective	Multi-objective mixed integer linear programming (MILP) Fuzzy-goal programming Polynomial dynamic programming Queuing model Non-linear programming		
Simulation methods	System dynamics (SD)		[23]	[24]
	Discrete event (DES)		[25]	[26]
Heuristic methods	Simple heuristic	Simulated annealing heuristics (SAH)		[27]
	Artificial intelligence (AI) techniques	Markov chains Object-oriented Petri nets Bayesian network modeling Fuzzy logic Artificial Neural network Grey system and rough sets	[28]	[29]
	Meta-heuristic	Genetic Algorithm (GA) Evolutionary Algorithm (EA) Differential evolution algorithm (DEA) Particle swarm optimization (PSO) Ant Colony Optimization Greedy Randomised Adaptive search procedure	[30]	[31]
Hybrid model	Hybrid simulation	SD-DES	[32]	
Analytical model	Multi criteria decision making (MCDM)	Analytical hierarchy process (AHP)	[33]	

Source: Own elaboration

Comparative analysis in the logistics sector involves comparing different sets of data, metrics, or processes to identify similarities, differences, and trends [34]. This type of analysis helps organizations make informed decisions by evaluating various options, strategies, or scenarios within their logistics operations. Correlation analysis in the logistics sector involves examining the relationships between different variables or factors to determine whether and to what extent they are related. Correlation analysis helps logistics professionals understand how changes in one variable might be associated with changes in another, which can provide valuable insights into the dynamics of logistical operations. Regression analysis in the logistics sector involves using statistical techniques to model and analyze relationships between variables, particularly to predict or explain outcomes. Regression analysis is useful in understanding how changes in one or more independent variables are associated with changes in a dependent variable. Regression analysis can provide insights into various aspects of supply chain and operational performance in the logistics sector. Regression analysis helps organizations make data-driven decisions by quantifying

relationships between variables and providing predictive insights. Taking into account factors such as model assumptions, potential multicollinearity (when independent variables are correlated), and the need for validation and refinement of the models. Optimization models are critical in improving efficiency, reducing costs, and making informed decisions within the logistics sector. These models use mathematical techniques to find the best possible solution to complex logistical problems. Optimization models in logistics often require advanced mathematical techniques, algorithms, and specialized software tools to solve complex problems efficiently. However, it's important to consider real-world constraints, data quality, and the dynamic nature of logistical operations when applying optimization models. Simulation models are used in logistics to replicate real-world processes and operations in a virtual environment. These models allow organizations to analyze and understand the behavior of complex logistics systems, test various scenarios, and make informed decisions without directly affecting the actual operations. Predictive analytics in the logistics sector involves using historical and current data to forecast future trends, outcomes, and events. By leveraging

advanced statistical and machine learning techniques, predictive analytics helps logistics professionals make informed decisions, optimize operations, and enhance supply chain efficiency. Supply chain network models are strategic tools used in logistics and operations management to design, optimize, and analyze the structure of a supply chain. These models help organizations make informed decisions about the location of facilities, distribution centers, suppliers, and customers to achieve cost-efficiency, responsiveness, and overall supply chain performance. Supply chain network models are strategic tools used in logistics and operations management to design, optimize, and analyze the structure of a supply chain. These models help organizations make informed decisions about the location of facilities, distribution centers, suppliers, and customers to achieve cost-efficiency, responsiveness, and overall supply chain performance. Supply chain network models often involve mathematical optimization techniques, including linear programming, integer programming, and heuristic algorithms. These models provide insights into how network structure, processes, and resource changes impact key performance indicators such as cost, lead time, and customer service. Agent-based modeling (ABM) is a computational modeling technique used in logistics to simulate and study the behavior and interactions of individual agents within a complex system. In logistics, agents can represent various entities such as customers, suppliers, vehicles, warehouses, and other supply chain components. ABM allows for the exploration of emergent behaviors and the impacts of individual decisions on the overall logistics system. Complex systems modeling in logistics involves studying and understanding the intricate interactions, interdependencies, and emergent behaviors within complex logistics networks. Logistics operations are often characterized by numerous variables, nonlinear relationships, and dynamic changes, making them prime candidates for complex systems modeling. This approach helps capture the logistics ecosystem's complexities and gain insights into how various factors influence overall system behavior. Complex systems modeling in logistics often involves techniques like network theory, agent-based modeling, system dynamics, and computational simulation. However, due to the intricate nature of complex systems, these models may require significant data, expertise, and validation efforts to ensure accuracy and relevance. The hierarchy of quantitative methods and models for investigating the application of digital technologies in the logistics sector is provided in Tab. 3.

Tab. 3 summarizes various modeling techniques and their corresponding solution methods in the context of the logistics sector. In summary, certain modeling techniques like descriptive analysis, comparative analysis, correlation analysis, regression analysis, optimization models, and predictive analytics are more widely employed in logistics due to their practical applicability and effectiveness in addressing operational challenges. Agent-based modeling and complex systems modeling are less commonly used, often requiring more specialized knowledge and resources, possibly requiring abundant data and intricate computer simulation aspects. Consequently, this method might be less studied due to its demand for more comprehensive

knowledge and resources. Complexity science and complex systems modeling are rather recent and specialized domains that could be less explored in the logistics sector. This method delves into dynamic processes and nonlinear interactions, which could present challenges when analyzing complex logistics networks. The application of novel or specific machine learning algorithms in the logistics context might be less researched, particularly if these algorithms have emerged recently or aren't traditionally within the focus of logistics research. While mentioned, the comparative analysis method might not be discussed as extensively as other modeling methods. This could indicate that this method might be less explored in the relevant context.

These techniques provide tools for analyzing and optimizing different aspects of logistics operations, considering various data-driven and mathematical approaches.

Table 3 The hierarchy of quantitative methods and models for investigating the application of digital technologies in the logistics sector

Types	Modeling Techniques	Solution Methods
Descriptive Analysis	Charts, graphs, histograms, heatmaps, time series plots	Data aggregation, visualization tools, basic statistical measures, pre-processing, segmentation, narrative, and reporting
Comparative Analysis	Comparative studies between different technologies or processes	Benchmarking, performance metrics, cost analysis, efficiency ratios
Correlation Analysis:	Correlation matrices, scatter plots	Correlation coefficients (Pearson, Spearman), scatter plot interpretation
Regression Analysis	Linear regression, multiple regression, logistic regression	Coefficient interpretation, hypothesis testing, prediction modeling
Optimization Models	Linear programming, integer programming, network optimization	Algorithmic optimization, sensitivity analysis, constraint analysis
Simulation Models	Discrete-event simulation, agent-based simulation	Scenario testing, sensitivity analysis, experimentation
Predictive Analytics	Time series analysis, forecasting models	ARIMA, exponential smoothing, machine learning algorithms
Supply Chain Network Models	Network optimization, supply chain mapping	Network optimization algorithms, strategic decision-making
Agent-Based Modeling	Simulating individual agents' behavior and interactions	Agent behavior rules, interaction dynamics, emergent behaviors
Complex Systems Modeling	Systems dynamics, complexity science	Understanding non-linear interactions, emergent properties, feedback loops

Source: Own elaboration

4.2 Statistical Analysis of Logistics and Technology Trends and Findings

The contribution of the logistics sector to the economy of EU countries is obvious. 10 million people work in the sector. employees (5.2% of all employed in the EU), and its contribution to GDP is 5% [35]. According to the EU

Commissioner for Logistics by 2050 the volumes of this sector will increase by 50%, and the application of digital technologies will be even more relevant for companies in the logistics sector.

Digitization in the logistics sector can help increase efficiency by up to 25%. Such a result is caused by the orientation of users of the logistics business and the services it provides to the use of the advantages provided by digital technologies [35]. 65% of logistics companies recognize the transition to a digital business model to remain competitive in the digital age. As a result of the application of digital technologies in logistics, it is possible to reduce the consumption of material resources and energy and increase the sector's capacity, i.e. increase the competitiveness of the logistics sector [35].

Understanding the intersection of logistics and technology is paramount in today's rapidly evolving business landscape. Eurostat data reveals the significant role played by the logistics sector in the European Union and provides statistics on the utilization of digital technologies within EU businesses. This analysis sheds light on both the opportunities and disparities in technology adoption across EU countries, underscoring the importance of integrating digital tools to enhance competitiveness within the logistics sector.

Eurostat data reveals that the logistics sector comprises 5.4% of the total number of companies in the European Union, contributing significantly to the region's total added value and employment at 7.9%. The labor productivity ratio within the EU's logistics sector stands at 12%.

Fig. 3 provides a snapshot of the concentration of logistics business activity across EU countries, showcasing notable disparities. Germany (DE) takes the lead with a 20% share in both value added and employment, followed by France (FR) at 40% and 38%, respectively. Italy (IT) emerges as the frontrunner with a remarkable 50% share in added value and employment at 43%, showcasing notable disparities that warrant further exploration for enhancing competitiveness in the logistics sector [35].

This data underscores significant disparities in value-added and employment levels across these countries, offering valuable insights for further analysis and enhancing competitiveness in the logistics sector.

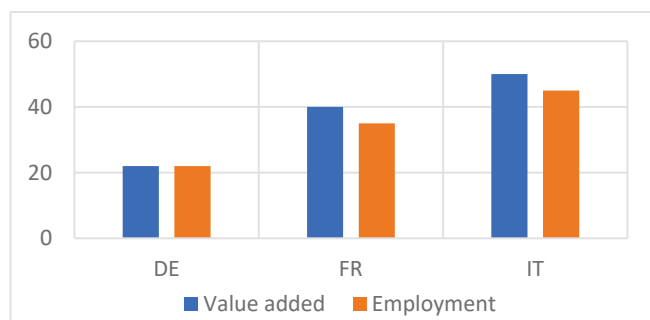


Figure 3 Concentration of logistics business
Source: Eurostat [35]

Tab. 4 provides information about status on logistics activity digitalisation in various European Union countries. The table covers the following categories and numbers:

- 1) Enterprises that use digital technologies for inventory management;
- 2) Enterprises that use digital technologies for the management of logistics activities;
- 3) Enterprises that use radio frequency identification technologies (RFIDs);
- 4) Enterprises that use digital fleet management technologies.

Table 4 Comparison of application of digital technologies across logistics sectors in European Union countries

Country	Enterprises that use digital technologies for inventory management	Enterprises that use digital technologies for the management of logistics activities	Enterprises that use RFIDs	Enterprises that use digital fleet management technologies
Germany	9 845	7 290	6 790	4 603
Italy	7 493	6 973	5 142	3 534
France	4 230	2 632	2 614	1 972
Portugal	2 051	1 275	1 134	863
Sweden	1 888	:	:	870
Romania	658	359	232	354
Greece	835	741	433	458
Poland	852	1 024	566	457
Hungary	540	616	196	186
Slovakia	275	272	259	144
Lithuania	363	161	119	275
Bulgaria	377	254	364	160
Croatia	342	320	272	166
Slovenia	342	187	248	142
Estonia	228	89	112	82
Latvia	90	57	44	52
Luxembourg	118	78	49	88
Malta	43	20	10	35

Source: Eurostat [35]

Among the European Union countries analyzed in the logistics sector, Germany, Italy, and France emerge as leaders. These nations demonstrate noteworthy efforts and investments in reshaping the logistics landscape.

Germany holds a competitive edge due to its substantial applications of digital technologies for inventory management, extensive efforts to implement and improve digital logistics technologies, a significant use of RFIDs, and a high number of fleet management technologies. This positions Germany as a leader in logistics digitalisation, showcasing a comprehensive approach across various technological aspects of supply chain management. The country demonstrates a comprehensive approach to embracing new delivery models and the automatic identification of products throughout the supply chain.

Italy shows strengths in its commitment to digital technologies in logistics, with considerable usage of inventory management technologies, robust efforts to implement and enhance digital logistics technologies, a notable applications of RFIDs, and a significant number of enterprises applying fleet management technologies. This places Italy as a significant player in embracing technological

advancements across its logistics sector. The country is actively exploring new delivery models and unique product identification across the entire supply chain, emphasizing a multifaceted approach to advancing its logistics sector.

France, while not at the same level as Germany and Italy in terms of numbers, showcases strengths in its focus on digital logistics technologies. It has made noteworthy applications of inventory management systems, efforts to improve digital logistics technologies, a moderate implementations of RFIDs, and a reasonable number of fleet management technologies. This indicates a developing approach towards embracing technological advancements within its logistics landscape.

Each country showcases its strengths in distinct aspects of digital technology application within the logistics sector, contributing to their respective positions in the global logistics landscape. While Germany, Italy, and France demonstrate robust digital technology in the logistics sector, other countries in the table exhibit varying degrees of progress. Some nations may be characterized by fewer or lower applications levels, indicating a relative lag compared to the leaders. It is crucial for these countries to consider strategies for catching up and fostering digital technologies within their logistics industries to stay competitive in the rapidly evolving landscape.

In Fig. 4, we compare enterprises across EU countries that use at least one AI technology. It is evident that the share of such enterprises ranges from 1% to 24%. Denmark has the highest share at 24%, followed by Portugal at 17% and Finland at 16%. In contrast, the lowest shares are found in Romania at 1% and Bulgaria, Estonia, Cyprus, Hungary, and Poland at 3% [35].

These findings shed light on the varying adoption rates of digital technologies across EU member states and highlight the potential for further growth and development in this important sector.

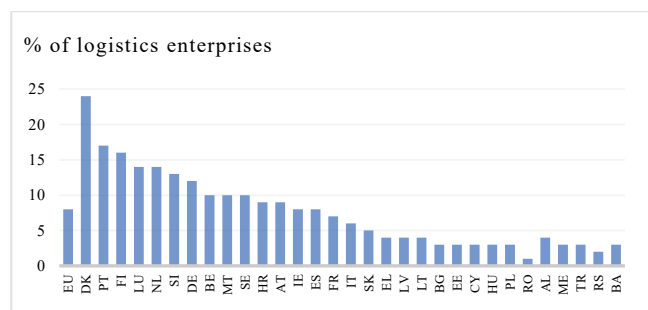


Figure 4 Logistics enterprises using at least one AI technology
Source: Eurostat [35]

The data highlights both the opportunities and disparities in adopting digital technologies across EU countries, emphasizing the importance of promoting the integration of digital technologies to unlock their potential to enhance competitiveness within the logistics sector.

The data clearly indicates that the logistics sector has not fully embraced digital technologies, presenting a significant growth opportunity for this industry. By increasing the adoption of digital technologies in logistics, companies can

enhance the efficiency of their supply chains, optimize routes, reduce both time and costs and improve customer service. This boost in competitive advantage has the potential to stimulate growth within the logistics industry and contribute to an overall increase in competitiveness.

Fig. 5 illustrates the variation in the use of digital technology across different economic activities, suggesting significant disparities in its relevance and adoption levels. This analysis allows us to gain insights into the diverse landscape of digital technology utilization in various sectors.

Notably, within this context, we observe that the logistics sector exhibits relatively lower levels of digital technology adoption, as indicated in the figure. This finding highlights potential areas for growth and improvement within the logistics industry [35].

In summary, Fig. 5 provides valuable insights into the varying adoption levels of digital technology across economic activities, particularly emphasizing opportunities for advancement in the logistics sector.

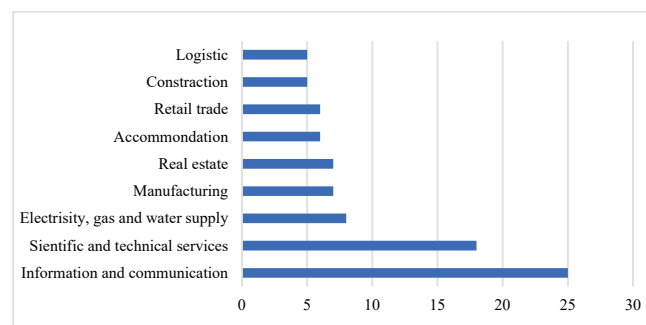


Figure 5 Enterprises using AI technologies by economic activity
Source: Eurostat [35]

This analysis emphasizes that understanding the interaction between logistics and technology is crucial in the rapidly changing context of today's business environment. This is essential to leverage opportunities and address disparities in technology adoption across European Union (EU) countries.

Eurostat data reveals the importance of the logistics sector in the EU, providing statistics on the utilization of digital technologies in businesses. This analysis provides insights into both opportunities and disparities in technology adoption, highlighting the importance of integrating digital tools to enhance competitiveness in the logistics sector. Analyzing the concentration of logistics activity reveals significant differences between countries. Germany, Italy, and France stand out as logistics sector leaders in application of digital technologies, but some countries lag behind, demonstrating fewer or lower interest. The table presents information on the efforts and investments of various EU countries in the logistics sector and the implementation of different technologies.

By increasing the adoption of digital technologies in logistics, companies can enhance the efficiency of their supply chains, optimize routes, reduce costs. This not only increases competitive advantage but also stimulates growth in the logistics industry and contributes to overall

competitiveness. Despite variations between countries, it is clear that the logistics sector still has considerable growth potential through the adoption of digital technologies.

This multifaceted analysis illuminates the intricate interplay between logistics and digital technology, highlighting the need for agile adaptation and innovative strategies in the logistics sector to thrive in the evolving business landscape.

5 CONCLUSION

The theme on digitalisation receives special attention. The statistical analysis shows that countries with the highest logistics sector concentration have the biggest applications numbers in digital technologies.

As a result of literature revision, the authors have identified that covered papers pay a special attention to the topic of digital technologies in logistics.

Digital technology exerts a substantial influence on augmenting the competitiveness of the logistics sector. It enables companies to operate more efficiently, improve operations and sales.

Digital technology is pivotal in managing inventory, warehouse and logistics handling, fleet management, and improving other logistics functions. Real-time tracking and data analysis empower logistics companies to make informed decisions, while electronic traceability systems ensure product quality.

In conclusion, the various analytical techniques employed in the logistics sector serve as invaluable tools for understanding and enhancing operational efficiency.

The authors presented the hierarchy of methods and models used for the researches on the topic. However, it's important to note that the field of logistics is constantly evolving, and researchers are always exploring new methods and approaches to gain deeper insights and improve operations. So, by construction the hierarchy of methods such aspect was taken into account. After, the construction of the hierarchy of methods and models, the authors revised which methods are applied for researching different topics such as technologies and digital technologies, business competitiveness and logistics competitiveness.

The author identified that among the methods, the most popular is the network model in studies dedicated to technologies. The authors identified that mathematical programming methods are rarely mentioned among quantitative methods used to research technologies.

Many studies on business competitiveness lack the application of mathematical programming methods, however, artificial intelligence (AI) techniques are also rarely used. And studies researching logistics business competitiveness are still behind with multi criteria decision making (MCDM) method applications.

Although the text extensively discusses various modeling techniques, it does not discuss potential limitations, challenges, or drawbacks.

A research gap could be related to a deeper study that requires future research on the limitations and practical challenges of applying these modeling methods in logistics.

This research can provide valuable insights into the utility and accuracy of these techniques in the real world and help practitioners make more informed decisions based on their strengths and weaknesses. In future the research could be given to practical decision making approach development.

In conclusion, the amalgamation of these diverse analytical approaches not only aids in addressing current challenges but also positions the logistics industry for a future characterized by informed strategies and optimized performance, ultimately enhancing business competitiveness in the digital era.

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5G Technology and Its Impact on the Global Economic Landscape

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Abstract: This paper examines the pervasive impact of technology and the Internet on the global economy, with a particular focus on the evolution of mobile telecommunications technologies and the potential implications of the introduction of 5G networks. The analysis is based on a survey of respondents' perceptions of the impact of 5G technology on the business environment, using quantitative and qualitative research methods, including a survey conducted among residents of the Republic of Croatia and the Republic of Slovenia. The paper aims to understand how 5G can reshape the global economy, create new business models, jobs and generate higher revenues, with research on technical aspects and the potential benefits and challenges that 5G brings to different sectors of the economy. The primary focus is on identifying the key advantages of 5G technology compared to previous generations of networks and its possible contribution to further economic growth and innovation, while the respondents' perception of the technical aspects and potential impact of 5G on the global economic environment is also explored.

Keywords: 5G technology; economic impact; global economy; innovation and development; mobile telecommunication technologies

1 INTRODUCTION

The use of technology and the global dependence on it is growing day by day and nowhere is this more evident than in the use of the Internet. Today's world is highly interconnected where a globalized economy, technology and the Internet play a key role in enabling economic growth and innovation. From communications and transportation to commerce and finance, technology is changing not only the way we live, but also the way businesses work and communicate with each other and with their consumers. The Internet is one of the key factors that increasingly drives economic growth and competitiveness, both within individual countries and at the global level. As such, continued investment in technology and its development are critical to the continued success of the global economy. One such technology is the various generations of mobile telecommunications that have been developed and introduced over the past few decades. While 1G (First Generation) and 2G (Second Generation) were significant generations in their own right, it was only with the advent of 3G (Third Generation) that the technology became influential enough to become widely known beyond strictly technical individuals and businesses.

