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III

## Attitudes of 3PL Providers of the Companies towards the Activities of Organizational Performance

İbrahim Kadir Demir\*, Dilşad Güzel

Abstract: Businesses today specialize in their core competencies and outsource their other operations due to the emerging perception of competition brought on by the largescale similarity of production, the quick spread of technology and information systems, and the disappearance of international borders. One of the most common fields of outsourcing activity is Third Party Logistics (3PL) service, and the Organizational Performance elements of 3PL service providers are listed as Service Quality, Relationship Management and Organizational Effectiveness. This research aims to examine the Organizational Performance criteria of the 3PL providers serving the production enterprises and to evaluate the relationship structure between the mean and standard deviation values of the statements in the survey. The empirical results obtained from frequency, regression and standard deviation analyses show that Guanxi, Reliability, Assurance, and Trust positively affect Organizational Effectiveness. However, only Trust has a positive and statistically significant impact on Service Quality.

Keywords: 3PL; logistics management; organizational effectiveness; relationship management; service quality

## **1** INTRODUCTION

Today's businesses, which focus on gaining competitive advantage and increasing their existing competitive power, tend to take various steps to achieve these goals, collect their existing operational capabilities at a certain point and distribute their financial resources optimally [1]. Businesses today perform their operations outside their primary field of activity through outsourcing with an emphasis on their core activities, to produce their core activities with the mentality of the lowest cost and highest quality and deliver them to their customers appropriately [2]. Ref. [3] reported in their study that outsourcing would benefit the company in terms of speed and low cost; hence it was quickly recognized by the companies.

In the current market, where it is essential to achieve a competitive advantage, logistics services are one of the most common areas where businesses concentrate on their core functions and outsource other operations. With each passing day, it becomes increasingly apparent how important the supply chain is and how much logistics operations impact a company's success [4]. The world's borders have vanished due to globalization, and the various nations' legal arrangements, customs procedures, and other international trade regulations have sped up the development of 3PL by requiring businesses to partner with logistics service providers who are industry experts [5].

Today, it is crucial to properly manage the logistics procedures in the supply chain and deliver the items to the consumer satisfactorily, in addition to cutting costs [6]. As a result, it has been established that logistics operations involve knowledge, competence, experience, and managerial abilities and that the responsibility for carrying out these activities should be delegated to logistics service providers with expertise in that area [7]. These vendors are independent logistics companies that are best able to meet the requirements of businesses in their logistical operations. Therefore, it is essential to properly evaluate the advantages of outsourcing in terms of quality and costs [8].

In this context, there is a large and growing literature focuses on 3PL service providers and their performance. Ref. [9] examined how basic and advanced forms of outsourcing logistics affect the outsourcing management process (OMP). Findings showed that the usage of basic logistics outsourcing directly impacts price and delivery. On the other hand, advanced logistics outsourcing impacts performance through interactions with OMP. Focusing on the Iranian automotive sector, Ref. [10] drew attention to the importance and difficulties of developing strategic relations with 3PL service providers, classified the factors used in selecting 3PL service providers and concluded that the price factor is an indispensable condition. Ref. [11] investigated logistics service quality from the perspective of supply chain quality and explained the relationship between the seven dimensions of logistics service quality and high customer satisfaction. Ref. [12] examined the connection between outsourcing logistics and financial performance and discovered that doing so substantially increased time-based competitiveness, costbased competitiveness, customer performance, and financial performance. Ref. [13] looked at the effect of relationship quality on supply chain performance in logistics outsourcing and stressed the significance of this factor as a selection criterion for 3PL service providers. Research on logistics outsourcing from a sustainable angle, Ref. [14] concluded that Japanese-style logistics management offers businesses outstanding performance in the economy, society, and the environment. Ref. [15] found that logistics digitalization strengthened customer cooperation and positively affected the financial and service performance of 3PL. Ref. [16] assessed the impact of logistics outsourcing on businesses' logistical performance and concluded that "collaboration and process characteristics" was the factor most strongly influencing logistics performance.

Studies in the pertinent literature suggest that "Service Quality," "Organizational Effectiveness," and "Relationship Management" structures make up organizational performance. The dimensions of these structures are, respectively, Tangibles, Reliability, Responsiveness, Assurance, Empathy, Productivity, Customer Service, Reputation and Goodwill, Guanxi, Commitment, and Trust. On the other hand, studies on performance measurement of 3PL service providers mainly focus on the relationship between "Service Ouality" or "Financial Performance" but do not consider the potential relationships between "Service Quality", "Relationship Management", and "Organisational Effectiveness" variables. When the literature was reviewed, it was observed that one study examined the "Service Quality", "Relationship Management", and "Organisational Effectiveness" activities of third-party logistics providers separately. Only Ref. [17] examined the analysis of these three variables using a structural equation model. Following the work of Ref. [17], the present study contributes to the existing literature by investigating the link between Service Quality, Relationship Management, and Organizational Effectiveness performances. Unlike Yuen's methodology, this study uses regression analysis and focuses on the enterprises providing 3PL services and production enterprises using 3PL in the Erzurum province of Turkey.