Although the impact of 4G (fourth generation) cannot be underestimated, the world is only entering a potentially revolutionary technological era with the arrival of 5G (fifth generation) networks that could affect the global economy to an unprecedented extent. At a basic technical level, 5G brings significant improvements in terms of speed, latency and connectivity compared to 4G networks. In essence, the widespread deployment of 5G networks will bring new and innovative applications and services that were simply not possible using 4G. Although the technological leap from 4G to 5G is much wider than from 3G to 4G, it is still possible to measure the impact of 5G technology by looking at how 4G transformed the socio-economic landscape when it replaced the previous, 3G network technology. With this in mind, this paper will create an overview of the improvements that occur with 4G networks and use them to analyze the economic impact of 5G networks. The paper will also create an overview of the main technologies driving economic growth, analyzing how they are affected by the development of 5G

networks. The goal is to investigate, present, and determine respondents' perceptions of the key benefits of 5G technology on their business environment.

2 LITERATURE REVIEW

The rapid advancement of technology makes it difficult to correctly measure and predict its impact on economic growth. Since economic growth is a slow and gradual process that takes time to develop and observe, it is entirely possible that a rapidly developing new technology will render all observations and predictions completely obsolete. In the past decade, many different technologies have emerged that are significantly important for economic growth. While these may vary by region and industry, there are some that have taken their place in the socio-economic landscape and are shaping the global economy:

- Artificial Intelligence (AI) and Machine Learning (ML): AI and ML are increasingly used to automate processes and increase business efficiency (McKinsey Global Institute, 2018). This is particularly important in logistics, where artificial intelligence has enabled massive data analysis in different links of the supply chain, and digitalized logistics lead to improvements and acceleration of logistical processes, strategies, and systems, are more available and customer-focused, leading to faster delivery methods. They incorporate machine learning elements for making critical data-based decisions and continuously improving supply chain processes [20].
- Internet of Things (IoT): IoT enables devices to collect and exchange data, leading to the development of new products and services. The combination of new technologies such as machine learning and artificial intelligence can easily be implemented in comprehensive IoT solutions, making IoT even more effective in process automation, creating new value for companies, and generating increased financial revenues [18].
- Blockchain: Blockchain technology is used to create new financial systems, reduce costs, increase transparency, and develop new business models [11].
- 5G and Other Telecommunication Technologies: Advanced network systems are crucial for the development

of new products and services, as well as for connecting businesses and consumers [4].

- **Cybersecurity:** A combination of advanced software that becomes increasingly important for protection against cyber-attacks and safeguarding sensitive data (World Economic Forum, 2019) [17].
- **Renewable Energy Technologies:** Renewable energy technologies, such as solar and wind energy, are becoming increasingly important to reduce dependence on non-renewable energy sources and encourage further innovations (OECD Report, 2015).

Although they fall into separate categories, the above-mentioned technologies are increasingly interconnected as the advancement of one influences the advancement of another. This is particularly the case with telecommunication technologies, as all the mentioned technologies depend on access to advanced systems powered and utilized through internet connection. In this sense, the fifth generation of telecommunication networks, or 5G, is the most significant emerging technology that will impact the socioeconomic landscape in the future. According to Rodriguez [15], 5G is the fifth generation of wireless communication technology and has the potential to revolutionize the way we connect and communicate. 5G is designed to be faster, more reliable, and more efficient than its predecessor, 4G, and is developed to support the growing demand for data-intensive applications. A technical comparison of different generations of network technologies is something that should be considered when measuring technological progress, as it is directly related to the use of technology in terms of economic growth. According to the International Telecommunication Union (2020) [10], the main components of network architecture between 3G, 4G, and 5G are:

- **Radio Access Technology (RAT):** All three generations use radio waves to transmit and receive data.
- **Multiple Access Technology:** All three generations use multiple access technology to allow a larger number of users to share the same frequency spectrum. For example, 3G uses WCDMA (Wideband Code Division Multiple Access), 4G uses LTE (Long-Term Evolution), and 5G uses both LTE and NR (New Radio).
- **Frequency Bands:** All three generations use different frequency bands to transmit data. 3G primarily uses the 2G frequency band, while 4G and 5G use more frequency bands of 3G and 4G, respectively.
- **Data Transfer Speed:** All three generations aim to provide higher data transfer speeds compared to their predecessors. 3G enabled a peak data transfer speed of 2 Mbps, 4G enabled a peak data transfer speed of 1 Gbps, and 5G aims to provide peak data transfer speeds up to 20 Gbps.
- **Network Architecture:** All three generations use a network architecture that includes a core network and a radio access network. The core network is responsible for routing and switching data, while the radio access network is responsible for transmitting and receiving data through the air.
- **IP-based Communication:** All three generations use the Internet Protocol (IP) as the primary means of communication. This allows seamless integration with other IP-based technologies, such as the internet.

The underlying technologies that drive each generation of telecommunications networks are improving in ways that either massively improve existing use cases or create entirely new ones that were not possible before. According to a group of authors in McKinsley Quarterly 2 (2017), this has proven to have a significant economic impact, bringing increased productivity, job creation and GDP growth. The same applies to industry-specific impacts, particularly in commerce (with an emphasis on retail due to the need for highly personalized communication), transportation, healthcare, agriculture, manufacturing and logistics. As a result of technological advances with the introduction of the 5G network, retailers have more and more options available that represent a great potential to improve the shopping experience for customers [6]. With these advances, a large proportion of customers have access to use their mobile phones in physical stores, allowing them to receive new information at the point of purchase [5]. At the same time, the mobile phone can be one of the biggest influencing factors on consumer buying behavior during retail sales [12]. The use of mobile phones in retail is therefore gradually opening up various questions among academics and retailers [2].

In terms of productivity, each subsequent network technology has brought faster data transfers, better real-time analytics, and more efficient automation, enabling new business models that can take full advantage of them. Innovations are the basis of improvement and the driving force behind the development of every economic area in a country, and technological innovations are those that relate to changes in technology and that reflect technological progress in a narrower sense [13].

Deloitte's report on 5G (2020) states that both the development of the technology and its implementation have the potential to create new jobs, as well as completely new job categories in the domain of augmented reality, the Internet of Things and smart cities. In particular, infrastructure development creates opportunities for more engineers, technicians and construction workers involved in the design, installation and maintenance of infrastructure. The telecommunications industry creates opportunities for positions related to network management, data analysis, and cyber security, while also creating demand for workers in third-party companies that manufacture and supply equipment such as chipsets, antennas, and radio units. Application development is increasing the demand for software developers, UX/UI designers, data scientists among many other types of IT professionals.

Innovations and digital transformation are ready to become a new driver of economic growth. The key to success in today's world is rapid development based on continuous innovation [19].

3 RESEARCH METHODOLOGY

3.1 Research Problem, Objectives, Hypotheses, and Questions

The research problem of this paper is to examine the impact of modern technologies on the development of the world economy, with a specific focus on exploring the potential impact of the 5G network on the global economy through quantitative and qualitative research methods.

The fundamental hypothesis of this paper states: "5G technology will provide a new platform for growth and development of the global economy", and the auxiliary hypothesis states: "5G technology will create new business models, jobs, and higher revenues".

Where applicable, qualitative research was used to gain a deeper understanding of the subjective experiences and opinions of stakeholders in the 5G ecosystem. This included conducting a survey using a random sample method from the regions of the Republic of Croatia and the Republic of Slovenia, with questions related to how often respondents use mobile devices such as smartphones and tablets that support 5G technology, and how well they understand the technical aspects of 5G technology and its impact on the global economic environment. Furthermore, respondents were asked about their expectations of 5G technology in terms of its impact on the global economic environment, which economic sectors they see as most promising in terms of 5G technology application, the advantages and challenges they see in implementing 5G technology in their business environment, the importance of speed, reliability, and low latency in their mobile devices, and how 5G technology could improve their business and personal activities. They were also asked whether they believe that 5G technology could provide new employment opportunities and create new jobs in various sectors of the economy and what risks they see in the implementation of 5G technology, especially in terms of data security and environmental impact.

This resulted in a nuanced, deeper understanding of the challenges and opportunities associated with 5G technology and its impact on the global economy. The results of a study conducted in 13 countries around the world show that many customers begin their shopping journey with online research through their mobile phones, even before visiting a store. This personal "survey" is also known as "we-brooming" and plays an important role during the retail process. The study further indicates the importance of personalized communication with customers [7].

Authors Bues [1] and author Roy [16] also discuss its importance and emphasize the need for highly personalized communication with specific customers in the retail process, as customer segmentation and division into certain groups can be a useful tool for achieving personalized communication with customers.

The quantitative and qualitative research methods in this sense aimed to provide a comprehensive and in-depth analysis of the potential impact of 5G on the global economy, and the conclusions drawn based on the research are presented in the final part of the paper.

4 PRESENTATION AND INTERPRETATION OF RESEARCH RESULTS

4.1 Sample Research

272 respondents from the Republic of Croatia and the Republic of Slovenia took part in the survey conducted for the purposes of this work, using the method of random sampling, and all answers were anonymous. The survey questionnaire was distributed online on social networks

Facebook and Instagram, in a period of one month, from April 3 to May 5, 2023. For the purposes of this paper, 9 questions from the survey questionnaire were analyzed using a Likert scale.

4.2 Research Results

Tab. 1 shows the profile of respondents by sociodemographic characteristics. Out of a total of 272 respondents, 156 respondents (57.4 %) are female, and 116 respondents (42.6 %) are male. With regard to the age structure, it was the following number of respondents: in the range of 18 to 25 years, 31 of them (11.4 %), from 26 to 33 years 74 respondents (27.2 %), in the age range of 34 to 41 years is 87 respondents (32 %), 35 respondents (12.9 %) are aged 42 to 51, 43 respondents (15.8 %) are 52 to 61 years old, while 2 respondents (0.7 %) are 62 and several years. According to the level of education, the structure of the respondents is as follows: among the respondents, there are no persons with completed elementary school. There are 124 respondents (46.6 %) who have completed secondary school, while 140 respondents (51.5 %) have a university degree, 2 respondents (0.7 %) have a master's degree in profession or science, and 6 of respondents (2.2 %) has a doctorate in science.

Table 1 Profile of respondents

Sociodemographic characteristics	Frequency (N)	Percentage (%)
Age		
18 – 25	31	11.4
26 – 33	74	27.2
34 – 41	87	32.0
42 – 51	35	12.9
52 – 61	43	15.8
62 and more	2	0.7
Sex		
male	116	42.6
female	156	57.4
Level of education		
Elementary School	0	0
High School	124	45.6
College	140	51.5
Master of Science or Profession	2	0.7
Doctor of Science	6	2.2

Table 2 Structure of respondents by employment sector

Employment sector	Frequency (N)	Percentage (%)
Public sector	73	26.8
Private sector	161	59.2
Craft	24	8.8
Family farm	3	1.1
The unemployed	7	2.6
Student or learner	4	1.5

Tab. 2 shows the structure of respondents by employment sector. Out of a total of 272 respondents, 73 (26.8 %) were employed in the public sector, 161 (59.2 %) in the private sector, 24 (8.8 %) in trades, 3 (1.1 %) in family farms, there were 7 unemployed respondents (2.6 %) and 4 students or pupils (1.5 %).

Fig. 1 shows how users use 5G technology, with 157 respondents (57.7 %) using 5G-enabled mobile devices on a daily basis, indicating a high rate of 5G usage and adoption

among these respondents. A smaller number of respondents, 28 (10.3 %) use 5G devices several times a week, and a very small number of respondents, 5 (1.8 %) use 5G devices only a few times a month.

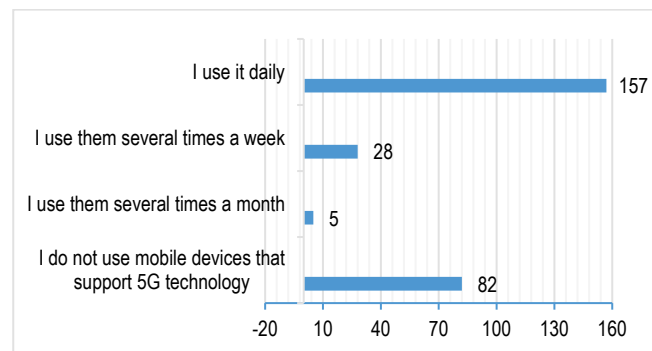


Figure 1 How often do you use mobile devices (such as smartphones and tablets) that support 5G technology?

However, it is evident that a significant number of respondents, 82 of them (30.1 %) do not use mobile devices that support 5G technology. This could indicate various possible factors, such as the unavailability of 5G network, the cost of 5G devices, the lack of information about the benefits of 5G technology, etc. Considering these results, it can be concluded that there is a significant use of 5G technology, but there are still a large number of people who have not yet accepted it. This could indicate opportunities for further expansion and improvement of 5G infrastructure, as well as the need for further education on the benefits of 5G technology.

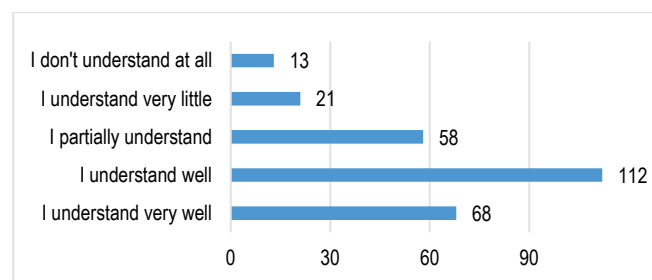


Figure 2 How well do you understand the technical aspects of 5G technology and its impact on the global economic environment?

When it comes to the question related to understanding the technical aspects of 5G technology and its impact on the global economic environment, the results of the survey are shown in Fig. 2.

A small number of respondents, 13 of them (4.8 %) do not understand at all the technical aspects of 5G technology and its impact on the global economic environment, while 21 respondents or 7.7 % understand these aspects very little. Partial understanding was expressed by 58 respondents (21.3 %), 112 of them (41.2 %) understand well the technical aspects of 5G technology and its impact, and 68 (25 %) respondents understand these aspects very well.

These results show that most respondents have at least a partial understanding of the technical aspects of 5G technology and its impact on the global economic

environment. However, there is still a significant number of respondents who have limited or no understanding.

This data can have different implications, on the one hand it shows that information about 5G technology and its advantages is available and easily understandable for a significant number of people, and on the other hand, it shows that there is still a need to improve education about 5G technology, especially for those who have limited understanding.

These results may also provide insight into potential opportunities for telecommunications companies, such as developing educational programs or tools to help users understand and use 5G technology.

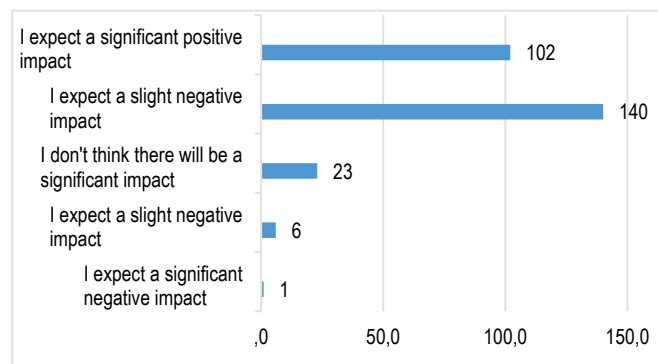


Figure 3 How would you describe your expectations of 5G technology regarding its impact on the global economic environment?

Fig. 3 shows the research related to respondents' expectations about the impact of 5G technology on the global economic environment, showing that a significant number of respondents, 102 of them (37.5 %) expect a significant positive impact of 5G technology on the global economic environment. The largest number of respondents, 140 of them (51.5 %) expect a slight positive impact, while a smaller number of respondents, 23 (8.5 %) do not expect a significant impact of 5G technology on the global economic environment. A very small number of respondents, 6 of them (2.2 %) expect a slight negative impact, while only one respondent (0.4 %) expects a significant negative impact.

These results suggest that the majority of respondents have positive expectations regarding the impact of 5G technology on the global economic environment, whether it is a slight or significant positive impact. Only a small number of respondents do not see a significant impact or predict a negative impact.

The data from Fig. 4 shows that logistics and transport (76 or 27.9 %), and health and financial services (each with 46 or 27.9 %) are the sectors that the largest number of respondents see as the most promising in terms of the application of 5G technology. The average number of respondents sees education, 34 of them (12.5 %), trade 29 of them (10.7 %), and tourism and hospitality 26 (9.6 %) as sectors with potential for 5G application. The fewest respondents believe that the manufacturing sector (15 of them or 5.5 %) is promising for the application of 5G technology.

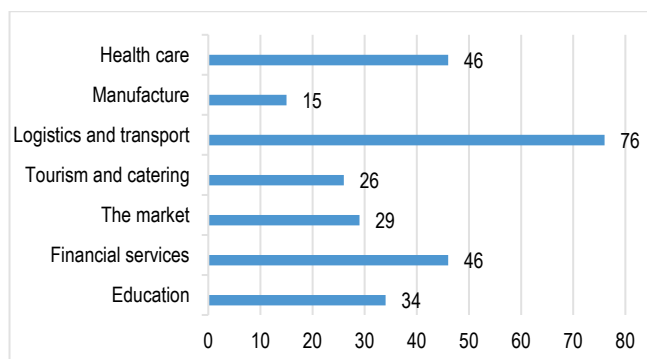


Figure 4 Which sectors of the economy do you see as the most promising in terms of application 5G technology?

These results suggest that respondents recognize a wide range of sectors that could benefit from the application of 5G technology. Healthcare and financial services are areas particularly highlighted by respondents, perhaps because 5G is expected to enable faster and more reliable wireless communications that could transform the way services are delivered in these sectors.

The data also shows that logistics and transportation are also seen as an important area for 5G applications, perhaps because of the potential to improve efficiency through things like autonomous vehicles and supply chain optimization.

It is important to note that although the manufacturing sector has the least votes among these respondents, 5G technology has the potential to provide significant benefits in that sector as well, for example by enabling Industry 4.0, automation, and other innovations.

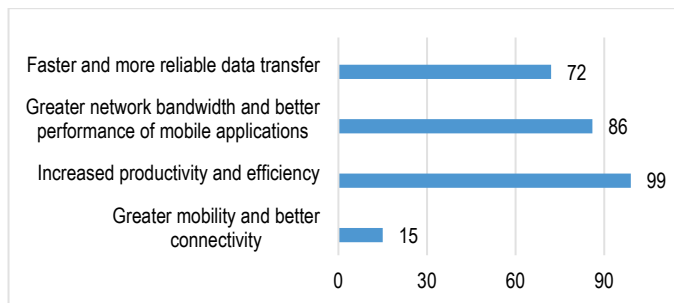


Figure 5 What advantages would you see in the application of 5G technology in your business environment?

From Fig. 5, it is evident that 72 respondents (26.5 %) see faster and more reliable data transmission as an advantage or key to the application of 5G technology in their business environment. This suggests that there is a significant demand for fast and reliable data transfer, which can be essential for activities such as fast download and transfer of large files, video conferencing, and the like. Higher network bandwidth and better performance of mobile applications were recognized as an advantage by 86 respondents (31.6 %). This may indicate that respondents value the ability to support more devices and better mobile application performance, which can be especially important in a business environment where many devices share the same network.

Increased productivity and efficiency were highlighted as an advantage by the largest number, i.e. 99 respondents

(36.4 %). This suggests that respondents see significant value in the possibility of 5G technology improving the productivity and efficiency of their work, perhaps through faster and more reliable connections, better application performance, or other functionalities enabled by 5G technology.

Only 15 respondents (5.5 %) highlighted greater mobility and better connectivity as an advantage. This may indicate that while mobility is important, it may not be the primary factor that respondents see as a key benefit of 5G technology in their business environment.

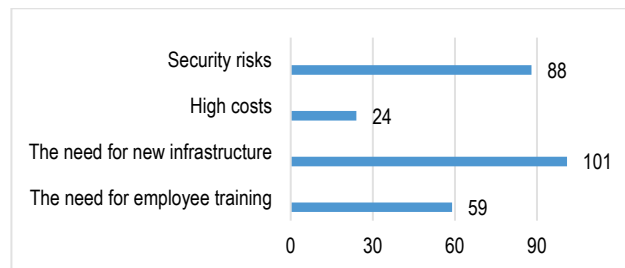


Figure 6 What challenges would you see in the application of 5G technology in your business environment?

Fig. 6 shows how 88 respondents (32.4 %) single out security risks as a challenge, so it is clear that there is a significant concern about the security associated with the introduction of 5G technology. This is understandable because 5G, like any technology that transmits or stores data, can be a target for cyber-attacks. This concern could point to the need to strengthen data protection and cyber security measures when introducing 5G technologies.

24 respondents (8.8 %) consider high costs as a potential challenge. Deploying 5G may require significant upfront investment, including upgrading hardware, software and possibly even infrastructure, which can be a financial challenge for some organizations.

The need for new infrastructure was highlighted as a challenge by most respondents, 101 of them (37.1 %). The implementation of 5G may require the installation of new infrastructure, including new antennas and base stations, which can be time and financially demanding. This suggests that companies and governments should consider how best to support the infrastructure upgrade required for effective 5G deployment.

The need for employee training was identified as a challenge by 59 respondents (21.7 %). The introduction of new technology often requires training of employees to ensure that they are able to use the new technology correctly and effectively. This could suggest the need for comprehensive training plans when introducing 5G technologies.

Fig. 7 shows the results of the survey, which provides an interesting insight into respondents' perceptions of the importance of speed, reliability and low latency - the key features of 5G technology - for their mobile devices. Very important: 21 respondents (7.7 %) consider these features very important, so this could suggest that this minority of respondents have jobs or living conditions that require high-end mobile performance. Important: The majority of respondents, 183 of them (67.3 %) consider speed, reliability

and low latency important, which shows that people value the ability to use their mobile devices quickly and reliably with minimal delays. Less important: 60 respondents (22 %) consider these features less important, which could indicate that these respondents have less demanding needs for their mobile devices, or may not have much experience with online activities that require high speed, reliability or low latency.

Unimportant: Only 8 respondents (2.9 %) consider these features unimportant which could suggest that these respondents may be less dependent on mobile technologies or that their activities do not require high speed, reliability or low latency.

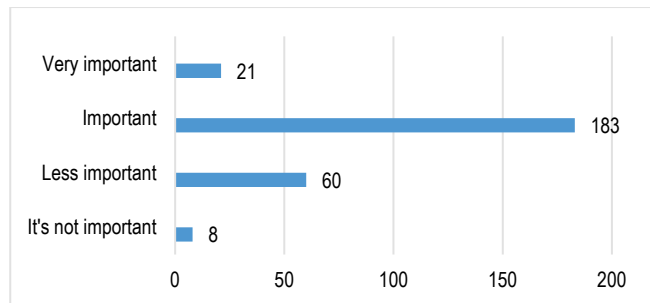


Figure 7 How important are speed, reliability and low latency in your mobile devices to you and how could 5G technology improve your business and personal activities?

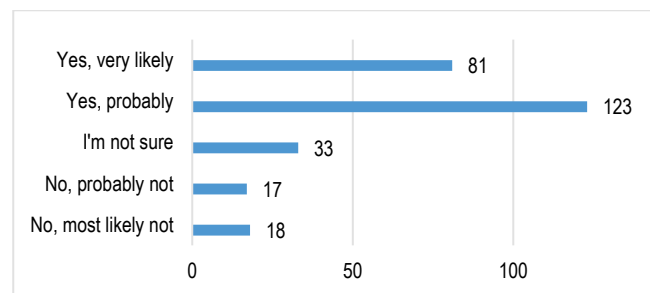


Figure 8 Do you think that 5G technology could provide new opportunities for employment and the creation of new jobs in different sectors of the economy?

Based on the research, Fig. 8 shows that the majority of respondents, 204 of them, believe that 5G technology can probably provide new opportunities for employment and the creation of new jobs in various sectors of the economy (75 %). This perception may indicate optimism about the economic opportunities that 5G can bring, including the creation of new jobs in sectors such as telecommunications, equipment manufacturing, software development, and the like. On the other hand, 33 respondents (12.1 %) are not sure about this question, which may indicate that some respondents may not have enough information or understanding about how 5G technology can affect the labor market. A smaller number of respondents, 35 of them, believe that 5G technology is unlikely to create new employment opportunities (12.9 %). This may indicate scepticism or concern about how technological advances, such as 5G, may affect the labor market, for example through automation or changing the way work is done in some sectors.

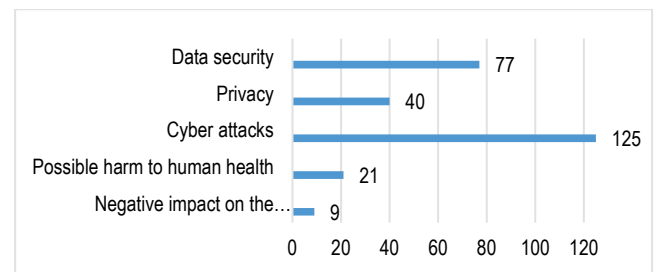


Figure 9 What risks would you see in the application of 5G technology, especially in terms of data security and environmental impact?

Based on the data presented in Fig. 9, it is evident what the respondents' views are on the possible risks associated with the implementation of 5G technology, as follows:

Regarding data security, 77 respondents (28.3%) consider data security as a risk and an area of great concern. Since 5G technology enables the rapid transfer of large amounts of data, the question of how to protect this data is becoming increasingly important.

When it comes to privacy, 40 respondents (14.7%) consider privacy as a potential risk, so this may indicate concern about how personal data is used and shared in the 5G environment. The risk of cyber-attacks was recognized by the most respondents, 125 of them (46 %). As more devices connect to the Internet via 5G networks, the number of potential entry points for cyber-attacks may increase, increasing the importance of cyber security.

Concern about potential harm to human health was highlighted by 21 respondents (7.7 %). Although current scientific research does not show that 5G technology poses a risk to human health, some public opinion continues to express concern about the potential effects of exposure to radio frequency radiation.

Only 9 respondents (3.3 %) believe that 5G can have a negative impact on the environment. Since the deployment of a 5G network may require the installation of a large number of new antennas, there may be some environmental impact, but this appears to be less of a concern among respondents.

4.3 Discussion of Results and Answers to Research Questions

The objective of the empirical part of this paper was to investigate, present and determine respondents' perceptions of the key advantages of 5G technology for their business environment. From these results, it could be assumed that companies developing or implementing 5G technologies could benefit the most by focusing on the benefits that respondents consider most important, such as increasing productivity and efficiency, improving network bandwidth and mobile application performance, and providing faster and more reliable transmission data.

4.4 Research Limitations

When interpreting the research, the limitations of the conducted research should be taken into account, given that the research was conducted on a random sample of 272 respondents who voluntarily wanted to fill out the survey

questionnaire. In order to generalize the conclusions, the sample should be increased and made representative. This research can be the basis for future research that would be conducted on a representative sample of respondents of all age groups.

5 CONCLUSION

These results support the hypothesis that 5G technology will bring improvements that will boost the global economy, through improving productivity, enabling new technological innovations, creating new industries and jobs, etc. However, it is important to note that respondents' perceptions and expectations do not necessarily reflect the actual impact that 5G may have an impact on the global economic environment, but they provide insight into the attitudes and opinions people have about this technology.

Finally, these results can provide insight into potential priorities for companies and governments considering how to best utilize 5G technology. Also, the results provide useful insights into the potential challenges that respondents see in relation to the application of 5G technology in a business environment. Understanding these challenges can help companies, governments and other stakeholders better plan and prepare for effective 5G deployment.

This and numerous other studies and analyzes dealing with the impact of 5G technology on the global economic environment confirm the hypothesis that 5G technology will enable faster and more efficient connection of devices and enable the development of new technologies such as autonomous vehicles, virtual and augmented reality, robotics, etc. Thus, the research confirms the main and auxiliary hypothesis that 5G technology will provide a new platform for the growth and development of the economy, creating new business models, jobs and income. The application of 5G technology in various sectors, such as trade, healthcare, manufacturing and logistics, could result in cost savings and increased efficiency.

However, the research indicates that there are also some challenges and risks that come with the application of 5G technology, such as security issues, environmental impact, technological dependence and the like.

The impact of 5G technology on the global economic environment will also depend on political, legal and regulatory frameworks, as well as on different social and cultural factors in different parts of the world.

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Mathematical Modeling of Forwarder Operation When Collecting Logs in the Forest Swath

Konstantin P. Rukomojnikov*, Natal'ya N. Aleksagina, Ilya S. Anisimov

Abstract: Optimization of the machines allows you to increase their productivity and reduce the labor costs for performing individual elements of the technological cycle of their work in the forest. In this regard, the authors offer theoretical studies that take into account the peculiarities of the work of one of the most popular logging machines today, namely, a machine for collecting and forwarding logs (forwarder). The article discusses the technological features of the functioning of these machines, identifies ways to reduce the cost of collecting logs, justifies the rational width of apiaries, which allows collecting logs with a minimum number of movements between work positions. The main purpose of the study is to substantiate the mathematical dependence for determining the rational values of such interrelated parameters of the forwarder's operation as the distance between the working positions of collecting logs and the width of apiaries. The authors propose an analytical approach to solving the problem. On the basis of the standard technological scheme of the harvester's movement through the swath, geometric regularities of the trajectory of the manipulator movement, dimensional characteristics and location of the prepared logs are revealed. As a result of the work, mathematical dependencies are constructed that make it possible to determine the rational values of the desired parameters. The results can be used by research organizations in planning the production process of logging operations. The introduction of author's recommendations into production will contribute to improving the efficiency and operation of forestry equipment.

Keywords: forwarder; forest swath; log; log forwarding; logging; manipulator

1 INTRODUCTION

In the normal Nordic harvesting tree stems are processed into logs at the cutting area. Usually 2 machines are used: harvester and forwarder, or felling of trees, pruning of branches and bucking are carried out by a feller with a chainsaw [20, 30, 35]. Thus, any of the variants of the technological process of harvesting logs of one of the machines of the technological process is a forwarder. This causes increased interest in modeling the technological process of the forwarder from scientists around the world [6, 10, 13, 15, 22, 26, 36].

The accuracy of the performance assessment using the obtained models should be sufficient to simulate production processes at various cutting areas. The research [21] proves that the technology of forwarder operators has become more labor-intensive in recent years, despite the successes achieved in the design of logging equipment. The species diversity of logs has increased during their sorting during the forwarder loading process due to more specific product requirements. The number of scattered logs is bunched has increased when unloading logs at loading points. This created more difficult working conditions when loading and unloading logs with a forwarder.

When choosing machines and mechanisms for the implementation of logging operations, as well as the organization of the production process, it is necessary to take into account many different factors. Optimization of the machines allows you to increase their productivity and reduce the labor costs for the implementation of individual elements of the technological cycle of their work in the forest [17, 27-29]. Focusing the attention of the readers of the article on the forwarder, as a machine that is one of the most popular by loggers around the world today, we can say that its productivity largely depends on the average volume of the stick, the distance of forwarding logs, the standing volume in the forest cutting area, the distances between forest swaths and the qualifications of the machine operator [16, 18, 23, 24, 31, 32]. According to the authors, the issue of optimizing

these parameters during the operation of machines for harvesting logs is currently not fully studied. In this regard, the authors offer additional theoretical studies, teaching the features of the work of these machines in the forest.

The purpose of the study is to substantiate the mathematical dependence for determining the rational values of such interrelated parameters of the forwarder's operation as the distance between the working positions of collecting logs and the width of forest swathes.

2 MATERIALS AND METHODS

The purpose of the study is to substantiate the rational values of such interrelated parameters of the forwarder's operation as the distance between the working positions of collecting logs and the width of forest swathes.

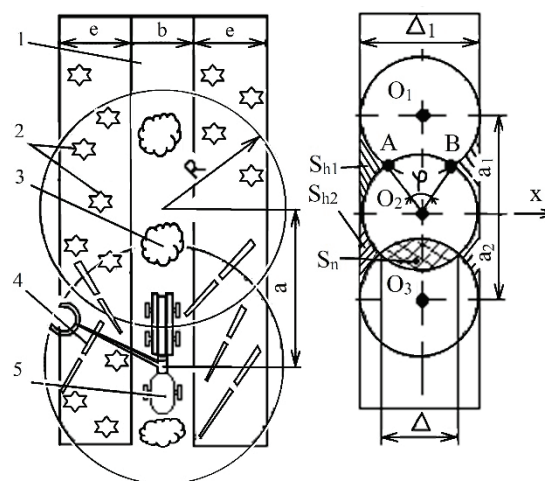


Figure 1 Scheme of forest swaths: 1 – forest swath; 2 – undergrowth; 3 – knots; 4 – logs; 5 – forwarder. Source: Compiled by the authors.

To analyze the work of the forwarder, the collection of logs used scheme, presented in Fig. 1a. On the forest swath with a width of Δ , the feeling of all trees intended for logging

is carried out, with the abandonment of part of the stand and undergrowth. After pruning the branches from the trees, they are laid on skidding track. The logs after cutting into lengths also remain on skidding track. They are collected and laid by the manipulator on the freight platform of the forwarder.

The time to collect a bundle of logs depends on the number of working positions. In turn, the number of working positions is inversely proportional to the area processed by the forwarder from one position. The scheme for calculating the area is presented in Fig. 1b.

If the width of the forest swath is $\Delta_1 = 2R$, and the distance between the working positions O_1 and O_2 is a_1 , then the untreated area S_{h1} appears on the forest swath. The greater the distance between the working positions, the larger the uncultivated area of the forest swath. Reducing the share S_h is possible in two ways: reducing the width of the forest swath being processed $\Delta_1 \rightarrow \Delta$; reducing the distance between working positions $a_1 \rightarrow a_2$. In the second case, there is an area of the double segment S_n , which can be processed from both the second and third working positions. One hundred percent processability of the forest swath can be achieved only with simultaneous accounting of the listed methods.

The width of the forest swath Δ being developed can be found using the circle equation:

$$(x-a)^2 + (y-b)^2 = R^2, \quad (1)$$

where, a and b are centers of circles.

$$\begin{cases} x^2 + y^2 = R^2 \\ x^2 - (y-a)^2 = R^2. \end{cases} \quad (2)$$

Having solved the system of equations for two given circles with centers $O_1(0, 0)$ and $O_2(0, a)$ and radius R , we find the coordinates of points C, D of the intersection of circles:

$$y = \frac{a}{2}, \quad (3)$$

$$x = \pm \frac{\sqrt{4R^2 - a^2}}{2}. \quad (4)$$

When using a forwarder for forwarding, it must be borne in mind that in order to ensure a reliable capture of logs, its dragging and laying to the forwarder's cargo platform, it is enough that only a part of it is in the range of the manipulator, the length of which guarantees the possibility of accurate guidance of the grab and the capture of the log. Taking into account the different location and angle of felling of trees, the scheme for calculating the area processed by the forwarder from one working position can be depicted in the form of Fig. 2. This figure shows the areas processed at the minimum and maximum angles of felling trees in forest swathes. Analyzing the data of the scheme, it can be concluded that the treated area, on which the logs obtained by cutting the sticks of trees

felled at the same sharp angle to the axis of the forest swath are located, will have an oval shape (Fig. 2a and 2b). Combining several design schemes that take into account the maximum and minimum angles of felling trees, and analyzing several adjacent working positions simultaneously (Fig. 2c), it can be noted that the width of the tape on which the collection of all logs is ensured, regardless of the angle of fall of the tree and the absence of untreated areas is provided, will be equal to

$$\Delta = \sqrt{4R^2 - a^2} + L, \quad (5)$$

where is $L = 2(l_{\text{cop}} - j_{\text{cop}}) \cdot \sin c$.

Where c - the minimum angle of felling of trees located on the border of the forest swath, hail; j_{cop} - the length of the part of the log, which must be in the zone of action of the manipulator to ensure a reliable capture of the log, m; l_{cop} - length of the log, m.

The performance of the forwarder is significantly affected by the time of collection of a bundle of logs, which can be represented in the form of equation:

$$T_1 = \sum_{g=1}^z \frac{M}{V_{\text{cg}}} \cdot \omega \cdot t_{\text{dzy}} + \frac{M \cdot \sum_{g=1}^z \frac{1}{\omega} \left(t_{yp} + \frac{a}{g_{pn}} + t_{ym} \right) \times 10^4}{q \cdot a \cdot k_i \cdot z \cdot \left(\sqrt{4R^2 - a^2} - L \right)}, \quad (6)$$

where ω - the share of the component of a certain variety group during sorting at the cutting site in the total volume of harvested wood; V_{cg} - the average volume of the log of g - component, m^3 ; M - the average volume of bundle of logs, m^3 ; z - the number of sorting components when collecting a bundle of logs; t_{dzy} - the time of capturing the log and stacking it on the cargo platform, sec; t_{yp} , t_{ym} - respectively, the time of installation of technological equipment in the working position and vice versa, sec.

By changing the distance between the work positions, it is possible to reduce their number, which is necessary to collect a bundle of logs, reduce the cycle time of work and, as a result, increase the replaceable performance of the forwarder. The optimal value will be the one in which the time to collect a bundle of logs is minimal. Having found the derivative of the obtained expression and equating it to zero, after the transformations we get:

$$\frac{d \cdot T_1}{d \cdot a} = \frac{M \times 10^4}{q \cdot k_i \cdot \left(\sqrt{4R^2 - a^2} - L \right)} \cdot \left(\frac{t_{pm} + \frac{a}{g_{pn}}}{\left(\sqrt{4R^2 - a^2} \right) \cdot \left(\sqrt{4R^2 - a^2} - L \right)} - \frac{t}{a^2} \right), \quad (7)$$

$$\begin{aligned}
& 4L^2R^2t_{pm}^2g_{pm}^2 - 16R^4t_{pm}^2g_{pm}^2 - L^2t_{pm}^2g_{pm}^2a^2 + \\
& + 16R^2t_{pm}^2g_{pm}^2a^2 + 8R^2t_{pm}g_{pm}a^3 - 4t_{pm}^2g_{pm}^2a^4 - \\
& - 4t_{pm}g_{pm}a^5 - a^6 = 0
\end{aligned} \quad (8)$$

where t_{pm} is the time of transfer of technological equipment from the working position to the transport one and vice versa, sec.

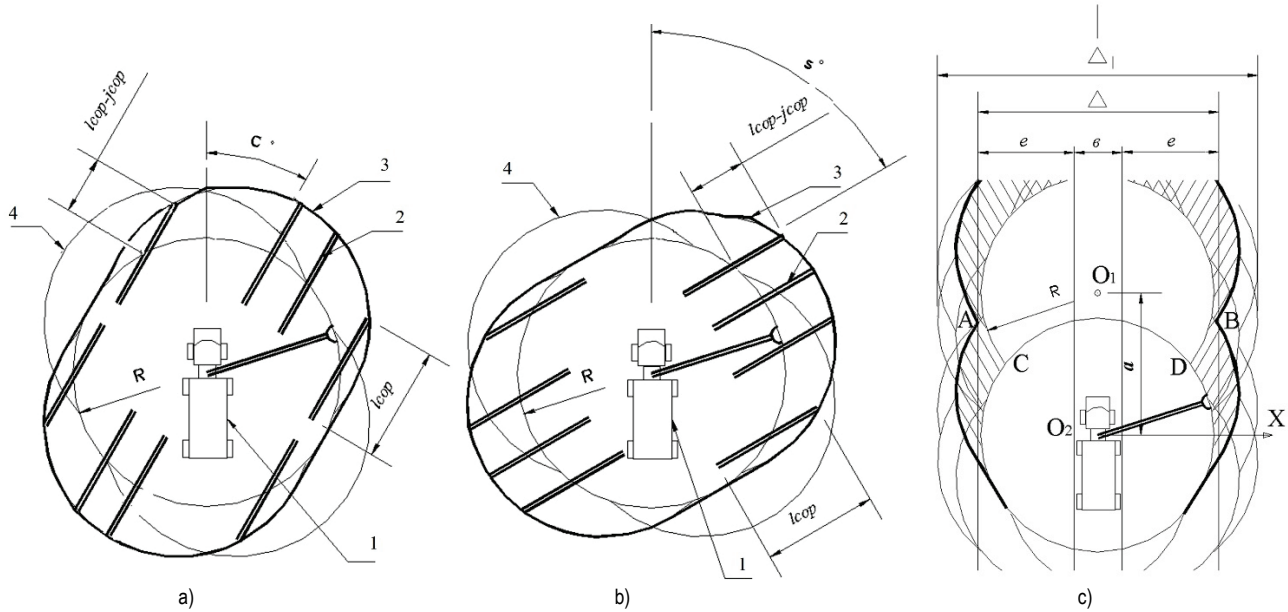


Figure 2 Calculation schemes for determining the optimal width of the forest swath and the distances between the working positions of the forwarder: a) at the minimum angle of felling of trees (α_0) located on the border of the forest swath; b) at the maximum angle of felling of trees (α_{max}); c) a combined scheme that takes into account the different arrangement of logs in the forest swath: 1 - forwarder; 2 - log; 3, 4 - zones of action of the manipulator at different angles of incidence of the tree; the direction of hatching corresponds to the direction of felling trees. Source: Compiled by the authors.