The rest of the paper is organized as follows: Section two explains the concepts of Service Quality, Relationship Management and Organizational Effectiveness. Section three introduces the research methodology and hypotheses and presents the empirical results. Section four concludes the research.

## 2 CONCEPTS OF SERVICE QUALITY, RELATIONSHIP MANAGEMENT AND ORGANIZATIONAL EFFECTIVENESS IN 3PL

Service quality, relationship management, and organizational effectiveness comprise the conceptual framework of 3PL organizational performance [17, 18]. The organizational performance model is displayed in Fig. 1.



Figure 1 3PL Organizational Performance Model

## 2.1 Service Quality

Unlike the basic concept of quality, defined as the total of a good or service's attributes based on meeting consumer demands and expectations, service quality is focused on customer perception. Service quality is defined as a company's capacity to meet and exceed the expectations of customers [19]. Because service quality expectations vary from person to person, it is possible to quantify service quality by comparing expected performance to actual performance [20].

The SERVQUAL scale, created to measure service quality, was set up to quantify customer expectations and

consists of five aspects. Examples of tangibles include reliability, responsiveness, assurance, and empathy [21].



Figure 2 3PL Service Quality Dimensions

## 2.2 Relationship Management

Customers may now quickly acquire the information they desire, especially in light of technological advancements, which have significantly increased client demands and requests. Businesses can obtain a competitive edge and determine customer expectations by properly evaluating customer feedback.

Relationship Management is described as a process that includes all the steps between the business and the customer before and after the sale, aiming to provide mutual needs and benefits satisfaction. As this definition suggests, the area of interest of customer relations is not limited to the moment of the purchase but covers the pre-sales and post-sales periods [22]. For this reason, it is foreseen that the understanding of competition of the future will be carried out not through technology but through customer relations [23].

Guanxi refers to a particular type of relationship that includes social relations and obligations based on mutual interests and benefits. With Guanxi, competitive advantage can be gained by providing easy access to limited resources, and this exchange of favours among Guanxi members is a strictly non-commercial form of social investment [24, 25, 26, 27, 17].

The services offered to the customers along with the product are perceived as more significant than the product itself and play an essential role in retaining the existing customer. Dimensions of the concept of Relationship Management [28] are listed as follows:

- Guanxi
- Trust
- Commitment.



Figure 3 Relationship Management Dimensions

Due to intense competition across industries, the challenges of ensuring customer satisfaction and loyalty, and the barriers to building customer relationships, businesses need to focus on strategies to increase customer value [29].

## 2.3 Organizational Effectiveness

A good organizational structure provides Organizational Effectiveness for 3PL service providers, and all 3PL service providers have measurable performance goals. In his research, Ref. [17] assessed the organizational effectiveness measurement for 3PL service providers and companies that buy 3PL services using the dimensions of productivity. financial performance and market share, cycle time, customer service, and reputation and goodwill. It is noted that dimensions from numerous criteria frequently classified as behavioural, financial, operational, and structural are employed in organizational effectiveness measurements. The most frequently cited structural dimensions are flexibility. innovation, integration, and stability. In contrast, the most frequently cited financial dimensions are profitability, return on investment, assets, and earnings per share. The most frequently cited behavioural dimensions are job satisfaction, adaptability, turnover, and commitment. Organizational Effectiveness variable may vary depending on the type of business being examined, and different dimensions are used. In the measurement of Organizational Effectiveness, the financial perspective targets commercial organizations more while covering non-profit organizations less [30]. When the studies on the measurement of Organizational Effectiveness in the literature are examined, it has been determined that the most common dimensions of the Organizational Effectiveness variable are Productivity, Customer Service, and Reputation and Goodwill. All 3PL service providers have measurable performance goals. The relationship between 3PL service providers and supply chain partners is gathered under five dimensions, and these are listed as Productivity, Financial Performance and Market Share, Cycle Time, Customer Service, and Reputation and Goodwill [31, 32, 33, 34, 28, 35, 36].



Figure 4 3PL Organizational Effectiveness Dimensions

Developing long-term relationships with supply chain partners of 3PL enables service providers to improve their financial performance and gain a competitive advantage. Collaborations also have other benefits for firms, including the ability to accommodate the shifting needs of customers, create a dynamic organizational structure, and increase market share [37].

Enhancing customer service is frequently mentioned as a critical objective. By using 3PL service providers, businesses may more easily deliver essential values for their clients while guaranteeing customer pleasure, one of their main priorities in today's cutthroat marketplace [37].

The concept of reputation and goodwill, interpreted as a whole of perceptions and contributions of internal and external stakeholders to the business, explains why consumers prefer certain goods or services and shows the difference between success and failure. Reputation and goodwill, defined as the combination of all economic and non-economic characteristics of the enterprise, emerge as a result of the past activities of the enterprise and shape future expectations depending on the image [38].