3 RESULTS

To find the optimal distance between the working positions, we will solve this equation using Newton's method proposed for solving equations of n -degree. Since the distance between the working positions is within $R < a < 2R$,

then as the first approximation of the desired value of the optimal distance between the working positions, we take $a = 1.4R$.

With further calculations, we will get

$$a = 1.4R - \frac{t_{pm}g_{pm}R[t_{pm}g_{pm}(1.02L^2 - 0.0032R^2) + 0.21952R^3] - 3.76477R^5}{t_{pm}g_{pm}[t_{pm}g_{pm}(0.448R^2 - 1.4L^2) - 14.896R^3] - 16.1347R^4} \quad (9)$$

To find the desired value with a sufficient degree of accuracy for practical calculations, we will use the equation

$$a_0 = a - \frac{f(a)}{f'(a)} \quad (10)$$

or

$$a_0 = a - \frac{t_{pm}g_{pm}\{t_{pm}g_{pm}[a^2(4(4R^2 - a^2) - L^2) + 4R^2(L^2 - 4R^2)] - 4a^3(a^2 - 2R^2)\} - a^6}{t_{pm}g_{pm}\{2t_{pm}g_{pm}[a(8(2R^2 - a^2) - L^2)] - 4a^2(5a^2 - 6R^2)\} - 6a^5} \quad (11)$$

With the subsequent replacement of a with a_0 , a more accurate value of the optimal distance between the forwarder's working positions can be obtained, although in order to find the optimal a_0 , the accuracy of which is sufficient for practical purposes, additional substitutions of the a_0 instead of the a are not required. By substituting the resulting value into the equation for calculating Δ , you can calculate the optimal value of the width of the forest swath.

Calculations were carried out for the following conditions: $q = 60 \text{ m}^3/\text{ha}$; $V_{cg} = 0.3 \text{ m}^3$; average length of the log 6 m ; $t_{pm} = 8 \text{ sec}$; $c = 30^\circ$; $g_{pm} = 1 \text{ m/sec}$; $\omega = 1$.

For the Valmet 860 forwarder with the technical parameters marked in the reference data $R = 7.2 \text{ m}$; $M = 14 \text{ m}^3$ the following results were obtained: $L = 5 \text{ m}$; $a = 9.38 \text{ m}$; $a_0 = 9.1 \text{ m}$; $\Delta = 16.1 \text{ m}$.

After substituting the parameters of the various

machines, the desired value of the optimal distance between the operating positions was 9.1 for the Forwarders Valmet 860, Ponsse S15, Valmet 840, Tumberjack 1010B, Farmi Trak 575F, LT-189 and Terri 2040D, respectively, 12.8, 9.5, 12.7, 10.9, 7.3, 6 m.

In order to solve the question of finding the optimal distance between the working positions, determining the effect of its change and checking the adequacy of the results obtained, graphs were drawn up of the dependence of the time of the collection cycle of a bundle of logs on the distances between the working positions and the forwarder (Fig. 3), which confirmed the optimal values of a_0 .

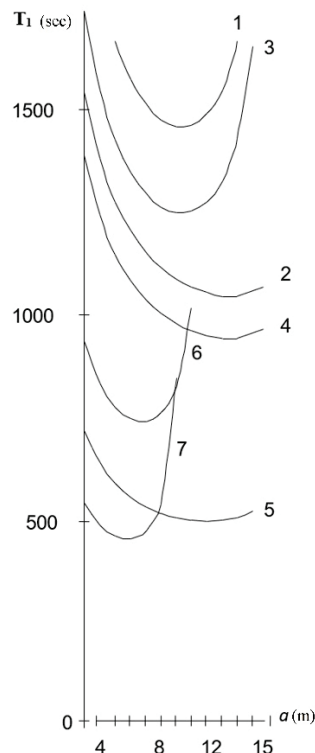


Figure 3 Graphs of the dependence of the time of the cycle of harvesting bundle of logs of timber on the average distance between the working positions of the forwarder (1 - Valmet 860; 2 - Ponsse S15; 3 - Valmet 840; 4 - Tumberjack 1010B; 5 - Farmi Trak 575F; 6 - LT-189; 7 - Terri 2040D). Source: Compiled by the authors.

4 DISCUSSION

Accurate predictions in forest operations can be used towards effective planning, costing, and maximizing the productivity of machines in mechanized cut-to-length harvesting [5]. Many scientists have been analyzing the factors affecting the forwarder's work. The forwarder's performance was evaluated based on modeling of individual elements of the cycle time. The main factors affecting productivity were recognized as: the size of the logs, the distance of the forwarding, the volume of logs forwarding at a time [10]. It is determined that the type of cutting works (thinning or final felling) has an important influence on the forwarder's performance [11, 12, 39]. It is noted that, regardless of other factors, the forwarder's operating time increases dramatically with increasing forwarding distance

[38]. These observations suggest that maximization of payload and optimization of timber extraction distance are more crucial for economic forwarding.

At the same time, the analysis of the work of forwarders conducted in the [14], shows that time consumption per load was more strongly associated with loading drive distance than with extraction distance, indicating that the relevance of extraction distance as a main indicator of forwarding productivity should be re-considered. The study of these authors increases the importance of analyzing the forwarder's work during the loading of logs. In the article [4] an assessment of the effectiveness of log forwarding using various techniques and mechanisms for felling and cross-cutting was carried out. The main task of these researchers was to determine the effect of the relative position of the logs on the speed of the forwarder manipulator during loading. The initial hypothesis that the location of logs in the forest swath during loading has an important effect on forwarder productivity has been confirmed. Loading operations on portages in the forwarder's technological cycle are well analyzed in the article [25]. The operation cycle of the forwarder manipulator on the fiber was divided into 21 loading processes. The impact of the technological features of the work during the implementation of each of the operations on the efficiency of the entire cycle of operation of this logging equipment has been assessed. Correlations have been found demonstrating the influence of a number of technical indicators on empty and loaded movements of the forwarder manipulator when loading logs.

Thus, the noted studies confirm that the process of collecting logs is an important element of the forwarder's work cycle time and should be comprehensively considered when modeling the technological process.

In addition, scientists noted that an important role in optimizing the process of log forwarding is played by the correct mathematical justification of the number of transport routes in the forest. With an increase in the number of forwarding roads, the forwarder's productivity increases, but at the same time this leads to an increase in the cost of transport routes in the forest. This analysis is based on minimizing the amount of financial costs for the construction and maintenance of forest roads, as well as the removal of logs and damage from the reduction of the area covered by forest [1, 2, 7, 8, 19, 33, 40]. As a result of these studies, the effect of the distance between the forwarding roads on the forwarder's performance has been proven. The issue of substantiating the number of skidding roads has been considered in detail from an economic point of view, but these scientific works do not address the issues of expediency of changing the technology of forwarder movements when changing the distances between forwarding roads. The next step towards improving the efficiency of log forwarding machines may be studies determining the effect of the distances between the forwarding roads on the choice of an effective forwarder technology when collecting logs.

It can be noted that scientists from different countries have carried out a significant amount of research on the analysis of the forwarder's work on the territory of various cutting areas. However, in previous studies, the influence of

the density of the forwarding road network, and, consequently, the width of forest swathes on the expediency of changing the technology of the forwarder when collecting logs has not been sufficiently studied.

Thus, the studies by other researchers of the work of logging machines do not contradict the conclusions and recommendations obtained in our article and emphasize the importance of choosing the correct parameters of the machine. In particular, the studies [36] offer a variant of substantiation of the algorithm of work and the search for rational distances between the working positions of the harvester on the basis of simulation modeling systems, including a sequence of actions that uses all the technical and technological capabilities of the machine and ensures an increase in its efficiency. However, simulation modeling, increasing the accuracy and reliability of calculations, does not allow the researcher to quickly analyze individual parameters of the machine without the use of specialized software tools.

In the work [9] an analytical calculation of the optimal parameters of forest swathes is carried out, as well as the method of their experimental determination in various natural and production conditions by methods of simulation modeling. The equations obtained in the work provide a maximum working area, and hence the maximum volume of a bundle of logs formed in the parking lot. However, the optimization of the considered indicators is carried out on the basis of the maximum area processed from one working position of the machine and does not take into account such important elements of the cycle time for forwarders as the time spent on moving between working positions, and the time of transferring equipment from the transport position to the working position and vice versa.

The noted shortcomings are absent in the work [3], but these studies are focused on the calculation of the operating parameters of forest swathes when using machine felling of wood, which has significant differences from the technology where the leading machine is a forwarder.

5 CONCLUSION

Therefore, we demonstrated in this study that the number of roads per unit area affects the technological factors of the forwarder's work.

Analyzing the equation obtained in the article, it can be concluded that the optimal distance between the working positions depends on the technical characteristics of the machine, the possibility of their implementation, the qualifications of the operator and the technology of work, and can be calculated in advance for any brand of machine engaged in the operation of collecting and forwarding logs.

One of the elements of the novelty of the work performed is the possibility of simultaneously taking into account the technical and technological parameters of the forwarder's work when collecting logs in the forest swath. The resulting mathematical dependence allows us to take into account the characteristic conditions of the use of machines. Namely, the various characteristics of the cutting areas being developed, the technological process, the method of developing the

cutting area, the angle of felling of trees located on the border of the forest swath, and to obtain adequate results.

Comparison of the labor costs for collecting a bundle, calculated taking into account the values obtained according to the mathematical dependence proposed in the article, with the calculated labor costs possible with incorrectly selected values of a and Δ , allows us to conclude that the correct choice of technological parameters of the forwarder's operation can reduce the cycle time for collecting a bundle of logs by 20%. The introduction of recommendations for determining the optimal values a and Δ will increase the efficiency of the operation of forwarders.

Acknowledgments

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Human Resource Management 4.0 - Empowerment from a Holistic Perspective

Patricia Girrbach

Abstract: The aim of this work is to examine the communication behaviour of Generation Z in a professional context and to identify their specific wishes regarding the behaviour of superiors. In addition, success factors of contemporary Human Resource Management 4.0 (HRM 4.0) are identified. A further goal of this paper is to demonstrate companies and superiors how they can meet the needs of Generation Z, in order to position themselves as good leaders and as an attractive employer in order to maintain the company's performance in the long term. The most important results of this study show that appreciative leadership behaviour creates trust between employees and superiors. This optimizes Generation Z's communication behaviour towards superiors. Furthermore, for Generation Z, an appreciative management culture that is committed to the well-being of employees is crucial for their choice of employer, their work productivity, their employee loyalty and their fluctuation behaviour. In consequence, it is essential for companies to consider the demands of Generation Z in order to remain competitive.

Keywords: empowerment; Generation Z; human resource management; leadership; social sustainability

1 INTRODUCTION

It is widely accepted that sustainability is a crucial success factor for companies, but many companies still only focus on ecological aspects. If social goals are considered, this often happens primarily regarding external social aspects in the context of corporate citizenship or donations [1, 2]. However, given the increasing shortage of employees and a new generation of employees – so-called Generation Z – this will no longer be sufficient to remain competitive. Companies must focus on internal sustainability and thus social responsibility for their employees to meet requirements of Generation Z (Gen Z). For instance, the consideration of internal social aspects such as appropriate appreciative leadership behaviour, which is also reflected in investments in the physical and mental health of employees, is increasingly important [3]. Employees are a company's most important asset, and their physical and mental health are essential factors for long-term company success [4].

This work focuses on Generation Z, those born between 1995 and 2010, since they are entering the workforce in increasing numbers [5]. The study focuses on the following research questions: (1) How can the communication behaviour of Gen Z in the workplace be described and what are the reasons for this? (2) How can superiors positively change communication behaviour of Gen Z employees? (3) What are the components of appreciative and thus trust-building leadership for Generation Z? (4) What are the effects of appreciative leadership on Generation Z?

The aim of this work is to examine the trends of the actual communication behaviour of Generation Z in a professional context and to identify their specific needs regarding the behaviour of their superiors. In addition, success factors of contemporary leadership for Gen Z Human Resource Management 4.0 (HRM 4.0) are identified, that in consequence are relevant for companies to remain competitive. The aim of this study is to generate practice-relevant insights that support companies in establishing a contemporary leadership culture 4.0 that takes into account the needs of Generation Z employees and thus promotes

internal social sustainability. Only if social capital in the broader sense is preserved by ensuring the physical and mental well-being of employees can internal social sustainability be guaranteed in the long term. Hereby, the appreciation of employees is not only proclaimed, but also implemented in the long term through appropriate leadership behaviour and investments in their physical and mental health.

The article is divided into several sections to provide a comprehensive approach to examining the success factors of HRM 4.0 in the context of companies' internal social sustainability. The second section creates a theoretical framework that clarifies the basic concepts and relevant theories. Chapter 3 describes the methodology of the empirical study, including the research design, sample selection, survey instruments and procedures, and data analysis. Afterwards the results of the study are presented and discussed. Chapter 4 summarises the most important findings, followed by implications and practical recommendations for action for designing a contemporary HRM 4.0 that meets the requirements of Generation Z. It will be shown how these results can be used in practice to increase productivity and employee satisfaction.

2 SUSTAINABILITY-ORIENTED HRM 4.0

Social objectives in corporate management such as respect for human rights, fair working conditions as well as the promotion of employee engagement and employee development are crucial for a holistic sustainability strategy and contribute significantly to the long-term stability and competitiveness of companies [2].

Companies which neglect the internal social dimension of sustainability will face challenges such as lower employee satisfaction, higher turnover rates, and a poor reputation, which will affect their competitiveness in the long term. Particularly in view of the increasing shortage of employees and the demands of Generation Z, the aspect of social sustainability in companies is coming to the fore.

Social sustainability in an internal context requires, above all, modern HRM that takes into account the needs of Generation Z in order to be sustainable. HRM 4.0 often focusses on the technological component of digitalization and forgets that still people use these technologies and are confronted with them. For this reason, the concept of HRM 4.0 is expanded in this work so that the focus moves away from technological aspects towards the employees of the future, Gen Z.

HRM 4.0 is based on an appreciative leadership culture, which is reflected in an appreciative behaviour of managers as well as in investments in the mental and physical health of employees, which is increasingly affected, especially in times of digitalization [5, 6] (Fig. 1).

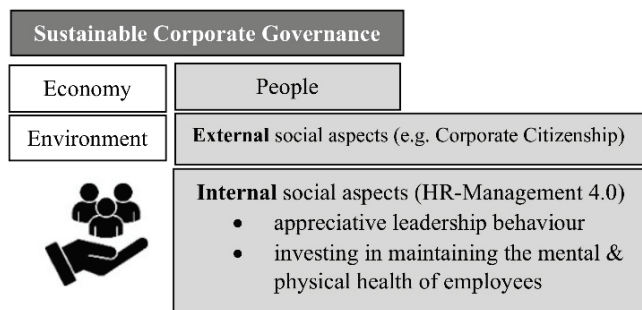


Figure 1 Elements of sustainable corporate governance

Companies which implement HRM 4.0 through a culture of appreciation will be able to successfully position themselves as attractive employers to Generation Z in the long term, as the following study will show.

3 STUDY ON GENERATION Z

In the following, the chosen methodology and research design as well as the sample selection are explained and justified. Then, the data analysis and results are presented, critically reflected, and compared with the results of other studies.

3.1 Methodology, Research Design and Sample Selection

The aim of this study is to examine the communication behaviour towards superiors and leadership preferences of Generation Z in a professional context. Moreover, this study aims to show effects on the behaviour of Generation Z and resulting advantages for companies when these demands are met. Thus, the interest of this study is to demonstrate companies and managers the relevance, components, and extent of the positive effects of an appreciative leadership culture that meets the requirements of Gen Z. Only then can social sustainability not only be proclaimed in the company, but also actively lived and anchored.

The study was sent to 320 students. The participants live and work in various cities in Germany such as Karlsruhe, Stuttgart, Freiburg, Regensburg, Mannheim, and Frankfurt. In this context, 265 questionnaires were received. Due to quality standards, only 251 were used for the analysis ($n = 251$). This is because some participants did not answer all

questions on the questionnaire. Another reason for the rejection of the questionnaires was that some students were too old and therefore did not belong to Generation Z. To ensure that the research design is valid, objective, and reliable, various factors were considered when conducting this survey.

To ensure reliability, the questionnaire was used as a standardised measurement tool and care was taken to ensure that the questions were clear and consistent when conducting the survey. So, the same results would be obtained with repeated questioning. In addition, various test versions were tested prior to the final version of the questionnaire to identify and eliminate potential problems with data collection.

To ensure objectivity as an important quality criterion for empirical studies, care was taken to minimise the bias of the researcher, both in the formulation of the questions and in the interpretation of the results. Thus, the objectivity of the study is ensured by the design of the questions, as all questions were formulated neutrally and do not contain any implicit opinion of the researcher. The answer options, which only offer clear, unambiguous evaluation options, also leave no room for interpretation, and can therefore be evaluated objectively, regardless of who analyses the data. In addition, the anonymised, standardised survey procedure, the use of coding procedures and the deployment of independent observers ensured an objective evaluation of the data.

Furthermore, quantitative, and qualitative methods were combined to improve the validity of the results and identify potential sources of error. In this context the study uses a standardized questionnaire based on the Likert scale with integrated open questions [7].

It is also important that the selection of the sample adequately reflects the research topic. For this reason, not the entire age range of Gen Z was surveyed, but only those who are already working. Gen Z is generally categorised as people born between 1995 and 2010 [5, 8], which means that the oldest is 29 and the youngest is 14. Hereby, it is important to mention that this paper only focuses on the working part of this generation, as it is important to have experience in professional life. Therefore, only participants between the ages of 18 and 29 were selected to ensure the validity of the study. The participants are students at the International University in Germany. They are studying e.g. media design, tourism management, marketing management, human resource management, health management, business administration, media design, tourism or marketing management. All participants are dual students, i.e. they are already working in their field of study, e.g. as a medical assistant, media designer or hotel waitress. The fact that all participants have a specific educational background, namely that of the degree programme, could lead to a bias of the answers. In addition, only a subset of the Gen Z age group, namely adults, is covered. The younger subgroup of Gen Z is underrepresented. The generalisation to the entire Gen Z is therefore limited.

The reason why Generation Z in particular was chosen as the target group for this study is, firstly, that they are entering the workforce in increasing numbers [5]. Therefore,

their preferences and behaviours have a significant impact on organisational dynamics and practices. Secondly, Generation Z is the first generation to have grown up entirely in the digital age. Their fluency with technology and social media has fundamentally changed the way they handle information and interact with other people. This also affects their behaviour at work. It is therefore important to recognise and analyse the potential changes compared to previous generations and to respond appropriately in order to remain competitive as an attractive employer.

The mixed methods approach was chosen as research method, which combines quantitative and qualitative data analysis [9]. It is justified for several reasons that can be derived directly from the objectives and requirements of the study: The combination of quantitative and qualitative methods makes it possible to capture both the breadth and depth of the subject of the study [9]. While quantitative data offers the measurement and analysis of the general trends and correlations between appreciative leadership culture and their impact on employee behaviour and company success, qualitative data allows a deeper understanding of the individual wishes, experiences, and perceptions of Generation Z. By using both methods, the results can be validated, and the credibility of the findings can be increased. When both quantitative and qualitative data support similar conclusions, the reliability of the study is strengthened. This is particularly important to provide convincing evidence of the importance of an appreciative leadership culture. The qualitative data can be used for further research to generate or refine hypotheses, which are then tested through quantitative analysis. This allows for an iterative approach to the topic, where qualitative insights guide the quantitative investigation and vice versa. Quantitative methods provide a comprehensive overview of the effects of an appreciative leadership culture, while qualitative methods provide additional dimensions and context that may not be captured in quantitative data. This expands the understanding of the effects and mechanisms of an appreciative leadership culture.

In summary, mixed methods approach was chosen to enable a comprehensive and valid investigation of the effects of an appreciative leadership culture on Generation Z employees and company success. This combination of methods allows both general trends and statistical correlations to be identified as well as deeper insights into individual experiences and contextual factors. The visual representation of the results supports the quick and effective communication of the study results to managers, which is crucial for the practical implementation of the theoretical findings.

The research design and therefore the structure of the study is presented below, which describes how the study was carried out to answer the research questions already presented.

A multi-stage research process took place. In a preliminary study, many statements were collected during interviews to specify the main possible dimensions and important aspects of the survey. This was followed by another round of interviews, which served to further specify the components of appreciative, trust-promoting leadership

and to shed light on the effects of such leadership on the behaviour of employees.

A standardized questionnaire was then designed. This resulted in standardized data collection that combines quantitative and qualitative elements. On the one hand, as part of the quantitative data analysis, the students were presented with individual statements and the respondents' agreement, or disagreement was scaled. Hereby, the Likert scale was used with 5-point scales with verbal support (strongly disagree – completely agree) being presented for each statement [7, 10]. On the other hand, the survey also collected qualitative data, which was obtained and analysed based on the open questions in the questionnaire. Based on this, the answers were categorized according to Mayring's qualitative content analysis methodology [10].