## 3 RESEARCH METHODOLOGY OF THE ANALYSIS PURPOSE OF THE RESEARCH

This research aims to explain the relations between the organisational performance activities of enterprises providing 3PL services in Erzurum and production enterprises using 3PL. In order to carry out this study, the contact information of the production enterprises having received a capacity report in Erzurum was obtained from the Erzurum Chamber of Commerce and Industry (ECCI). A logistics department official from each of these 35 businesses was contacted by phone for an interview and applied a questionnaire after 31 of them indicated they would support the project. Ref. [39, 40] gave the minimum sample size required for the number of alternatives and independent variables in multivariate linear regression analysis. Therefore, the sample size in the study is sufficient.

## 3.1 Research Method

In the questionnaire, the study used the SERVQUAL scale developed by Parasuraman, Zeithaml and Berry [21, 41, 42] for Service Quality. In addition, for Relationship Management and Organizational Effectiveness, the study benefited from Ref. [28]'s study titled "Performance Measurement and Management of Third-Party Logistics: An Organizational Theory Approach".

## 3.2 Research Model and Hypotheses



Figure 5 Research Model

The hypotheses regarding the research are as follows: H1: Service Quality of 3PL service providers affects Organizational Effectiveness.

H1a: The development of the tangibles of 3PL service providers positively affects Organizational Effectiveness.

H1b: The reliability of 3PL service providers positively affects Organizational Effectiveness.

H1c: The responsiveness of 3PL service providers to respond to needs positively affects Organizational Effectiveness.

H1d: Assurance on 3PL service providers positively influences Organizational Effectiveness.

H1e: The empathy ability of 3PL service providers positively affects Organizational Effectiveness.

H2: Relationship Management of 3PL service providers affects Organizational Effectiveness.

H2a: The Guanxi of 3PL service providers positively affect Organizational Effectiveness.

H2b: Trust in 3PL service providers positively affects Organizational Effectiveness.

H2c: Commitment by 3PL service providers positively affects Organizational Effectiveness.

H3: Relationship Management of 3PL service providers affects Service Quality.

H3a: Guanxi of 3PL service providers positively affects Service Quality

H3b: Trust in 3PL service providers positively affects Service Quality.

H3c: Commitment by 3PL service providers positively affects Service Quality.

## 3.3 Evaluation of the Research Findings

In this section, the study tests the above hypotheses using frequency, reliability, mean & standard deviation, and regression analyses and interprets the results.

## 3.3.1 Demographic Characteristics of Respondents

The study analyses the demographic characteristics of the respondents working in the logistics unit manager position of the sample companies by employing frequency analysis. The results are shown in Tab. 1.

	Ν	%
GENDER		
Woman	6	19,40
Man	25	80,60
AGE		
20-30	8	25,81
31-40	15	48,39
41-50	6	19,35
50 and over	2	6,45
Total	31	100

Table 1 Demographic Characteristics of Participants

When the information obtained regarding the logistics unit managers of the companies forming the sample is evaluated, it is determined that the majority of the respondents were men with 80.6 %, and the majority of the respondents, with a value of approximately 48 %, were between the ages of 31-40.

# 3.3.2 General Profiles of the Companies Participating in the Research

Tab. 2 indicates the values from the surveys applied to enterprises regarding information on the type of company,

the industry in which they operate, the duration of activity in the sector and the number of employees.

When the company types of the enterprises forming the sample are examined, it is determined that approximately 68% are limited liability companies, and 32 % are joint stock companies.

When the enterprises are evaluated in terms of the industry in which they operate, it is seen that the largest part of the enterprises forming the sample operates in the food sector, with 35.5 %, 22.6 % in the construction sector and 19.4 % in the metal sector.

Approximately 42 %, 32 %, 20 %, and 6 % of these companies have been operating for more than 25 years, 6-15 years, 16-25 years, and 1-5 years, respectively. In addition, approximately 52 % of these companies are 26-50 employees, while 29 % have 1-25.

Table 2 General F	Profile of Businesses
-------------------	-----------------------

	Ν	%
Company Type		
Incorporated Company	10	32,26
Limited Company	21	67,74
Total	31	100
Industry		
Food	11	35,48
Construction	7	22,58
Metal	6	19,35
Furniture	2	6,45
Mining	1	3,23
Chemical	1	3,23
Air Conditioning	1	3,23
Recycling	1	3,23
Packaging	1	3,23
Total	31	100
<b>Operating Time (Year)</b>		
1-5	2	6,45
6-15	10	32,26
16-25	6	19,35
26 and Over	13	41,94
Total	31	100
Number of Employees		
1-25 People	9	29,03
26-50 People	16	51,61
51-100 People	4	12,90
100 and Over	2	6,45
Total	31	100

## 3.3.3 Reliability Analysis

Reliability analysis is concerned with the consistency of measurement and is indicative of the frequency with which repeated measurements achieve the same results. In the study, the mean value of each dimension was first calculated, then subjected to a reliability test. The Cronbach Alpha coefficient was calculated to calculate the reliability value of the dimensions in the study. The results are given in Tab. 3.