The dimensions of the survey initially included the communication behaviour of Gen Z in the work environment towards superiors, as well as the question of possible reasons for the uncertainty found here. The question was then asked about possible behaviours of superiors that could have a positive influence on the communication behaviour of Generation Z. Significantly, appreciation and the resulting trust were shown to be fundamental for positive leadership behaviour. The question was then asked about the most important factors that characterize appreciative leadership. Finally, the effects of such leadership on the behaviour of the respondents in the work environment were asked.

3.2 Data Analysis and Results

The study shows that high personal insecurity among Generation Z is a common phenomenon in communication between Generation Z employees and managers (70% agree). The reasons for this general uncertainty are the increasing flood of information, the increased consumption of social media and the ideals of beauty conveyed therein, which, in the opinion of the respondents, promote self-doubt (77% strongly agree, 23% agree). According to the participants, these effects cause a strong sense of insecurity, especially at a young age, which also persists in later life. Generation Z is also characterized by very unstable living conditions and the resulting additional uncertainty, which is experienced as an unpleasant permanent condition [5, 8].

As a result of this uncertainty, Generation Z is inhibited in their communication behaviour, especially towards superiors (70% agree). Generation Z employees are hesitant to openly express their thoughts and ideas because they fear negative consequences or rejection. This leads to a lack of transparency, innovation and efficiency in the work environment and affects long-term team performance. In this context the participants have the opinion that managers could counteract existing communication problems through appreciative, trust-promoting behaviour.

For the respondents appreciative, trust-promoting leadership is based on several aspects such as support by superiors (46% strongly agree, 38% agree), respect and appreciation for performance (76% strongly agree, 23% agree), empathy and understanding in dealing with employees and, above all, communication at eye level (76%

strongly agree, 23% agree). Moreover, a trust-promoting leadership is characterized by an open communication (46% strongly agree, 53% agree). Managers should actively listen to understand the needs and perspectives of their employees. In addition, the reliability of statements from managers (69% strongly agree, 30% agree), transparency (76% strongly agree, 23% agree) and fair and equitable treatment of all employees regardless of their position were rated as important for sustainable trust building (53% strongly agree, 46% agree) (Fig. 2).

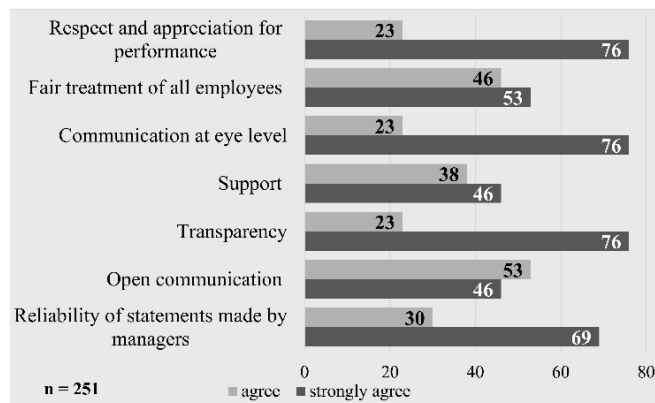


Figure 2 Components of appreciative trust-promoting leadership

Hereby, the appreciation of employees includes not only verbal expressions of appreciation such as praise, but also support in the form of investment. Especially investments in mental well-being and mental health are viewed as very important (62% strongly agree) as an expression of appreciation. Hereby, individual coaching to maintain physical and psychological stability is becoming increasingly important in uncertain times. This is caused in the reason that the demands on employees in terms of their performance and productivity are high, which often leads to stress, overwork and burnout [5]. Coaching, focusing on mental and physical aspects, is therefore an effective tool for promoting employee health and performance, which Generation Z employees are increasingly demanding. Employees learn, for example, effective coping strategies for stressful situations and concrete measures to strengthen their resilience.

In the following the direct and indirect effects of appreciative leadership on Generation Z are shown. The implementation of appreciative HRM 4.0 is identified as a solution to the existing uncertainty and inhibited communication behaviour of Gen Z towards superiors. Superiors act as role models and demonstrate credibility by actively modeling such appreciative behaviour [11]. The respondents are convinced that such a HRM 4.0 has direct influence on building trust and thus reduces indirectly existing insecurities (83% strongly agree, 17% agree). This would significantly improve their communication behaviour with superiors in everyday work (77% strongly agree, 15% agree), because it eliminates the fear of rejection or negative reaction from the superior, which the respondents consider to be the main reasons for this inhibited communication behaviour. Moreover, appreciative leadership and the building of trust promote work productivity (70% strongly agree, 30% agree) and employee loyalty (76% strongly agree, 23% agree) (Fig. 3).

agree, 30% agree) and employee loyalty (76% strongly agree, 23% agree) (Fig. 3).



Figure 3 Direct and indirect effects of appreciative leadership

The results of the study clearly show that for Gen Z, an appreciative management is crucial for their choice of employer (62% strongly agree), employee loyalty (76% strongly agree) as well as fluctuation behaviour and thus staying in the company.

Failure to comply with these requirements could result in termination. The most common reason given by those surveyed for changing employers is a lack of appreciation from managers (69% strongly agree, 30% agree), followed by poor working conditions (54% strongly agree, 46% agree), a lack of support (38% strongly agree, 38% agree) and financial aspects (46% strongly agree, 54% agree).

Now the question arises: How can these results be used in practice to increase productivity, efficiency and employee satisfaction? First, it is important for managers to understand that Generation Z's communication behaviour has changed due to the existing personal uncertainty. This can have a negative impact on the work area. Furthermore, the demands and needs of Gen Z are different from those of previous generations. Therefore, it is crucial to deal with their demands appropriately. Second, options for overcoming these challenges are presented.

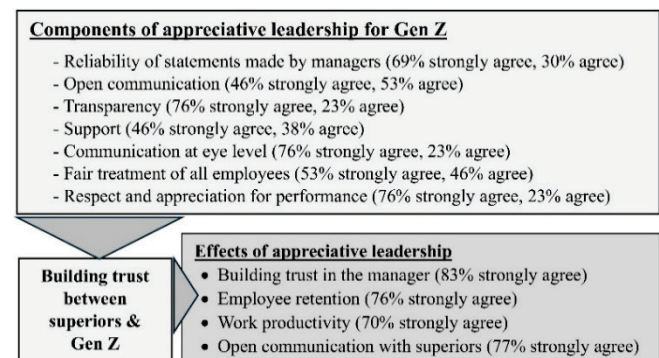


Figure 4 HRM 4.0 & its effects on Generation Z

According to the results, superiors who treat employees on an equal level with respect and support can build a relationship of trust. As the study shows, this is very important. On the one hand, this will change the communication behaviour of Generation Z employees. Hereby, an open communication optimizes business activities, as problems that arise can be mentioned and solved directly instead of creating even worse consequences. From a practical perspective, it can be useful for Generation Z

employees to privately present their ideas, suggestions or their own emerging problems and challenges to their manager. So, neither the manager loses authority nor the employee is afraid of losing respect from others. On the other hand, appreciative, trust-promoting leadership will increase also the productivity, and employee satisfaction, what is crucial for choosing an employer and staying in the company, as the results show (Fig. 4).

3.3 Discussion of the Results

In the following the results of the study are discussed critically and limitations of the paper are presented. Moreover, the results are aligned to other studies in this field.

With regard to the sample, a broad spectrum of different participants from different geographical regions in Germany was selected. Care was also taken to ensure that they cover a variety of study programs and related professions. However, all participants are dual students with a specific educational background, namely studying at a university. So, the focus was placed on students. This could lead to a bias of the answers. Therefore, surveying members of Generation Z who are currently undergoing or have already completed vocational training could lead to further interesting results. In addition, only a subset of the Gen Z age range is covered, as a study of 14 to 17-year-olds does not make sense regarding the research questions. The generalisation to the entire Gen Z is therefore limited. The results rather present the adults of Gen Z. The subgroup of Gen Z is underrepresented here. Moreover, the survey focuses only on German students. So, it would be interesting to extend further research to other countries.

Another limitation of the study is its theoretical focus. As described in the paper, fulfilling the wishes of Generation Z requires the active involvement of superiors. In their role as mentors, they should offer the employees of Generation Z guidance and support each employee individually. These additional demands on employee management pose a challenge in view of the existing burden on management staff. Managers are often required to perform a balancing act between their previous understanding of their role and the changed expectations of the Generation Z which are shown in this paper. Therefore, a reorientation of the management role and additional training in leadership as well as in employee management issues are necessary. In this context the knowledge of the specific requirements of the Generation Z shown in this paper can serve as an initial orientation. Nevertheless, a limitation of the study is that it does not show an implementation plan or a guideline how these conflicts and challenges can be solved in practice. These aspects would be interesting for further research.

In the following the results are compared with the results of other studies. There are corresponding studies that also examine the characteristics of Gen Z and their expectations of employers and managers. For example, when it comes to the characteristics of Generation Z, Deloitte also notes that nearly half of Generation Z feel stressed or anxious at work all the time or very often [12]. Results of other studies show that feel-good factors are particularly important for

Generation Z when choosing an employer. A caring attitude from superiors in professional life is therefore recommended [13, 14].

A study by the Federal Ministry of Labor and Social Affairs examined the extent to which employees of all age groups are willing to commit themselves to the workplace and commit to an employer in the long term. The result of this study is that this depends above all on an employee-oriented organizational culture. In general, fairness, respect, team orientation and individual support of employees are considered important [15]. This also agrees with the results of the present study. In addition, there are studies that, in line with the present study results, show that good, harmonious collaboration promotes employee satisfaction. According to the studies, this is how companies secure their workforce and their existence in the face of demographic change [16]. In this context, Klaffke's generation management also aims to increase employer attractiveness by designing the operational conditions in such a way that all age groups in the company are able and willing to contribute and exploit their performance potential [13]. In this respect, there is agreement with the study results of this study.

Although some of the studies mentioned reached similar conclusions, Gen Z's communication behaviour specifically with their managers was neglected. This study closes this gap by focusing on the relationship between employees and their superiors. It also highlights Gen Z's expectations of their managers' behaviour and the resulting positive impact when these expectations are met.

Likewise, previous studies lack a concrete analysis combined with a clear visualization of the extent of the direct and indirect effects of appreciative and trust-building leadership on the behaviour of Gen Z employees in the professional environment. This gap is closed by the present study. The results are clearly visualized and presented graphically in bar charts and in the theoretical model, which shows the effects of HRM 4.0 on employee behaviour (Fig. 2, 3, 4).

This visualization of the direct and indirect effects of modern HRM 4.0 is important to give today's managers a quick and meaningful impression of the influence their leadership behaviour has on Generation Z employees. Only with a clear presentation can the necessity and importance of appropriate leadership behaviour be made clear, especially since managers hardly have time to deal with articles and their most important quintessences. This is crucial for ensuring that the theoretical recommendations find their way into practical implementation. So, visualization shows companies and managers the relevance of modern HRM that meets the requirements of Gen Z, which is becoming increasingly important in times of labour shortages.

4 CONCLUSIONS

First of all this study focuses on the research question how can the resulting communication behaviour of Generation Z in the workplace be described and what are the reasons for this? The study shows that Generation Z is

characterized by a high level of personal insecurity when communicating with superiors (70% agree). This high level of uncertainty has an impact in the professional context through the resulting inhibited communication behaviour towards managers. The reasons given for this uncertainty were the increasing flood of information, the increased consumption of social media and the ideals of beauty conveyed therein, which, in the opinion of those surveyed, promote self-doubt (77% completely agree).

The second research question was if superiors could change that communication behaviour in a positive way. The participants clearly confirm this and state that appreciative leadership behaviour creates trust between them and their superiors and thus optimizes their communication behaviour towards superiors.

The third research question focuses to concretize the components of appreciative and trust-building leadership for Generation Z. For the participants, appreciative, trust-promoting leadership is characterized by support and open communication. It also includes respect and appreciation for performance, empathy and understanding when dealing with employees, and communication on an equal level. In addition, the reliability of managers' statements, transparency and the fair and equal treatment of all employees were assessed as essential for building trust (Fig. 2).

The last research question focusses on the effects of appreciative leadership on Generation Z. The results of the study clearly show that for Generation Z, an appreciative management culture is important. The respondents are convinced that it has direct influence on building trust and thus reduces indirectly existing insecurities. This would significantly improve their communication behaviour with superiors, because it eliminates the fear of a negative reaction from the superior. Moreover, appreciative leadership and the building of trust promote work productivity and employee loyalty (Fig. 3).

The results of this study clearly show that appreciative leadership and investments in employee health promote a positive culture of trust in which Generation Z employees can develop freely and exploit their full potential. Managers act as key people for successful organizational cultural change because appreciative leadership improves decision-making processes, especially in today's uncertain, complex times, and promotes employees' identification with the company [3], which has a positive effect on company performance.

A contemporary HRM 4.0 that meets the needs of Generation Z should consider holistic coaching as an integral part of its personnel development strategy. Programs that are tailored to the individual needs of employees should promote physical and mental health [17]. This can be done through workshops, and individual coaching on topics such as stress management, work-life balance, and personal development. These investments in the well-being and physical and mental health of employees are increasingly being demanded by Generation Z as an expression of appreciation.

HRM 4.0, which meets the needs of Generation Z, will help companies position themselves as an attractive employer and maintain the company's performance in the long term.

Although Generation Z, unlike previous generations, is not original in its attitudes, thoughts and demands, there is a significant difference from previous generations. Generation Z grew up with a large presence of social media, countless information and insecurities that influence personality and result in a lack of self-confidence. Of course, newcomers are always looking for respect or open communication with superiors and expect constant improvement of their knowledge through courses and training. Nevertheless, the mentioned significant change in the communication behaviour and the growing insecurity of Generation Z represents a new challenge for companies. This is crucial because companies need an appropriate communication culture to be able to react quickly to increasingly rapidly changing circumstances. In addition, they need Generation Z as employees who will choose the company that best meets their needs. So, yes, Generation Z is not original in their attitudes and in their thoughts and demands, but they are original in terms of the circumstances in which they grew up, which have a great influence on the workplace and the success of companies. This allows companies to decide whether to ignore the insights presented in this paper or remain competitive. Especially at a time when the war for talent is becoming increasingly intense, employee appreciation as a tool for retaining and recruiting employees is becoming more and more important for the long-term success of companies.

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Tools of Artificial Intelligence Technology as a Framework for Transformation Digital Marketing Communication

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Abstract: The article researches the transformative possibility of Artificial Intelligence (AI) technology tools in digital marketing communications. By leveraging machine learning, natural language processing, and data analytics capabilities, AI tools enable marketers to automate tasks, personalize content, optimize campaigns, and gain deeper insights into customer behaviour. The paper examines applications of AI in digital marketing, analyses the way of transforming digital communication by AI, compares it to the traditional PESO communications model, presents the utilization of AI tools within the PESO framework and their collaboration to enhance communications, and proposes a framework for successful implementation. The research question in this paper is: how do artificial intelligence tools transform communication in a digital marketing environment? The results provide valuable insights into how AI-based technology transforming digital marketing communications.

Keywords: Artificial Intelligence; Digital Communication; Digital Marketing; PESO Model; Transformation

1 INTRODUCTION

Digital technologies such as artificial intelligence (AI) are known to be highly complex and continuously evolving. Embracing them necessitates organizations to consistently realign their resources, personnel, culture, and decision-making procedures [1]. They are defined as "products or services that are either embodied in information and communication technologies or enabled by them" [1]. They exist as digital platforms or artifacts with digitized components. While there are various types of digital technology, they all share a common theme: separating digital information from the physical form of the device [1]. Digitalization extends beyond implementing technology to signify a fundamental shift in the entire business model and the evolution of work [1]. AI has been touted as a means for organizations to reduce costs and enhance the quality of their services, coordination, productivity, and operational efficiencies [1]. According to a market analysis of global AI in marketing, it is projected that the global AI in marketing market will experience a compound annual growth rate (CAGR) of 30% between 2023 and 2028 [2]. This demonstrates the rapid growth and adoption of AI in the marketing sector worldwide. Additionally, research by Statista shows that 84% of marketers are either using AI in their marketing activities or planning to do so, indicating the widespread adoption of AI among marketing professionals [2]. Furthermore, a study by Gartner predicts that by 2025, 80% of marketing organizations will utilize AI to personalize customer experiences, highlighting the increasing emphasis on using AI for customer-centric marketing strategies [2].

Spending on AI-powered advertising is expected to reach \$35 billion worldwide by 2025, indicating a significant rise in AI-driven marketing budgets [2]. The rapid growth of AI technologies emphasizes the need for extensive research in this field, as they are increasingly utilized in various business operations creating new opportunities for digital transformation, and presenting fresh challenges for process managers.

This article aims to identify available scientific literature and AI tools as a framework for transforming digital

marketing communications and to determine how AI tools transform digital communication.

Literature reviews on AI tools in digital marketing communication are being conducted, analysing key applications and benefits, and describing utilization of AI tools within PESO digital communications framework and provide examples of how they are incorporated in practice.

The primary aim of our research was to explore the ways in which artificial intelligence tools are revolutionizing communication in the context of digital marketing, how AI reshaping communications and compare it to the traditional PESO communications model (paid, earned, shared, and owned media). Furthermore, the study presents the utilization of AI tools like ChatGPT within the PESO framework. It determines how they can collaborate to enhance communications and also explores how businesses can use ChatGPT to enhance their PESO communications strategy.

The scientific contribution of this study is an exploration of a relatively unexplored and under-researched field, guiding future studies of AI-based technologies that enhance digital marketing communications.

The paper is structured as follows: Firstly, we outline the aims and purpose of the study. The main section of the study will introduce the research approach, including a review of the literature, an exploration of the framework for developing a comprehensive digital communication strategy, and an analysis of AI tools that transform communication. Our research findings offer valuable insights into the potential and challenges of AI in revolutionizing digital marketing communications. Finally, the last part of the paper will cover research limitations and provide recommendations for future research.

2 RESEARCH APPROACH

Through an in-depth analysis of relevant literature, we have identified the framework for developing an effective communication strategy in digital marketing. Additionally, we exemplified how AI, illustrated by Chat GPT, is reshaping digital transformation.

2.1 Literature Review

AI tools are pivotal in enhancing digital communication across diverse industries. These tools empower designers by expanding the range of solutions available [3], enable marketers to craft personalized customer experiences and gain a deeper understanding of their audience [4]. AI-powered tools not only provide quick insights and simulations to designers but also facilitate personalized and automated message-based interventions to promote sustainable lifestyles and healthy choices [4]. When integrated into digital marketing, AI allows marketers to automate tasks, enhance customer interactions, and gain insights into consumer behaviour, ultimately simplifying their work and improving communication strategies.

The utilization of AI tools in digital communication continues to transform various industries, offering innovative solutions and enhancing overall efficiency. According to citation database Web of Science there is a great interest in studying AI tools that are involved in all segments of life and speed up work processes and automation. Analyzing the available articles using the keyword according to the topic "AI and digital communication", 874 articles are available, which leads us to believe that this is still an unexplored topic. The oldest works appear in the early nineties of the 20th century. Refine our search by Web of Science Categories: Business, Management, and Economics we get 68 articles.

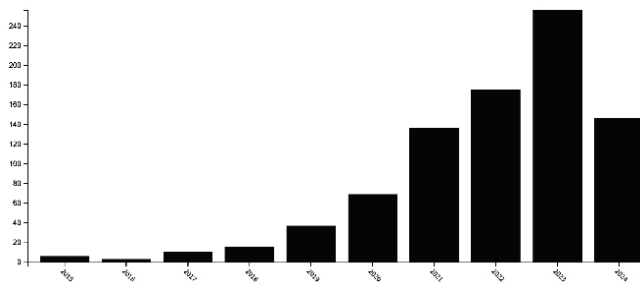


Figure 1 AI and digital communication Articles from Web of Science Published by Year [5]

By examining the documents, the thematic framework evolves to prioritize personalized user experience and the utilization of various AI tools in their integration into the business process. When we look at the broader digital economy, AI technologies, such as machine learning and big data analytics, are transforming various sectors, improving efficiency, and personalizing customer experiences [6]. While AI offers significant value for businesses in areas such as process automation, decision-making, and personalization, its implementation also presents challenges related to security, privacy, and staff training. Successful AI application requires a strategic approach, including adaptation of work processes and organizational culture [7].