Cronbach Alpha coefficient exhibits a distribution between 0 and 1 and is interpreted as follows:

 $0.00 < \alpha < 0.20$  (Less Reliable)

 $0.20 < \alpha < 0.40$  (Rather Reliable)  $0.40 < \alpha < 0.60$  (Quite Reliable)

 $0.40 < \alpha < 0.00$  (Quite Kell 0.60 <  $\alpha < 0.80$  (Reliable)

 $0.80 < \alpha < 1.00$  (Highly Reliable).

Table 3 Reliability Analysis Table				
	Variable	Cronbach Alpha		
	Tangibles	0,83		
	Reliability	0,92		
Service Quality	Responsiveness	0,93		
	Assurance	0,85		
	Empathy	0,93		
	Guanxi	0,78		
Relationship Management	Trust	0,97		
	Commitment	0,93		
	Productivity	0,91		
Organizational Effectiveness	Customer Service	0,95		
	Reputation and Goodwill	0,93		

When the reliability scores in Tab. 3 have been examined, it is determined that the guanxi dimension of the Relationship Management variable is reliable. In contrast, the reliability levels of all other dimensions are highly reliable.

## 3.3.4 Standard Deviation & Mean Values

The mean and standard deviation values of the questions in the questionnaire applied within the scope of the study are given in detail in this section.

 Table 4 Standard Deviation and Mean Values (Service Quality)

		Mean	Std.
	Ν	Values	Errors
	Tangibles		
	Has "up to date" equipment	3,74	1,13
	Has useful facilities	3,45	1,12
	Has presentable (neatly dressed) employees	2,87	1,34
	Has literature on available services	3,48	1,48
	Reliability		
	Fulfils promises	3,74	1,29
	Express sincerity in problem-solving	3,65	1,31
	Provides efficient and consistent service	3,65	1,31
	Is punctual with service commitments	3,74	1,29
	Provides error-free service (target) assistance	3,55	1,03
Ŋ	Responsiveness		
ıali	Provides consistent punctual service	3,52	1,24
õ	Provides prompt service	3,52	1,24
ce	Expresses a consistent willingness to help	3,71	1,30
.N	Is responsive to requests	3,71	1,30
Š	Assurance		
	Engenders corporate confidence	3,77	1,09
	Provides transaction security (e.g., ensures	3,52	1,48
	minimal loss)		
	Is consistently courteous	3,68	1,28
	Displays knowledge during inquiries	3,48	1,48
	Empathy		
	Provides tailor-made customer service	3,52	1,36
	Has convenient office hours	3,52	1,36
	Is perceptive of customer needs and problems	3,71	1,13
	Has customer's interest at heart	3,45	1,23
	Is understanding of specific needs	3,52	1,36

For Service Quality variable, it is seen that the judgment with the highest mean value is the statement "Engenders corporate confidence" belonging to the Assurance dimension with 3.77 points. Average values of service quality show that respondents care about meeting their needs and seek to obtain institutional trust. In addition, respondents are not interested in having a presentable appearance of the staff.

Table 5 Standard Deviation and Mean Values (Relation Management)

	۸ĭ	Mean	Std.
	N		Errors
	Guanxi		
	Initiates inter-organizational relationships	3,45	1,23
	Possesses efficient managerial skills	3,61	1,02
	Values good working relationships	3,90	1,08
	Has a key representative who is accessible	4,13	1,02
	Has a key representative who socializes with	3,77	1,26
	customers		
	Trust		
	Adheres to a principle of complete trust	3,90	1,11
ent	Is accessible during service problems	4,23	0,92
em	Expresses confidence in customers	3,90	1,17
lag	Is attentive and makes inquiries	3,42	1,12
<b>1</b> ar	Communicates with sincerity	3,84	1,10
A d	Honours service commitments	3,94	0,96
shij	Provides consistent service	3,81	0,98
ons	Provides quality service	3,65	0,99
lati	Commitment		
Re	Adheres to a moral social principle	3,94	0,96
	Adheres to a principle of ethical service	3,94	1,06
	Adheres to a service principle of respect and	3,97	0,95
	acceptance		
	Demonstrates commitment	3,90	1,01
	Demonstrates a willingness to honour	3,90	1,01
	commitments		
	Provides optimal attentiveness	3,61	1,09
	Demonstrates loyalty	3,94	1,03
	Is patient	3,77	1,23

Table 6 Standard Deviation and Mean Values (Organizational Effectiveness)