AI tools are transforming digital communication across various domains, including social media marketing, healthcare, and interpersonal interactions. In social media, AI-powered tools enable automated analysis of key performance indicators, supporting decision-making in

marketing strategies [8]. However, the accessibility of AI-mediated communication (AI-MC) tools varies based on factors like software access, demographics, and AI literacy [9]. In healthcare, AI chatbots offer versatile applications for information dissemination, appointment scheduling, and patient support, though challenges remain in their integration [10]. Across diverse contexts, AI technologies like virtual assistants, chatbots, and translation tools promise enhanced efficiency, personalization, and accessibility in communication. While these advancements offer significant benefits, further research is needed to address ethical concerns, improve accessibility for vulnerable groups, and develop user-centered guidelines to ensure responsible innovation in AI-mediated communication [11].

Travel and tourism industry (TTI) stands to gain the most from artificial intelligence (AI), potentially reshaping the entire industry [12]. Blümel identifies how customer service agents and conversational artificial intelligence (AI) applications can provide a personal touch and improve the customer experience in customer service [13]. The potential of AI tools in marketing communication suggests that there is a need for future research to delve into the impact of integrating AI into digital marketing on consumer behavior and brand-to-consumer relationships. Investigating the long-term effectiveness and sustainability of digital communication tools can provide insights into improving communication practices.

Examining the potential ethical implications and societal impacts of the widespread adoption of AI in digital marketing, such as job displacement and privacy concerns, to ensure the responsible and accountable use of AI in marketing practices.

2.2 Theoretical Background: A Framework for Developing a Comprehensive Digital Marketing Communications Strategy

AI has substantial potential within the field of marketing. It facilitates the dissemination of information and data sources, enhances the capabilities of software data management, and develops sophisticated and advanced algorithms [14]. AI is revolutionizing the dynamic between brands and users, fundamentally altering the nature of their interactions [14].

The definition of digital communication describes any electronic transmission of information that is digitally encoded and transmitted through digital media [15]. This available data covers multiple communication formats and different communicators (e.g. consumers, traders, etc.) [15]. Digital communication, can also be broadly categorized as one-way (e.g. digital ads, customer reviews, etc.) or interactive (e.g. chats via e-services, online brand communities, etc.), and it appears on a large number of platforms (e.g. Instagram) and stores (e.g. digital signage). As digital communication is purposefully constructed, repetitive, and subject to change, its dynamic development is just as important as its current content. In addition to its dynamism, digital communication is characterized by

different modalities (e.g. numerical, textual, audio, image, and video) [15].

The success of the PESO model as an integrated approach to digital communications is reflected in its application in practice in the last 10 years. Gini Dietrich, the author, and originator of the PESO Model™, introduced in 2014, combines paid, earned, shared, and own digital content to establish the thought leadership, credibility, trust, and authority that fuel a brand's reputation [16]. The PESO Model is used by experts to develop marketing or communication programs, suggesting how to strategically integrate the four types of digital content, how to measure results, and how to influence the organization's goals [16]. The PESO model has evolved from the initial categorization of media content into paid, owned, and earned, which Burcher calls the "media trinity" in 2012 to the present day, i.e. from the approach of acquiring space in the media for the distribution of brand messages in which marketers have access to three key types, i.e. the "media trinity" [16]. The rise and growth of social media and widespread access to the internet for direct publication by organizations have radically changed production and distribution strategies in both public relations and corporate communication, as well as in integrated marketing communication, with the priorities of the PESO model [17]. Undoubtedly, the importance of social media marketing has become a key foundation for organizations that communicate with existing and potential consumers [18]. Social media allows organizations to directly promote their brand and products to consumers and receive direct feedback [16]. For this, organizations use all four elements of the PESO model in social media to generate a positive attitude about the brand [16].

The integrated PESO model combines four types of digital content (paid, earned, shared, and owned) to frame a comprehensive media strategy. According to Gini Dietrich, the foundations of the integrated PESO model are [16]:

- 1) Paid media for a communication program refers to advertising on social media sites, sponsored content, and email marketing.
- 2) Earned media is commonly known as publicity or media relations. Content is recognizable by the printing of the name of the brand and/or organization, and includes publications in newspapers or trade publications that write about the brand and/or organization, then for example appearing in the midday news where experts would talk about their product or appearing in podcasts. Everything that the public relations industry is commonly known for because it is one of the few tangible things done so far.
- 3) Shared media is known as social media that evolves and continues to build on and beyond only the marketing or customer service teams that use it. Organizations have begun to use it as the main source of internal and external communication. This includes not only social networking, but also community, partnerships, distribution, and promotion.
- 4) Owned media is primarily known as the content that an organization owns and "lives" on its website and/or blog.

The organization controls the sending of messages and tells the story the way it wants.

When these four types of media content are integrated, it is revealed that there is also influencer engagement, partnerships, and incentive programs that go beyond the internal boundaries of the organization itself [15]. An organization's digital content elements can be used in social media marketing to generate a positive attitude about the brand [18]. In 2024 Dietrich's insight into understanding PESO model integrated approach in today's digital age is pivotal. For this reason, traditional success metrics, like media impressions, number of stories, follower numbers, or advertising equivalencies, are insufficient for capturing the actual value and reach of communications activities [19].

As one of the most significant advantages of the PESO model, when it achieves the set goals and works best, the author states that it can help organizations establish authority [15]. For Dietrich, authority means that the organization and/or brand is a thought leader, who is viewed by others as an expert, even by competitors themselves, while Google positions him on the first page of results because it also recognizes him as an expert [15].

2.3 AI Transforming Communication: Comparison of the Use of ChatGPT and the PESO Model

AI is poised to enter a transformative phase, where its utilization will lead to enhanced productivity, organizational efficiency, and increased profitability for businesses [20]. By leveraging AI, organizations can achieve a deeper understanding of customer needs and behaviors, thereby fostering and sustaining customer loyalty [20]. As AI technologies become increasingly cost-effective and accessible, they are expected to emerge as indispensable assets for digital marketers [20]. These advanced methodologies are likely to wield substantial influence over consumers' decisions regarding brand selection and product preferences. Consequently, it is imperative for markets to integrate these technologies into their operations to facilitate growth and align with evolving customer expectations. Notably, AI technology applications are anticipated to disrupt the digital marketing landscape over the forthcoming decade [20].

Rapid advancements in technology have firmly established AI as a critical and indispensable element in modern communications [21]. The potential of AI to significantly enhance the industry lies in its ability to improve efficiency, boost productivity, and refine audience targeting [21].

As businesses and organizations continue to navigate the ever-evolving landscape of communications and marketing, it's crucial to comprehend the different strategies and tools available. Many AI tools enable the transformation of communication like Google Bard (LaMDA), Microsoft Bing Chat, Anthropic's Claude, Meta's LLaMA, Amazon Lex, IBM Watson Assistant, Replika, Dialogflow, Rasa, ChatGPT, etc. AI and natural language processing have given businesses a new tool for enhancing communications and marketing efforts.

ChatGPT, a powerful language model created by OpenAI is selected for further analysis. ChatGPT can help with various tasks, including content generation, answering questions, and offering personalized recommendations [21].

The PESO Model is a framework for developing and executing a comprehensive communications strategy that covers all forms of media. Experts in the field recommend implementing the PESO Model using ChatGPT and emphasizing the importance of human editing, illustrated in Tab. 1, which compares the use of ChatGPT and the PESO model [21].

Incorporating ChatGPT and the PESO model in communication (Tab. 1) provides various benefits, regarding better efficiency, upgraded audience insights, improved messaging control, and powerful relationship building. Also, should be considered some challenges, such as adopting new technologies and the possibility of overuse of AI tools [21].

Table 1 Comparison of the use of ChatGPT and the PESO model

Aspect	Traditional communications without ChatGPT	Communications with ChatGPT and PESO model
Media types	Focused on owned and earned	Incorporates paid, earned, shared, and owned media
Efficiency	Relies on manual effort and time-consuming tasks	Can improve efficiency and productivity by automating certain tasks
Audience insights	Limited understanding of audience behavior and preferences	Can provide valuable insights into audience behavior and preferences through AI analysis
Messaging control	Relies on interpersonal communications and limited control over messaging	Allows for greater control over messaging and communication through ChatGPT
Coverage placement	Limited ability to influence coverage placement	Can use AI tools to monitor and place stories to improve odds of favorable coverage
Relationship building	Relies heavily on traditional relationship-building methods	Can use shared media and AI tools to build relationships with influencers and target audience

Table 2 Revolutionizing marketing and communications with the assistance of AI

PESO model	AI applications	Examples
Paid Media	Programmatic Advertising	Using AI algorithms to automatically purchase and optimize ad placements for maximum ROI
	Chatbots	Using chatbots to automate customer interactions and improve customer service
Earned Media	Media Monitoring	Using AI-powered tools to monitor media coverage and track sentiment around a brand or topic
	Influencer Identification	Using AI algorithms to identify and connect with influencers who are most likely to engage with a brand's message
Shared Media	Social Listening	Using AI to monitor social media conversations and identify trends and insights relevant to a brand or industry
	Content Creation	Using AI to generate personalized content that resonates with specific audiences
Owned Media	Website Personalization	Using AI to personalize website content and user experiences based on user behavior and preferences
	Chatbots	Using chatbots to automate customer interactions and improve customer service

Tab. 2 provides an example of how AI is revolutionizing marketing and communications using the PESO model as a framework [21].

Tab. 2 provides an in-depth analysis of AI transforming marketing communication by outlining specific guidelines for its application across the PESO model [21]. This comprehensive overview serves as a fundamental stepping stone for conducting extensive research into additional AI tools that can be leveraged for marketing purposes.

In marketing, ChatGPT can enhance content creation, customer service, and research efficiency [22]. However, ethical considerations and potential risks must be carefully managed [22, 23]. The technology's applications extend across various industries, including healthcare and education, with challenges such as data biases and safety issues requiring mitigation strategies [23]. In communication strategies, ChatGPT offers advantages in social media, customer support, and content creation, though its implementation comes with both benefits and drawbacks [24].

The findings affirm AI's significant potential in reshaping digital marketing communications. However, the responsible and strategic adoption of AI tools is crucial. Future research should focus on the long-term impacts of AI, ethical considerations, and developing frameworks that balance AI capabilities with human expertise.

3 RESEARCH RESULTS

The study yielded the following key results based on the systematic literature review and analysis of AI's integration into digital marketing communication within the PESO framework.

AI tools significantly enhance digital communication by: (a) Expanding Design Solutions: AI tools offer designers a wider range of solutions, enabling more innovative and customized designs; (b) Personalizing Customer Experiences: By analyzing customer data, AI facilitates personalized marketing strategies, enhances customer interactions, and tailors content to specific audience segments; (c) Automating Tasks: AI reduces the manual effort needed for repetitive tasks, allowing marketers to focus on strategic activities, and (d) Providing Insights: AI-powered tools provide quick and accurate insights into consumer behavior and preferences, aiding in the development of more effective communication strategies [25].

AI's transformative potential covers various industries: Social Media Marketing: AI tools automate analysis of key performance indicators and facilitate decision-making; Healthcare: AI chatbots assist in scheduling appointments, disseminating information, and providing patient support; and Travel and Tourism: AI improves customer service through personalized interactions and conversational applications [26].

Implementing ChatGPT within the PESO model offers several advantages: Efficiency and Productivity: automates content generation, customer interactions, and targeted

communications, thereby enhancing overall efficiency and productivity; Audience Insights: provides valuable insights into audience behaviour, preferences, and engagement, allowing for more precise targeting and personalized messaging; and Relationship Building: facilitates relationship building through shared media and AI-driven influencer identification and engagement strategies.

4 DISCUSSION AND CONCLUSION

This research provides valuable insights into the potential and challenges of AI in transforming digital marketing communications. While the findings suggest a strong belief in the transformative power of AI, the research also highlights the need for a strategic and responsible approach to AI adoption. The research approach and research results exhibit a lack of scientific studies on ai tools in digital communication process. The lack of research opens up a new niche for research in this area.

The long-term implications of AI in digital marketing suggest a significant shift in marketing practices, emphasizing the need for responsible AI deployment that balances technological capabilities with ethical standards [27]. Future research should focus on the evolving impact of AI on consumer behavior and brand relationships [28]. It is recommended to include the following three components: qualitative studies: conducting in-depth interviews and focus groups with marketing professionals to gain a deeper understanding of their experiences and perspectives on AI, case studies: analyzing the implementation of AI in specific marketing contexts to assess its real-world impact and effectiveness, longitudinal studies: tracking the long-term impact of AI on digital marketing strategies outcomes.

This study, however, has some limitations. The main limitation is mirrored in the first stage of the study, i.e. in the selection of the scientific databases.

There may be other relevant published papers that could potentially contribute to this study but were not considered because they were not indexed in the selected database. Additionally, the tools mentioned in the second phase were not the only ones available on the market It's important to acknowledge that new tools are constantly emerging, improving various aspects of business. AI tools are highly dynamic, just like the communication process, and more comprehensive tooling is required.

Recent studies have explored the potential of ChatGPT in marketing communications, highlighting its ability to enhance content creation, customer service, and data analysis [29]. While ChatGPT offers numerous opportunities in various marketing fields, including consumer behavior and advertising, researchers emphasize the need for human intervention and oversight [24, 30]. The technology's implementation across different communication channels, such as social media and customer support, has been analyzed, revealing both advantages and challenges [24]. Ethical considerations, including privacy concerns and potential biases, have been identified as crucial factors to address when integrating ChatGPT into marketing strategies [22]. Despite these challenges, ChatGPT has the potential to

revolutionize marketing practices by improving efficiency and enabling more personalized customer interactions, provided that ethical guidelines are followed and human expertise is maintained [22, 29].

The ultimate aim of this study was to indicate to scholars and marketing and communication experts that AI tools enhance digital marketing communication. The most effective approach will vary depending on specific needs and objectives. However, both the PESO model and ChatGPT can complement each other. ChatGPT can rapidly and precisely generate content across diverse media channels, while the PESO model offers a comprehensive framework for media strategy. It can be concluded that ChatGPT has the potential to enhance the PESO model.

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Automatically Guided Vehicles (AGV) in Agriculture

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Abstract: In this paper, new types of autonomous systems used in agriculture were analysed. The paper shows new self-guiding systems such as AGVs with full autonomy in degrees operation. It explains internal transport and systems of autonomous vehicles in outdoor agriculture. New autonomous systems used outside such as appliance of special navigation systems and their purpose in agriculture are present in this work. Navigation systems with GPS signal and RTK technology, vehicle guidance camera and AI machine vision for manipulation are described. Light and laser technologies for fully autonomous robotic technologies such as LiDAR system in vehicle for detection of the presence of pests and diseases are presented in this paper. The paper emphasized advantages of using AGVs as result of their autonomy, clean power sources without harmful impact on the environment. Navigation in indoor spaces that uses LTE Direct protocol is explained, whereby the Wi-Fi ceiling antenna and wireless APP for horizontal movement of AGVs is shown. The ways of using UAVs for warehouse inventory through web applications with an advanced navigation system guided by AI are given in this work.

Keywords: AI detection; automatic guided vehicles; GPS; sensors

1 INTRODUCTION

The Automatic Guided Vehicle (AGV) is used in many kinds of applications. They have done many kinds of important tasks in the field of indoor transportation [1, 2, 3], movement of outdoor goods [4, 5], as well as agricultural [6, 7] works. Automated guided vehicles are defined as vehicles with their own: operation, energy source and transshipment devices intended for the transport of materials. They can also be defined as floor transport vehicles without a driver, computer-controlled, most often electrically powered with batteries. AGV appeared in 1954 and it can be said that they represent one of the most significant developments in the automation of transport operations in industry, on assembly lines, in warehouses and in goods transport centers and terminals [8, 9, 10, 11]. Authors [12] and [13] state how AGV systems have become a key component of today's intralogistics. The technological standard and the current level of experience with this automation technology have led to the introduction of AGVs in almost all branches of industry and areas of production. According to [14], AGVs are mobile robots and come in several variants depending on the way of guidance such as wire guidance, guidance tapes, laser targets, gyroscopic guidance and guidance with camera vision. In 2019, the International Federation of Robotics categorized 41% of robots as service robots, followed by maintenance robots 39% and vacuum robots 19%. According to [9], the AGV market is growing rapidly and the number of companies adopting AGV systems is increasing [15]. In general, AGVs are driverless vehicles that are used to automatically transport materials between locations and thereby automate internal transportation [16]. Considering that AGVs are highly mobile, their networking is done wirelessly, mostly using Wi-Fi connection [17]. Authors [18, 19] observed that the use of AGV in future factories will not be able to support the current wireless communication systems therefore the next generation of systems will be implemented. According to [20] the next generation of wireless communication systems such as 5G band and Wi-Fi6 communication aim to support industrial operation.

According to [21] AGVs are significantly used as part of a reliable and flexible internal transport system. Automation of logistic vehicles can also have other benefits, such as reduction of costs and working time [22, 23, 24]. Author [25] states that AGV replace 70% of human working time which is significant automation. In addition, the authors [26] state that multiple loading of AGV will reduce system penalty cost up to 44%.

2 TYPES OF AGVs IN INTERNAL TRANSPORT

AGV for internal transport include automatically guided platforms, forklifts with automatic guidance, AGV cargo decks and tug AGVs. Author [27] states that the most common form of platform is the industrial transport platform (Fig. 1), which is used in systems where full automation and higher flexibility in connection with other subsystems is required.



Figure 1 Industrial transport platform
(Source: <https://italcarrelli.eu/agv>)



Figure 2 Automatic guided forklift
(Source: <https://www.agriexpo.online/prod/bogaerts/product-180911-46289.html>)

Automatically guided forklifts are used in warehouses and for material handling which purpose is loading and unloading of both one load more pieces from cargo simultaneously, to different locations and at many heights which results to become one of the most commonly examples of AGV (Fig. 2). The authors [28] state that recent developments in machinery have increased production and production rates in industry resulting in the need for faster material handling systems. To meet the requirements, vehicles for handling heavy materials such as forklifts, pallet movers, electric forklifts with balanced levers are introduced in factories. For navigation of AGVs at the workspace there are many methods and they are categorized as follows: using AGVs to follow a specific route which are putted inside warehouses (guided vehicles):

1. Wired AGVs (Fig. 3) that use a wire installed into the floor to follow the intended path of AGV. The line sends a electromagnetic radiation which AGV can detect and follow like track (Fig. 4). Authors [29] state that the use of human labor has been replaced by the use of wire AGVs thus they are classified into main types based on their utility;

2. Guidance tape – a magnetic tape (Fig. 5) or a colored tape is used that is set along the intended path of the AGV which the vehicle follows [30, 31], also the main disadvantages are magnetic tape maintenance, magnetic tape cost and not suitable for complex paths [32];

3. AGVs that have transmitter and receiver have possibility to collect and spot lasers. According to [33] lasers are classified either by the US Performance Standard (21 CFR 1040) of the Center for Devices and Radiological Health (CDRH) or the International Code (IEC 60825-1). Classification is based on the level of hazard of the laser beam during normal operation and includes factors such as wavelength, power output, accessible emission level, and emission duration. The following classes are defined: Class 1 and 1M, Class 2 and 2M, Class 3R (formerly 3a) and 3b, Class 4.

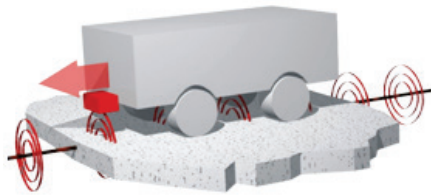


Figure 3 Wire guidance system

(Source: www.goetting-agv.com/components/inductive/introduction)



Figure 4 Scheme of induction guidance

(Source: <https://hy-tek.com/resources/whats-the-difference-between-amr-and-agv/>)



Figure 5 Magnetic tape for guidance

(Source: <https://www.roboteq.com/applications>)

If AGVs want to have navigation through laser orientation then it is needed to put reflective tapes on surface, also to have adequate technique AGVs to calculate their location related to the map stored in their memory when laser light is reflected from the tape. AGVs have laser transceivers on a rotating dome that automatically calculate the angle and distance to any reflecting tape in the line of sight (Fig. 6). According to [34] LGVs (laser-guided vehicles) are a kind of AGV that use floor-mounted reflective tape and laser sensors (as opposed to markers, wires, and magnet crumb trails) to triangulate position and navigate the warehouse. The disadvantage of navigation use of laser light are higher costs and more system maintenance requirement [35];

4. Inertial navigation – Inertial guidance where the current position of AGV is found by last information about position of the warehouse technique and their speed. AGVs are equipped with many types of sensors: accelerometer, gyroscopes and magnetometers. AGVs with current position can not be fully autonomous – they need it to have communication with a transponder that is usually installed in the floor. According to authors [36] automated guided vehicle (AGV) system has a central unit which takes control of scheduling, routing, and dispatching decisions for all AGVs, AMRs can communicate and negotiate independently with other resources like machines and systems and thus decentralize the decision-making process (Fig. 7).