	λ		Std.
	11	Values	Errors
	Productivity		
	Minimizes service failure probabilities	3,52	0,26
	Provides business operational consultancy service	3,48	0,48
	Provides competition enhancement service	3,35	0,05
	Provides quality efficient service	3,65	0,99
	Provides a high order rate service	4,06	0,85
	Provides efficient and reliable transportation	3,94	0,00
	service		
	Maintains a high level of productivity	3,65	0,99
	Customer Service		
less	Is responsive to purchase decision making	3,71	1,30
ven	Provides good after-sales services	3,65	1,23
cti	Responds efficiently and quickly to needs	3,48	1,12
ffe	Provides a punctual delivery service	3,52	1,18
Ξ	Welcomes feedback or comments	3,23	1,28
tio1	Provides a precise quantity service	3,32	1,19
iza	Provides a highly satisfactory service	3,45	0,89
an	Responds quickly to changes	3,32	1,19
<u>Drg</u>	Is responsive to specific requirements	3,42	1,31
0	Is flexible and adaptable to changes	3,32	1,19
	Employs value-added logistics services	3,26	1,26
	Provides an abnormally high value-added service	3,26	1,26
	Has few complaints	3,97	1,02
	Reputation and Goodwill		
	Engenders a positive or favourable image	3,77	1,09
	Correlates expertise with strategic missions	4,13	0,96
	Is reputable within the logistics industry	3,77	1,09
	Has relevant experience	4,13	0,96
	Has a good track record in customer service	3,77	1,06

When the Relationship Management variable is examined, it is observed that the judgment with the highest mean value is the statement "Is accessible during service problems?" belonging to the Trust dimension with 4.23 points. It is also worth mentioning that the second highest scoring statement is "He has a key representative", with a score of 4.13. The mean values of the two highest-scoring expressions are very close to each other. In light of these results, it can be argued that 3PL companies are expected to have accessible and authorized personnel in case of a possible issue.

Tab. 6 shows that the judgments with the highest mean values for the Organizational Effectiveness variable belong to the Reputation and Goodwill dimension. These are "Correlates expertise with strategic missions" and "Has relevant experience", with a score of 4.13. When these results are examined, it is understood that; the respondents give importance to 3PL providers to have experience in line with their strategic goals and to be experts in their fields.

Judgments with the lowest mean value for Service Quality, Relationship Management and Organizational Effectiveness variables, respectively; "Has presentable (neatly dressed) employees" with a score of 2.87, "Is attentive and makes inquiries" with a score of 3.42, and "Welcomes feedback or comments" with a score of 3.23.

Overall, it has been determined that survey questions are generally in the 3-4 score range, and the average score of the statement "Is accessible during service problems?" belonging to the "Trust" dimension is the highest value with 4.23 points.

## 3.3.5 Regression Analyses

Before performing the Regression Analysis, the mean values of the dimensions that make up the Organizational Effectiveness, Service Quality and Relationship Management variables were calculated, mean values were obtained for the variables, and these values were used in the analyses.

## 3.3.6 Dimensions of Service Quality Variable – Organizational Effectiveness

This section explores the regression relationship between the dimensions of the Service Quality variable and the Organizational Effectiveness variable.

Table 7 Summary of the Model				
$R$ $R^2$ Adjusted $R^2$ Standard Error of Estimation				
0,94	0,88	0,87	0,30	

The values related to the goodness of fit criteria obtained from the analysis results are given in Tab. 7. Accordingly, 88% of the change in the dependent variable is explained by the independent variables included in the model.

	Table	8	Model Significance	Test
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Model	F	Sig.
	103,67	0,00

Considering the results of the model integrity significance test, the null hypothesis referring that "the parameters are equal to zero and the model as a whole is insignificant" has been rejected at the 1 % significance level (F = 103,668; p = 0.000).

According to the values in Tab. 9, reliability and assurance, which are dimensions of Service Quality, have statistically significant and positive impacts on Organizational Effectiveness as the p-values for these variables are lower than 0.05.

Table 9	Regression	Analysis	Table
Tuble 0	rtogrooolon	7 1101 9 010	i ubio

In dan an dant Wanahla	Organizational Effectiveness			Degult
independent variable	В	t	Sig.	Result
Fixed Term	0,81	3,84	0,00	
Tangibles	(-)0,17	(-)0,99	0,33	Reject
Reliability	0,28	4,43	0,00	Accept
Responsiveness	0,08	0,76	0,45	Reject
Assurance	0,51	8,40	0,00	Accept
Empathy	0,06	0,54	0,60	Reject

When the relationship between the dimensions of Service Quality and Organizational Effectiveness variable is examined, it is found that hypotheses H1b (reliability of 3PL service providers positively affect Organizational Effectiveness) and H1d (assurance in 3PL service providers positively affect Organizational Effectiveness) were approved. Yet, hypotheses H1a, H1c, and H1e were rejected.

As a result, the coefficients of the reliability and assurance dimensions (respectively) have been determined as 0.277 and 0.514. A 1-point increase in the reliability dimension causes an increase of 0.277 points in the Organizational Effectiveness variable. In comparison, a 1point increase in the Assurance dimension causes an increase of 0.514 points in the Organizational Effectiveness variable.

Furthermore, a positive relationship exists between the Service Quality of 3PL service providers and Organizational Effectiveness. Considering the multiple regression results between the Organizational Effectiveness variable and the dimensions of Service Quality, it has been determined that assurance and reliability positively affect the Organizational Effectiveness variable, and there is no statistically significant relationship between the other dimensions and Organizational Effectiveness.

## 3.3.7 Dimensions of the Relationship Management Variable – Organizational Effectiveness

This section examines the regression relationship between the dimensions of Relationship Management and Organizational Effectiveness.

		Table 10 Summary	/ of the Model
R	$R^2$	Adjusted R <sup>2</sup>	Standard Error of Estimation
0,94	0,88	0,87	0,31

The values related to the goodness of fit criteria obtained from the analysis results are given in Tab. 10. Accordingly, approximately 88 % of the change in the dependent variable is explained by the independent variables included in the model.

Table 11 Model Significance Test		
Model	F	Sig.
	99,22	0,00

Considering the results of the model integrity significance test, the null hypothesis that "the parameters are equal to zero and the model as a whole is insignificant" is rejected at the 1 % significance level.

I able 12         Regression Analysis         I able				
Indexeduat Venichte	Organiza	Organizational Effectiveness		
independent variable	В	t	Sig.	Kesuit
Fixed Term	0,12	0,47	0,64	
Guanxi	0,48	2,56	0,02	Accept
Trust	0,45	2,62	0,01	Accept
Commitment	0,18	0,97	0,34	Reject

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As is shown in Tab. 12, change in the Organizational Effectiveness dependent variable could be explained by Guanxi and Trust (t = 2.563, p < 0.005 and t = 2.624, p < 0.005, respectively). The results depict that there is a positive relationship between Guanxi and Trust dimensions and Organizational Effectiveness. Therefore, H2a (3PL service providers' Guanxi ability positively affects Organizational Effectiveness positively.) hypotheses have been accepted. However, H2c (3PL service providers' fulfilment of their commitments positively affect Organizational Effectiveness.) hypothesis is rejected.

The coefficient of Guanxi is determined as 0.482. A 1point increase in the average score of the Guanxi dimension is associated with a 0.482 increase in the average score of the Organizational Efficiency variable. Additionally, the coefficient trust dimension is determined as 0.449, meaning that a 1-point increase in the trust dimension leads to a 0.449point rise in the Organizational Effectiveness variable.

In general, it has been determined that Relationship Management performance has a positive effect on Organizational Effectiveness. At the same time, it is seen that the Guanxi and Trust dimensions of the Relationship Management variable affect Organizational Effectiveness performance positively. However, the same is not the case between the Commitment dimension and Organizational Effectiveness.

## 3.3.8 Dimensions of the Relationship Management Variable – Service Quality

In this section, the regression relationship between the dimensions of Relationship Management and Service Quality variable is examined.

As shown in Tab. 15, a positive relationship is found between the Trust dimension of the Relationship Management variable and the Service Quality (t = 9,636, p < 0.005). Hence, the H3b (Trust in 3PL service providers positively affects Service Quality) hypothesis is accepted, while hypotheses H3a and H3c are rejected. More specifically, A 1-point increase in the average score of Trust leads to a 0.935-point increase in the average score of the Service Quality variable.

Table	13	Summary	of	the	Model
I abie	10	Ourninary		uic	mouci

R	$R^2$	Adjusted R <sup>2</sup>	Standard Error of Estimation
0,87	0,76	0,75	0,48

The values related to the goodness of fit criteria obtained from the analysis results are given in Tab. 13. Accordingly, approximately 76 % of the change in the dependent variable is explained by the independent variables included in the model.

Table 14 Model Significance Test		
Model	F	Sig.
	92,85	0,00

Considering the results of the model integrity significance test, the null hypothesis that "parameters are equal to zero and the model as a whole is insignificant" has been rejected at a 1 % significance level, and it has been concluded that the model as a whole is significant (F = 92.850; p = 0.000). Moreover, the results shown in Tab.15 reveal that only the Trust dimension of Relationship Management has a positive and statistically significant impact on the Service Quality variable.

Table 15 Regression Analysis Results

Indonandant Variabla	Service Quality			Degult
independent variable	В	t	Sig.	Kesult
Fixed Term	(-)0,05	(-)0,13	0,90	
Guanxi	0,29	1,17	0,25	Reject
Trust	0,94	9,64	0,00	Accept
Commitment	0,16	0,62	0,54	Reject

Fig. 6 shows the overall outcomes of the regression analysis, and the arrows represent positive and statistically significant effects.



Figure 6 Regression Analysis Results

## 4 CONCLUSIONS AND SUGGESTIONS

This study investigates the link between Service Quality, Relationship Management, and Organizational Effectiveness, which are the elements of Organizational Performance. The study focuses on the enterprises providing 3PL services in the Erzurum province of Turkey. The results from the regression analysis indicate that there is a positive association between the variables in question. However, when the multiple regression relationships between the variables and dimensions of these variables are examined, the dimensions do not show a relationship as a whole in the model.