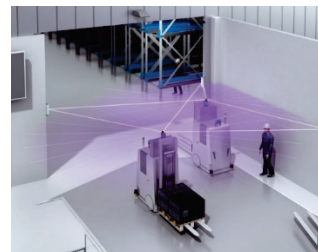


Figure 6 Laser determination of position in space

(Source: <https://www.sick.com/es/en/end-of-line-packaging/automated>)

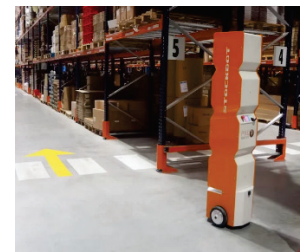


Figure 7 Stockbot for automating inventory-taking

(Source: <https://blog.pal-robotics.com/advanced-factories-autonomous-mobile-robots/>)

According to [37] one of the ways of using UAVs for warehouse inventory through web applications is the application of modern drones with an advanced navigation system guided by artificial intelligence. Skydio is a fully automated solution. After we mapping sophisticated drones fly the routes using AI-driven navigation system to capture images of bar codes, LPNs (Fig. 8) and then drone returns to

its dock, where all the data can be securely uploaded to warehouse or yard management system.



Figure 8 Drone capturing code and LPN
(Source: <https://www.inboundlogistics.com>)

3 MECHANISMS FOR MOVEMENT

Mechanisms for movement allow the robot to have ability to motion and perform under low constraints. These mechanisms are modeled after movements in nature such as walking, running, rolling, sliding and jumping [27]. Mainly, robots can operate with two type of moving: on wheels (Fig. 9) and with articulated legs. The mechanism on the wheels is the simplest, in contrast to the legs, which require greater degrees of freedom with a high level of complexity [38]. Mechanisms with legs (Fig. 10) are more suitable for rough terrain where irregularities prevent the use of wheels because they need a larger contact surface. Their energy consumption of foot style is more higher compared to style with wheels on solid and flat areas. If the area is getting softer then energy consumption is higher. The foot style of robot has dot contact with the area it becomes more effective on light terrain. The inclusion of machine vision in agriculture is increasingly used especially in agricultural vehicles (autonomous and non-autonomous) and can be used for various agricultural operations, including row detection (Fig. 11), special application, identification and monitoring. With progress, the machine vision is becoming an imperative in autonomous vehicles [39, 40, 41, 42].



Figure 9 Transport platform with wheels (Source: www.arbeitsbuehnen-weiss.de)

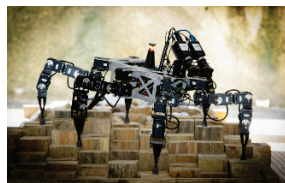


Figure 10 Complex movement mechanism for overcoming difficult terrains (Source: Kottege, 2017)

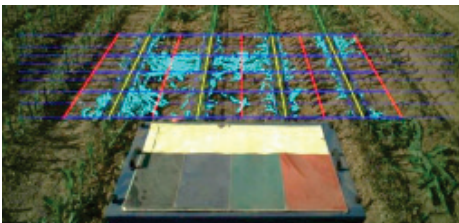


Figure 11 Detection rows with machine vision (Source: Pajares et al., 2016)

The same authors [38] state that image sensors are used for numerous tasks in agriculture such as guidance, weed

detection or phenotyping analysis. Crop row detection and identification are the most common tasks in agriculture when image processing techniques are used for obstacle detection or environment mapping. Newer technological advances allow vision systems to be connected to unmanned aerial vehicles (UAV), which are also considered autonomous vehicles. The positioning of sensors on a vehicle requires a geometric relationship between the sensor, the vehicle, and the field of view that the sensor uses for guidance information. A commonly used machine vision system is AutoTrac Vision, which uses the technology and methods to extract information from an image on an automated basis to follow the machine in crop rows. Using new technology, it can generally to make less crop destruction due to machine wheel passes throughout the time of certain operations (Fig. 12) [43].



Figure 12 Camera locations in AutoTrac Vision system
(Source: <https://www.heavyquippmag.com>)

Autonomous vehicles for successful driving and filling of transport vehicles during harvesting often use the John Deere Active Fill Control system, which consists of dual cameras for having 3D real time checking and management of the refilling of transport trailers throughout the time of autonomous driving and harvest (Fig. 13). The Case IH AFS autonomous steering system is a navigation technology, which can be used with the Precision Land Management laser guidance navigation for crops (Fig. 14). Also in plant production often can be used navigation system SmartSteering for laser detection of crops that uses an IR camera system during driving for the technology and methods to extract information from an image on an automated basis to follow the machine and to have opportunity to see and to control of trailer load level [44]



Figure 13 Active monitoring of trailer loading
(Source: www.deere.com).



Figure 14 CAM PILOT 3D camera
(Source: docplayer.org/53262082)

There are two types of attachment control for successful autonomous control of agricultural equipment: an active control system (uses GPS signal or a vision sensor) and a passive system that has a location detection sensor [45].

During the movement of autonomous vehicle on production fields, there is a negative impact because of the surface inhomogeneity, which affects the deviation from the planned path. Because of the mentioned, specialized guidance of attachment that can be adapted to different types of autonomous vehicles is increasingly being used. An autonomous vehicle is a part of an autonomous system that includes an autonomous attachment and a control unit (main controller for precise vehicle control) [46]. Autonomous vehicles use numerous systems to correct the accuracy of the attachment, which are installed on autonomous vehicles such as the ProTrakker 500DB, which has the ability of 2.54 cm accuracy. The ProTrakker 500DB (Fig. 15) is compatible with numerous attachment control options from GPS signal to ultrasonic sensors [47]. A similar alignment system for the autonomous attachment is the use of a Dynatrac drawbar (Fig. 16) with a GPS guidance camera along with RTK signal to reduce the attachment drift [48].



Figure 15 ProTrakker 500DB system
(Source: <https://www.protrakker.com>)



Figure 16 DynaTrac® system
(Source: www.laforgegroup.com)

The application of autonomous vehicles in agriculture is often reflected in the use of a robot-electromechanical machine that can move, perform operations using limbs, feel external stimulation and physically influence its environment while using modern navigation systems [49]. Autonomous agricultural robots and autonomous vehicles have the potential to improve the efficiency of agricultural production and reduce resource consumption [50, 51]. An example of an autonomous vehicle for crop health monitoring is the LadyBird. LadyBird (Figure 17) is used for autonomous crop monitoring, where crop condition assessment is performed using hyperspectral cameras, thermal and infrared detection systems, also panoramic and stereo vision cameras, LiDAR and GPS guidance [52]. According to [53] main advantages of using LiDAR are: data can be collected quickly and with high accuracy, surface data has a higher sample density, can be used day and night, can be used to map inaccessible and featureless areas, also has minimum human dependence. Disadvantages of LiDAR: high operating costs in some applications, degraded at high sun angles and reflections, the laser beams may affect the human eye in cases where the beam is powerful.

The use of the LadyBird autonomous vehicle enables detection of the presence of pests and diseases [54]. Authors [55] state that nowadays autonomous vehicles and robots are increasingly used as a fleet of vehicles. The impact of fleet coordination automation on commercial agriculture is huge. Future systems will require a high degree of autonomy and

the potential to operate as a fleet because of concerns about the availability and operation cost on family farms [56, 57]. Authors [58] state four main sensors in vehicles, which are in the autonomous vehicle fleet: inertial measurement unit (IMU), camera, RTK-GPS receiver and LiDAR system.



Figure 17 Ladybird autonomous vehicle
(Source: <https://www.abc.net>.)

4 NAVIGATION IN INDOOR SPACES

LTE Direct is the autonomous long-distance D2D (Device to Device) protocol. This communication protocol will exploit direct communication between nearby LTE devices. LTE direct technology is used for data transmission over long distances (Fig. 18), i.e. for the use of AGV devices via IoT in protected areas [59]. According to [60], a ceiling antenna connected to a wireless APP is often used to move the AGV in the horizontal plane and send commands (Fig. 19.). According to [62] in greenhouses, warehouses and indoor environments often are used AGV equipped with RFID sensors for RFID localization tags and environmental mappig (Fig. 19).

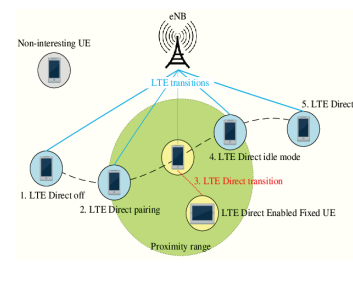


Figure 18 Communication between nearby LTE devices (Source: [61])

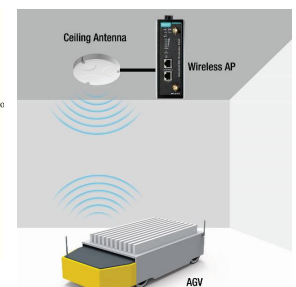


Figure 19 AGVs operating on floor level with Wi-Fi network (Source: [60])

RFID read/write devices can detect tags at ranges of up to 2 m (depending on the transponder used). This means that pallets or trolleys can be identified during the AGV's approach (Fig. 20). Once read, the tag data is verified via the warehouse management system, supporting consistent traceability of goods flows.

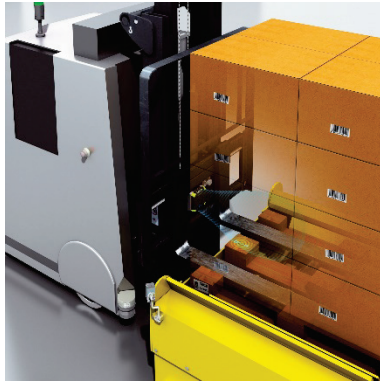


Figure 20 RFID on AGV

(Source: <https://www.sick.com/ag/en/industries/logistics>)

5 CONCLUSIONS

The advantages of AGVs are manifested in the adequate replacement of human resources/operators, high efficiency, the possibility of 24-hour work, lower labor costs compared to human labor in the long term. AGVs are equipped with numerous systems for avoiding objects, thus minimizing damage to products, machines and infrastructure. They have safety sensors and under high-frequency operation they remain in their work zones without endangering the environment. They can be programmed to handle different products with a certain degree of finesse as required, thus reducing the potential level of damage during handling. In processes that may include conveyor belts for sorting and serial collecting it is needed to have warehouse software to manage and command the best time for using a fleet of AGVs, also to schedule the input of stock. The result is maximum use of working time. AGVs can operate under low changes so they become a machines with better manipulation unlike conveyor belts or flow racks, AGVs can operate with minimal changes to the existing layout of the workspace or warehouse. Initial costs when purchasing an AGV can be significant due to the high purchase price and maintenance costs of the charging station, however, in the long run they are easier and more predictable than the human sector of workers because they do not require compensation for shift work, holidays or need for a day off. For the successful operation of AGV, it is necessary to provide quality markings for the successful operation of the sensors and to familiarize the staff of the work area or warehouse. AGVs are autonomous vehicles that are at the top of the niche in the automation ecosystem due to their autonomy and the use of clean power sources without harmful impact on the environment.

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A Development and Evaluation of a Vertical Yam-Pounding Machine

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Abstract: A vertical yam pounding machine having a similar operational principle to the traditional method of pounding was developed. The machine consists of a shaft, pulleys, V-belts, bearings, an electric motor, a vertical pounder, a gear train and a pounding bowl. White yam was used to carry out a performance evaluation of the developed machine compared to a commercial yam pounder QASA® (LBQ041A, made in China) yam pounding machine and pounded yam from the traditional method of using mortar and pestle. It was observed that the traditional pounding operation, the developed and the QASA® yam pounding machines gave 89.73, 96.24 and 98.25% of well-pounded yam excluding lumps. However, the QASA® yam pounding machine is limited to a maximum of 4 kg mass of boiled yam. The average throughputs of the traditional pounding operation, the developed and the QASA® yam pounding machines were 20.3, 39.46 and 47.34 kg/h, while pounding times were 18 min, 10 min, and 5 min respectively. The developed machine had comparable quality with similar sensory scores with regards to the taste, aroma, stretchability, and mouldability to the one from the traditional method. It also had a comparative long-life span, and overall acceptability score and was preferred over the pounded yam produced by QASA® pounding machine.

Keywords: mortar; pounded-yam; pounding-bowl; pounding-force; traditional-pounding; vertical-pounding

1 INTRODUCTION

Pounded yam is the choicest sumptuous food being prepared and eaten all over Nigeria and West Africa at large. It is being processed from yam tubers. Boiled yam when pounded in a wooden mortar traditionally forms a mass of sticky-bond starchy food called pounded-yam or 'Iyan' in Yoruba, 'nriji' in igbo and 'shokora' in Hausa tribes in Nigeria. The Ekiti people are known for their love for pounded yam which is laborious to prepare for consumption. Research has shown that yam pounding traditionally using mortar and pestle is unhygienic, labour intensive and sometimes leads to musculo-skeletal disorders, especially for commercial pounders [1].

Pounding yam traditionally, occasionally changes the colour of yam due to some bleaching or peeling off in mortar as force is being applied via the pestle during the pounding process. In the quest for eliminating this stressful process of preparation, various machines had been developed by researchers [1-8] using beater which does not pound the yam in an actual sense but rather does size reduction, disintegration, dispersion, and homogenization to a variety of solid which directly cuts the cooked sliced yam into piece, "stirs" the yam in an horizontal direction, this is similar to paddle mixer/high speed mixer used in food processing industry, due to its operational design and this affects the textural quality of the pounded yam. Existing yam pounding machines are mostly for family use and the set-up principles make them difficult to upgrade for commercial use because of the associated high torque and speed requirement.

This research work made use of a vertical dumbbell shaped pounder like the traditional pestle for pounding, scrapper, pounding bowl and gear train to mention but a few. It can be used for wide range pounding (commercial and domestic) can be easily upscale, requires low torques and cost effective. It is user friendly.

The aim of this work is to develop and evaluate a vertical yam pounding machine with operational principles mimicking the traditional pounding system. To evaluate the sensory and textural characteristics of pounded yam produced by the developed machine in comparison to a

commercial yam pounder and pounded yam from the traditional method of using mortar and pestle.

2 METHODOLOGY

2.1 Design Calculations

The pounder. The pounder was made from stainless steel solid rod in the form of a dumbbell shape.

Volume of the scrapper. The scrapper was made from stainless steel of length 200 mm, breadth of 15 mm and thickness of 3 mm.

The volume of the pounding bowl. V_{pb} = volume of the pounded yam + volume of the pounder + volume the of scrapper (1)

2.1.1 Determination of Pounding Force and Power Requirement

The pounding force is the force required to pound the yam to the required texture.

Pounding force = mass of the pounder × gravitational force (2)

Pounding pressure. $P_p = \frac{\text{Pounding force}}{\text{Area of pounding}}$ (3)

Area of the pounder, A_p = surface area of the frustum head + surface area of the cylindrical rod:

$$A_p = \pi \cdot h_f \cdot (R_b + r_t) + 2\pi \cdot r_c \cdot (L_c + r_c). \quad (4)$$

Torque acting on the pounder. The torque acting on the pounder T_p = pounding force × perpendicular distance travelled by the pounder from the line of action.

2.1.2 Determination of Pulley Size

The pounding mechanism pulley. Assuming a speed ratio of 5 and using a driving pulley of 70 mm.

$$\begin{aligned} \text{Speed ratio} &= \frac{\text{speed of driving shaft}}{\text{speed of driven shaft}} = \\ &= \frac{\text{diameter of driven pulley}}{\text{diameter of driving pulley}} = \frac{5}{1} = \frac{d_2}{70}. \end{aligned} \quad (5)$$

d_2 = diameter of driven pulley (the eccentric shaft) = 350 mm
 Since the ratio of transmission is 5:1, the diameter of the large pulley (pounding mechanism pulley) = $5d_2$
 Speed of the electric motor pulley n_e = 1440 rpm
 Speed of the pounding mechanism can be determined using:

$$\frac{n_p}{n_e} = \frac{D_e}{D_p} \quad (6)$$

Where: n_p – speed of pounding mechanism; D_p – diameter of pulley on pounding mechanism; n_e – speed of electric motor:

Therefore,

$$n_p = \frac{n_e \cdot D_e}{D_p} = \frac{1440 \cdot 0.07}{0.350} = 288 \text{ rpm}. \quad (7)$$

2.1.3 Power Required by the Pounding Mechanism

Power required by the pounding mechanism (P_{pm}),

$$P_{pm} = \text{Pounding torque} \times \text{Angular speed} \quad (8)$$

Angular speed

$$\omega_{pm} = \frac{2\pi \cdot n_p}{60} = \frac{2\pi \cdot 288}{60} = 30.16 \text{ rad/s}. \quad (9)$$

Hence,

$$P_{pm} = T_{pm} \cdot \omega_{pm} = 3.18 \text{ N} \cdot \text{m} \times 30.16 \text{ rad/s} = 95.91 \text{ W}.$$

2.1.4 Power Required to Revolve the Pounding Bowl

$$P_{pb} = \text{Torque} \times \text{Angular speed of gear train} \quad (10)$$

$$\omega_{pb} = \frac{2\pi \cdot n_{ps}}{60} = \frac{2\pi \cdot 72}{60} = 7.5 \text{ rad/s} \quad (11)$$

$$P_{pb} = T_{pb} \cdot \omega_{pb} = 3.18 \text{ N} \cdot \text{m} \times 7.5 \text{ rad/s} = 23.85 \text{ W}.$$

2.1.5 Total Power Required by the Machine

Total power required by the machine = Power required to revolve the pounding bowl + Power required by the pounding mechanism

$$P_T = P_{pb} + P_{pm} = 23.85 \text{ W} + 95.91 \text{ W} = 119.76 \text{ W}. \quad (12)$$

Considering the service factor by the National Electrical Manufacturers Association standard service factor of 1.25 was used, therefore the minimum power requirement for the developed machine = $1.25 \times 119.76 = 149.7 \text{ W}$.

Table 1 Description of the developed vertical yam pounder

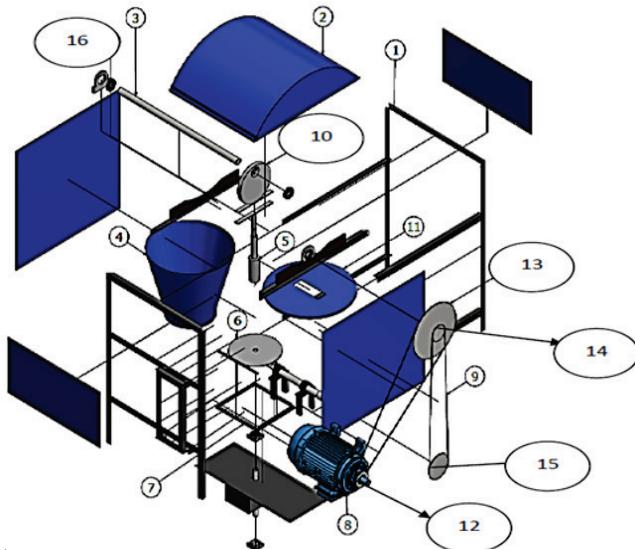
S/N	Part	Description	Dimension	Material	Quantity
1	The Pounder	A cylindrical dumbbell-shaped device designed to carry out the pounding process	$L_c = 0.2 \text{ m}$, $r_c = 0.025 \text{ m}$, $R_c = 0.038 \text{ m}$	Stainless Steel	1
2	The Scraper	Scrapes the wall of the pounding bowl thereby aiding the churning and tumbling process as the pounding progresses	$L_s = 0.2 \text{ m}$, $B_s = 0.015 \text{ m}$, $T_s = 0.003 \text{ m}$	Stainless Steel	2
3	The Pounding Bowl	Is the frustrum-chamber where the sliced boiled or cooked yams are poured for pounding	$R_b = 0.153$, $r_b = 0.102 \text{ m}$, $H_b = 0.1903 \text{ m}$	Stainless Steel	1
4	The Base Plate	A circular plate mounted on the Gear Train that carries the pounding bowl rail slot	$D = 0.204 \text{ m}$	Mild Steel	1
5	Concentric Shaft	Carries the vertical pounder which converts the rotatory motion of electric motor into reciprocating motion for the pounder	$D = 0.030 \text{ m}$, $L = 0.8 \text{ m}$	Stainless Steel	1
6	Pulleys	Use for power transmission	350.70 and 280	Mild Steel	3
7	V-Belt	Transmit power from the electric motor to the concentric shaft of the pounding unit	A75 and A66	Rubber	2
8	Gear Train	An arrangement of toothed wheels revolves the pounding bowl.	The gear tooth is 40 while the pinion tooth is 8, hence the reduction ratio is 5 to 1.	Mild Steel	1
9	Pounding Bowl Rail.	This provides ease for sliding in and out of the pounding bowl on the slot of the train	$L = 0.24 \text{ m}$, $B = 0.16 \text{ m}$	Mild Steel	1
10	Machine Frame and Housing	This houses the assembled components	$H = 0.85 \text{ m}$, $B = 0.50 \text{ m}$, $L = 0.60 \text{ m}$	Mild Steel	1

2.2 Performance Evaluation using the three Methods of Pounding

White yam was used to evaluate the machine. The yams were manually peeled, sliced into small sizes, and weighed. The sliced yams were steam cooked. The cooked yam of

masses 2, 4, 6, 8, 10 and 12 kg were pounded each using the traditional method, the developed vertical pounding machine and the QASA (LBQ041A, made in China) pounding machine sold in the market. The pounded samples were examined to determine the mass of well-pounded yam, the

mass of lumps and the time taken for pounding each mass by various methods were recorded.