It has been determined that the dimensions of the Service Quality and the Organizational Effectiveness variable positively affect the dimensions of assurance and reliability. There is no such relationship between the other dimensions and Organizational Effectiveness. Based on these findings, knowledgeable, courteous, and reassuring service understanding [41] and dependably and fulfilling service agreements [41, 43] are signs of excellent service quality. These traits are crucial for boosting organizational effectiveness and achieving objectives.

There is a positive link between Guanxi and Trust dimensions of the Relationship Management variable and Organizational Effectiveness. However, the same is not the case between the Commitment dimension and Organizational Effectiveness. Therefore, with the good establishment of the Guanxi and Trust relationship, the idea of mutual cooperation between 3PL providers and their customers is reinforced, and it can be said that they play a critical role in enhancing institutional efficiency [17].

When the association between the dimensions of Relationship Management and the Service Quality variable are examined, it is seen that only the Trust dimension has a positive impact on Service Quality. It follows that the higher the level of service quality, the more trust there is between 3PL firms and their clients.

The statements with the highest mean values for each variable in the questionnaire belong to the Assurance, Trust, Reputation and Goodwill dimensions. Also, almost all statements' mean values range between 3 and 4. These results are similar to the results obtained from the regression analysis.

This study not only explores the relationships between organizational performance elements of 3PL companies but also provides useful information for these companies to adopt organizational performance indicators and seize opportunities for improvement. In this context, the following actions should be taken into account by 3PL organizations to enhance their organizational performance.

- They should give confidence, keep their promises, be willing to provide error-free service assistance and solve problems.
- They must build organizational confidence, guarantee transaction security (for example, ensuring low losses), and constantly be polite to their clients.
- They should initiate relationships between organizations, possess effective management abilities, prioritize strong working relationships, and have a key representative who interacts with clients.
- They should be available during service problems, communicate sincerely, and provide consistent and quality service.

The main limitation of this study is that the sample size is small, and the 3PL service providers have similar characteristics to each other. For example, 3PL providers with similar tangible assets cause low customer expectations. Therefore, the company that receives 3PL services is unaware of companies with better tangible assets and may miss the advantages it will provide. In this respect, studies that will be carried out using a larger sample group may provide additional contributions to the literature.

#### Notice

This study is derived from İbrahim Kadir Demir's master thesis titled "Firmaların 3PL Hizmet Sağlayıcılarının Kurumsal Etkinlik, Hizmet Kalitesi Ve İlişki Yönetimi Aktivitelerine Yönelik Tutumları" conducted under the supervision of Associate Professor Dr. Dilşad Güzel.

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## **QOTUM:** The Query Optimizer for Distributed Database in Cloud Environment

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Abstract: In distributed and cloud database system, large amount of resources are used by complex queries that increase in payment overheads of cloud users. These resource needs can be minimised by evaluating common join operations and caching their results so that they could be applied to the execution of additional queries. In this research, the Query Optimization Technique Using Materialization (QOTUM) system is designed and developed that uses the mechanism of materialized views during query execution at distributed database in cloud environment. Extensive experiments are conducted with the help of standard benchmarks datasets and query workloads in cloud environment. The performance of QOTUM system is studied and evaluated against conventional SQL system based on various performance parameters.

Keywords: cloud computing; distributed databases; materialized views; query optimizer; query optimization technique

## **1** INTRODUCTION

This paper continues the earlier research we published in Bachhav et al. [1]. To perform complex queries on large databases more effectively, cloud customers can hire a lot of resources for a short period of time with the help of virtual machines [2]. One of the most difficult research problems in the Big Data age is how to make the requirements for relational query processing efficiency across clouds [3].

Through the use of stronger query optimisation strategies, the cost of hiring resources for cloud users can be decreased [4]. The devise of *Query Optimization Technique Using Materialization (QOTUM)* is the main contribution of this research in the field of database query optimization. It materializes views during query execution at distributed database in cloud environment. The *QOTUM* system will provide the following contributions in the field of database management and query optimization in distributed system on cloud:

- It can be used as a pre-processor for effective query optimization on the top of any databases system.
- The design of query optimizer that uses materialized views to execute future queries.
- An optimization strategy has been introduced that reduces total execution cost of queries in distributed databases which will be more beneficial in cloud environment.
- Cloud resource utilization has been improved by reducing query evaluation time and overall execution cost.

*QOTUM* system has been developed on Java platform with the help of ZQL Parser [5]. The performance of the system is tested on cloud platform of Amazon Relational Database Service (RDS) [6] using standard benchmark dataset and the workload of TPC-H [7]. The MySQL database engine is initially setup on Amazon RDS instances and TPC-H database is distributed among all these RDS instances. Numerous tests have been carried out using all different types of TPC-H query workloads.

Remainder of this research paper is organized as follows. The working of *QOTUM* system is elaborated in section 2. Section 3 presents an experimental setup for testing performance of *QOTUM*. The result analysis is explained in section 4. Observations and Plugin to deal with *QOTUM* system are presented in section 5 and section 6 concludes the work with future directions.