PART LIST		
ITEM	QTY	DESCRIPTION
1	1	Machine frame
2	1	Machine housing
3	2	Shaft
4	2	Pounding bowl
5	1	Pounder
6	1	Gear train
7	1	Pounding bowl rail
8	1	Electric motor
9	2	v-belt
10	1	Eccentric shaft
11	1	Cover
12	1	Pulley
13	1	Pulley
14	1	Pulley
15	1	Pulley
16	1	Ball Bearing

Figure 1 Exploded view of the developed vertical yam pounding machine

2.2.1 Yam Pounding Efficiency

The yam pounding efficiency (E_p) was determined using the following relationship:

$$E_p = \frac{m_{wp}}{m_{wp} + m_l} \cdot 100\%. \quad [10] \quad (13)$$

Percentage of lump was determined using

$$E_l = \frac{m_l}{m_{wp} + m_l} \cdot 100\%. \quad [10] \quad (14)$$

The pounding capacity C_p was determined using

$$C_p = \frac{m_{wp}}{t_p} \left(\frac{\text{kg}}{\text{h}} \right). \quad [10] \quad (15)$$

Where: m_b – mass of boiled yam fed into the pounder (kg); m_l – mass of lumps picked in the pounded yam (kg); m_{wp} – mass of well-pounded yam (kg).

$$m_{wp} = m_b + m_l \text{ (kg)}. \quad (16)$$

The description of the parts, dimensions, materials and quantities of the developed vertical yam pounder are presented in Tab. 1. The exploded view and the picture of the developed vertical pounding machine are presented in Figs. 1 and 2 respectively.



Figure 2 The developed vertical yam pounding machine

2.2.2 Acceptability Test of Pounded Yam

Sensory evaluation of the pounded yam was carried out using a panellist in a sensory laboratory. Participants were given orientation and instructions regarding what was required for the test such as what kind of judgment and evaluation was to be made, handling of samples and the use of questionnaires. Three food samples were investigated with code names MOPD, QMPD and DMPD. Where: MOPD - Pounded Yam Produced by Mortar (Traditional Method of Pounding); QMPD - Pounded Yam produced by QASA® Machine; DMPD - Pounded Yam produced by Developed Machine.

The questionnaires consisted of food quality (such as Aroma, Stretchability, Mouldability, Appearance and Taste) that provided general information regarding what types of tests were to be performed, what kind of information that was requested, and what to think about when performing the test use hedonic scale (ranging from 9 = like extremely to 1 = dislike extremely).

2.2.3 Data Analysis

The t-test analysis was used to determine whether there were differences among the performances of developed machine compared to a commercial yam pounder QASA® (LBQ041A, made in China) yam pounding machine and pounded yam from the traditional method of using mortar and pestle.

3 RESULTS AND DISCUSSION

3.1 Pounding Time

Pounding time increases as feed mass increases as shown in various pounding methods in Tabs. 2, 3 and 4. The Pounding time of the developed machine differs from the

previous pounding machine developed by other researchers. The developed machine. had pounding times ranging from 3.06, 6.50, 8.30, 11.10, 13.07 and 16.08 minutes for 2, 4, 6, 8, 10, 12 kg respectively. Oke et al. [9] reported a pounding time of 30, 40, and 60 seconds for feed masses of 1, 1.5 and 2 kg while Onuoha et al., [7] reported 1, 1.7, 2, 2.3 and 2.5 minutes for feed masses of 2, 2.5, 3, 3.5 and 4 kg respectively. It was observed that the developed machine had a higher pounding time compared to others, this is due to the difference in pounding mechanism involved. However, the pounding time of the traditional method was observed to increase as the feed mass increases similarly QASA® pounding machine.

Table 2 Performance Evaluation of the Traditional Method of Pounding

	m_t (kg)	m_i (kg)	m_{wp} (kg)	E_i (%)	E_p (%)	t_c (min)	t_p (min)	C_p (kg/h)
	2.00	0.080	1.920	4.000	96.000	25.00	7.42	15.526
	4.00	0.220	3.780	5.50	94.500	37.00	12.15	18.667
	6.00	0.550	5.450	9.167	90.830	42.00	15.10	21.657
	8.00	0.850	7.150	10.625	89.375	47.00	19.25	22.286
	10.00	1.650	8.350	16.500	83.500	51.00	23.30	21.502
	12.00	1.900	10.100	15.833	84.167	56.00	27.12	22.345
Mean	7.00	0.875	6.125	10.271	89.729	43.00	17.39	20.331
SD	3.741	0.751	3.015	5.161	5.161	11.045	7.282	2.715

Table 3 Performance Evaluation QASA Pounding Machine

	m_t (kg)	m_i (kg)	m_{wp} (kg)	E_i (%)	E_p (%)	t_c (min)	t_p (min)	C_p (kg/h)
	2.00	0.020	1.98	1.000	99.000	25.00	2.50	47.52
	4.00	0.070	3.93	1.75	98.250	37.00	5.00	47.16

Table 4 Performance Evaluation of the Developed Pounding Machine

	m_t (kg)	m_i (kg)	m_{wp} (kg)	E_i (%)	E_p (%)	t_c (min)	t_p (min)	C_p (kg/h)
	2.00	0.030	1.970	1.500	98.500	25.00	3.06	32.83
	4.00	0.090	3.910	2.250	97.750	37.00	6.50	36.92
	6.00	0.155	5.845	2.583	97.420	42.00	8.30	42.25
	8.00	0.210	7.790	2.625	97.380	47.00	11.10	42.11
	10.00	0.570	9.430	5.700	94.300	51.00	13.00	46.15
Mean	7.00	0.334	6.666	3.763	96.239	43.00	9.673	39.953
SD	3.742	0.356	3.419	2.494	2.495	11.045	4.687	4.659

Table 5 Performance Evaluation of the Traditional Method of Pounding

	m_t	m_i	m_{wp}	E_i	E_p	t_p	C_p
2		0.08±0.00 ^a	1.92±0.00 ^a	4.00±0.00 ^a	96.15±0.21 ^c	7.43±0.01 ^a	15.53±0.00 ^a
4		0.22±0.01 ^b	3.78±0.00 ^b	5.52±0.02 ^b	94.52±0.02 ^f	12.2±0.06 ^b	18.67±0.01 ^b
6		0.55±0.00 ^c	5.45±0.00 ^c	9.17±0.00 ^c	90.83±0.01 ^d	15.12±0.03 ^c	21.67±0.02 ^d
8		0.85±0.00 ^d	7.15±0.00 ^d	10.63±0.01 ^d	89.38±0.00 ^c	19.26±0.01 ^d	22.30±0.02 ^c
10		1.65±0.00 ^e	8.35±0.00 ^e	16.52±0.02 ^f	83.49±0.01 ^b	23.35±0.07 ^e	21.52±0.02 ^c
12		1.92±0.02 ^f	10.12±0.02 ^f	15.83±0.00 ^e	84.17±0.00 ^a	27.13±0.01 ^f	22.35±0.00 ^f

Mean values with different superscript are significantly difference ($p < 0.05$)

Table 6 Correlation Matrix between Performance Parameter of the Traditional Pounding Method

	m_t	m_i	m_{wp}	E_i	E_p	t_p	C_p
m_t	1						
m_i	.975**	1					
m_{wp}	.998**	.961**	1				
E_i	.970**	.979**	.959**	1			
E_p	-.970**	-.978**	-.960**	-1.000**	1		
t_p	.999**	.973**	.997**	.967**	-.968**	1	
C_p	.850**	.725**	.874**	.796**	-.800**	.846**	1

** Correlation is significant at the 0.01 level (2-tailed).

Table 7 Performance evaluation of the developed vertical yam pounding

m_t	m_l	m_{wp}	E_l	E_p	t_p	C_p
2	0.03±0.00 ^a	1.97±0.00 ^a	1.52±0.02 ^a	98.48±0.03 ^c	3.62±0.03 ^a	32.85±0.02 ^a
4	0.09±0.00 ^b	3.92±0.01 ^b	2.24±0.01 ^b	97.75±0.01 ^d	6.43±0.11 ^b	36.88±0.06 ^b
6	0.16±0.00 ^c	5.85±0.00 ^c	2.56±0.03 ^c	97.40±0.04 ^c	8.32±0.03 ^c	42.35±0.14 ^c
8	0.21±0.00 ^d	7.81±0.02 ^d	2.63±0.01 ^d	97.37±0.02 ^c	11.11±0.01 ^d	42.16±0.07 ^d
10	0.57±0.00 ^e	9.43±0.01 ^e	5.74±0.06 ^e	94.28±0.03 ^b	13.68±0.04 ^e	42.36±0.08 ^e
12	0.95±0.00 ^f	11.05±0.00 ^f	7.92±0.01 ^f	92.08±0.00 ^a	16.83±0.04 ^f	39.46±0.01 ^e

Mean values with different superscript are significantly difference ($p < 0.05$)

Table 8 Correlation matrix between performance parameter of the vertical pounding machine

	m_t	m_l	m_{wp}	E_l	E_p	t_p	C_p
m_t	1						
m_l	.915**	1					
m_{wp}	.999**	.897**	1				
E_l	.910**	.996**	.892**	1			
E_p	-.910**	-.996**	-.892**	-1.000**	1		
t_p	.998**	.932**	.995**	.926**	-.926**	1	
C_p	.683*	0.36	.710**	0.373	-0.375	.643*	1

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Table 1 Correlation of the sensory attributes for the overall acceptability of the pounded yam samples

	Appearance	Aroma	Stretchability	Mouldability	Taste	Overall Acceptability
Appearance	1.0000					
Aroma	0.9728	1.0000				
Stretchability	-0.9933	-0.9396	1.0000			
Mouldability	-0.9968	-0.9513	0.9994	1.0000		
Taste	-0.9653	-0.8785	0.9890	0.9830	1.0000	
Overall Acceptability	-0.9911	-0.9334	0.9998	0.9986	0.9914	1.0000

Table 10 Analysis of variance of results obtained for sensory test

	Appearance	Aroma	Stretchability	Mouldability	Taste	Overall Acceptability
MOPD	7.02±1.19 ^a	6.84±1.24 ^a	7.96±1.04 ^b	7.78±1.25 ^b	7.88±1.35 ^b	7.84±1.22 ^b
QMPD	7.73±1.25 ^b	7.14±1.27 ^a	6.12±1.57 ^a	5.33±1.69 ^a	7.26±1.21 ^a	6.68±0.99 ^a
DMPD	6.98±1.70 ^a	6.72±1.26 ^a	7.82±1.121 ^b	7.69±1.39 ^b	7.74±1.27 ^b	7.73±1.09 ^b

Where: m_t – feed mass (kg), m_l – mass of lumps (kg), m_{wp} – mass of well pounded yam (kg), E_l – efficiency of lumps (%), E_p – efficiency of well pounded yam (%), t_c – cooking time (min), C_p – pounding capacity (kg/h), t_p – pounding time (min).

3.2 Pounding Efficiency of the Machine

The test ran with various weights of yam for the developed machine as shown in Tab. 4. The efficiency of pounding ranges from 92.083% to 98.50% the optimum efficiency of the machine was observed to be 98.5% at a feed mass of 2 kg of cooked yam and a pounding time of 3.06 minutes and the least pounding efficiency of 92.083% was obtained at a feed mass of 12 kg while 98.19, 98.80 and 93% optimum pounding efficiency at 1, 2.5 and 1.8 kg were recorded by Oke et al. [9], Onuoha et al. [7] and Adebayo et al. [10] respectively.

It is worth to note that the pounding efficiency of the machines decreases as the feed mass increases for all the machines. While the highest percentages of lumps present were found at a feed mass of 12.00 kg at 7.92% and 15.83% for the developed machine and traditional method respectively. Oke et al. [9], reported 1.81, 0.57 and 1.38% for feed mass of 1, 1.5 and 2 kg which shows that the percentage of lumps increases as feed mass increases.

3.3 Pounding Capacity

The QASA machine could not pound more than 4 kg of mass with 98.25% of well-pounded yam at 5 minutes similarly, the performance evaluation carried out on the developed machine showed it had an average pounding efficiency of 96.24%, an average pounding time of 10 minutes, an average lump percentage of 3.76% at an average feed rate of 7 kg and an average pounding capacity of 39.08 kg/h. Which translates to a pounding time of 1.2 min per person (that is 12 people for 10 min and 60 person for an hour). Oke et al. [9], and Adebayo et al. [10] reported an average pounding capacity of 31.71 g/s, 1.68 kg/min and pounding efficiency of 99.18, 93% respectively this is due to the stirring mechanism.

3.4 Power Required

The minimum power required to operate the developed vertical yam pounding machine was 149.7 W while the minimum power required for other machines that use beater were 483.632 W [3], 483.632 W [11]; 663.59 W [5] while that of Onuoha et al. [7] was powered using a 6 HP petrol engine. It is worth noting that the developed machine requires less power (energy consumption) and could be upscaled easily due to fewer torques required for pounding, unlike the

previously designed machines that required high torque and high speed for its operation.

Tab. 5 shows the mean value of performance for the traditional method of pounding. m_l , m_{wp} , E_l , E_p , t_p and C_p ranged from 0.08 to 1.92; 1.92 to 10.12; 4.00 to 15.8; 96.15 to 83.49; 7.43 to 27.13 and 15.53 to 22.35 respectively. All dependent variables significantly ($p < 0.05$) increased with increasing total mass (m_t) except E_p . This was corroborated by correlation matrix in Tab. 6, indicating a negative correlating value ($>85\%$). The mass of lump, mass of well pounded yam, efficiency of lumps, and pounding time highly positively correlated with the feed mass while the pounding capacity moderately positively correlated with the feed mass. However, the efficiency of well pounded yam highly negatively correlated with the feed mass. The higher the feed mass the higher the mass of lumps, mass of well pounded yam, efficiency of lumps and the pounding time. However, the efficiency of well pounded yam decreased with the feed mass (Tab. 6).

Tab. 7 shows the mean value of performance for the developed yam pounding machine. m_l , m_{wp} , E_l , E_p , t_p and C_p ranged from 0.03 to 0.95; 1.97 to 11.05; 1.52 to 7.92; 98.48 to 92.03; 3.62 to 16.83 and 32.85 to 39.46 respectively. All dependent variables significantly ($p < 0.05$) increased with increasing total mass (m_t) except E_p . This was corroborated by correlation matrix in Tab. 8, indicating a negative correlating value ($>68.3\%$). The higher the matrix value, the higher the correlating factor. E_p also correlated negatively with m_l , m_{wp} , E_l , t_p and C_p . The mass of lump, mass of well pounded yam, efficiency of lumps, and pounding time highly positively correlated with the feed mass while the pounding capacity moderately positively correlated with the feed mass. However, the efficiency of well pounded yam highly negatively correlated with the feed mass. The higher the feed mass the higher the mass of lumps, mass of well pounded yam, efficiency of lumps and the pounding time. However, the efficiency of well pounded yam decreased with the feed mass (Tab. 8).

The optimum efficiencies of the developed machine, QASA machine and traditional pounding method were observed to be 98.5%, 99% and 96% for 2 kg of cooked yam and pounding times of 3.6 min, 2.5 min, and 7.42 min respectively.

Tab. 10 shows the analysis of variance of the sensory /acceptability test result carried out on the three samples of pounded yam served to panelists of 50 persons. The mean value for sensory evaluation of pounded yam is depicted in Tab. 9. Appearance, aroma, stretchability, mouldability, taste and overall acceptability values ranged from 6.98 to 7.73, 6.72 to 7.14, 6.12 to 7.96, 5.33 to 7.78, 7.26 to 7.88 and 6.68 to 7.84, respectively. A significant difference ($p < 0.05$) was observed for all sensory attributes except for aroma. The result also indicated that samples of MOPD and DMPD have similar sensory scores for all sensory attributes ($p > 0.05$).

In terms of appearance and aroma, QMPD was rated the highest. A closer look at the results obtained showed that the appearance of the QASA® pounding machine was rated higher than the mortar and pestle (MOPD) and the developed pounding machine (DMPD). The reason for this could be

because of the difference in neatness and mechanisms of their operations.

QMPD used an entirely mixing (shearing) mechanism which may not have produced much operational heat that could enhance discolouration because of non-enzymatic browning. Similarly, the aroma of QMPD was better rated compared to the two pounding systems. This may be due to the more spontaneous loss of volatility that forms the aroma of the product. QMPD operation is fully enclosed whereas DMPD and MOPD are partially and fully open. The result further shows that it could be possible to replace the old technology of mortar and pestle used by the indigenous processor with a mechanical one and still arrive at a very close or better result.

Correlation analysis (Tab. 9) showed that stretchability and mouldability were the most correlated sensory attribute to the overall acceptability of the pounded yam sample. It is interesting to note that these two properties are textural attributes. This confirms the reports of previous studies [12, 13] that pounded yam as a food product is more relished for its textural attributes.

3.5 Mechanism of Operation

The developed machine was made up of a vertical pounder which pounds the yam in a reciprocating motion (impact-based) and scrapers that scrapes the wall of the revolving pounding bowl while previous pounding machines developed by researchers and QASA machine used beaters for milling, disintegration, and homogenization of the yam particle in a horizontal direction to form a texture of pounded yam.

4 CONCLUSION

A first-of-its-kind vertical yam pounding machine has been developed. It does actual pounding with an operational principle similar to the traditional pounding method, unlike previous designs that mills the yam.

Performance evaluation and acceptability tests carried out on the developed machine showed that the Pounded yam produced with the developed machine has comparable quality with similar sensory scores with regards to the taste, Aroma, stretchability and mouldability to the one from the traditional method. Both had comparative long-life span, and overall acceptability score and was preferred over the pounded yam produced by QASA® pounding machine. Based on this study, it can be concluded that the developed machine can replace the traditional method of pounding.

Notice

This invention has been patented in Nigeria on 08/08/2022 with Patent Number NG/PT/NC/2022/6296.

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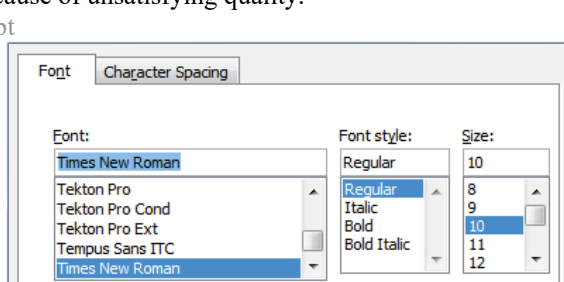


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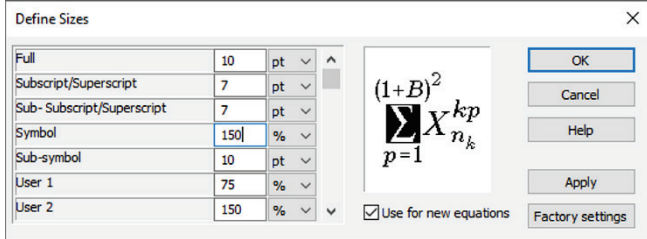


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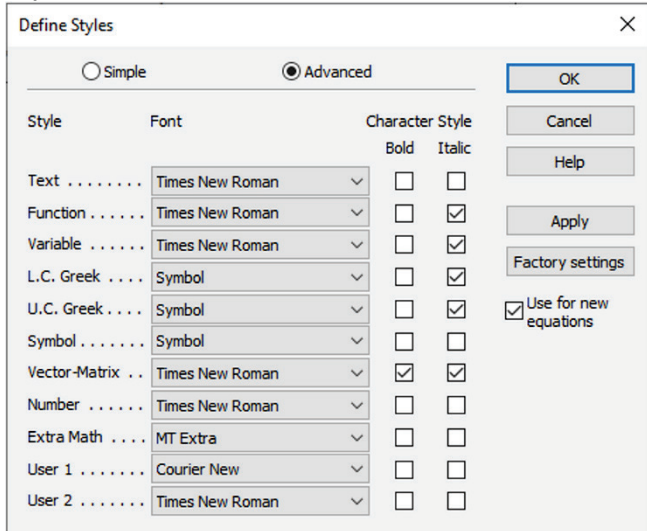


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