## 2 QOTUM (QUERY OPTIMIZATION TECHNIQUE USING MATERIALIZATION)

After extensive literature survey published in our paper [1, 8] on numerous methods of database query optimization, it is determined that there can be a query optimization technique which will work as a pre-processor on the top of database management system. conventional Ouerv optimization technique named QOTUM uses the mechanism of materialized views during query execution at distributed database in cloud environment. The main aim of this study to innovate the query optimizer in distributed and cloud environment that reduces overall query execution cost. QOTUM materializes results generated during query evaluation that can be reused for evaluation of additional queries. The Fig. 1 shows architecture of QOTUM, the query optimizer technique using materialized views presented in [1, 9].



During evaluation of a future query, if materialized view matches with any of its subqueries then instead of evaluating that matched subquery again, materialized view can be directly used for further processing [10-13]. Aggregation queries across big relations can be processed more quickly by using materialised views [14, 15].

The relations requested by a query can be stored in several places in cloud and distributed systems. The cost of moving data between various cloud sites should now be taken into account in addition to the cost of local computing [16]. It can be difficult to determine the best join order for queries with many relations in distributed systems since the search space expands exponentially as the number of relations increases [17]. *QOTUM* trying to reduce the execution time, I/O operations and communication cost.

## 2.1 How QOTUM works?

*QOTUM* system performs the query optimization process with the help of three modules – View Manager, View Navigator and Query Evaluator by maintaining View Store and View Catalogue as elaborated in Algorithm 1.

*QOTUM* performs the following steps.

- 1. Submitted query is divided into subqueries (Makes use of Zql Parser [5]).
- 2. Finds the relation names and predicates from subqueries
- 3. View Navigator navigates the View Catalogue and using the view matching algorithm provided by Bachhav et al. [1], attempts are made to locate the view store entry to find longest match view name.
- 4. View Manager finds a matching view name in the view catalogue and maps it to the view store.
- 5. If match is found, then returns the matched position of View Store. Additionally, partly interim findings are used to evaluate upcoming queries. The commutative rule for natural join is followed during match.
- 6. The query execution is performed after replacing the matched views in a query.
- 7. After evaluation of query, the generated views are maintained in View Store by View Manager.

- 8. View Manager also updates the View Catalogue after storing views in view store.
- 9. View Manager updates the read/write timestamps and reference count for the view which is referred.
- 10. When View Store becomes full, Views those are not referred from longest period of time are deleted by View Manager and also updates the corresponding entries in View Catalogue by invoking logistic regression algorithm as per step 11.
- The value of Read/Write timestamp for a view in View Store is used to take decision for deletion of view from View Store.
   Logistic Regression algorithm of Machine Learning [18]

is applied to classify View Store entries into two classes. (I) Entries to be deleted

(II) Entries not to be deleted.

Logistic regression algorithm uses Eq.(1) to find the value between 0 and 1 that predicts in which class a View Store entry belongs [19].

$$y = \frac{1}{1 + e^{-x}} \tag{1}$$

Where x is read/write timestamp of view, and y is the predicted value generated.

A threshold value is set to classify the predicted value into appropriate class.

For example – if threshold value is 0.5 and predicted value y is 0.3 then our predicted value <0.5, will classify it as the class "Entry to be deleted", otherwise classify it as the class "Entry not be deleted".

12. Materialized view get removed from View Store, if there are updates in base relations involved in it to avoid inconsistency in resultant set (Details presented in section 5.2)

	Algorithm 1 Algorithm for QOTUM		
	Algorithm <i>QOTUM</i>		
	Input:		
	- Query to be evaluated		
	Output:		
	- Updated View Store - Updated View Catalogue		
1	Begin		
2	Split a query into subqueries using Zql Parser		
3	Get view pattern used in subqueries		
4	Location $\leftarrow$ Call Algorithm ViewMatching(catalogue, view pattern)[1]		
5	If location is in View Catalogue		
6	Get corresponding Materialized Views from View Store		
7	Evaluate query using Materialized Views		
8	Else		
9	Evaluate query using conventional method		
10	End If		
11	If View Store is Full		
12	Find appropriate views to remove using Logistic Regression algorithm		
13	Remove such views from View Store		
14	Update corresponding entries in View Catalogue		
15	End If		
16	Materialize the newly generated view in View Store		
17	Add entry into View Catalogue about newly generated view		
18	Update View Reference Count and Read/Write Timestamps in View Store		
19	End		

## 3 EXPERIMENTAL SETUP

The *QOTUM* System is developed on Java platform using Zql Parser Java library. The performance of this

technique has been already tested at small scale level where horizontal fragmentation is applied on benchmark relations and fragments are randomly distributed on two nodes [1]. However, this research paper presents the performance of OOTUM at large scale level on cloud platform of Amazon Relational Database Service (RDS) using standard benchmark dataset and the query workload of TPC Benchmark<sup>™</sup>H (TPC-H). TPC-H is made up of a collection of business databases and queries that are intended to test the functionality of any sophisticated business analysis applications [7]. The process of a wholesale supplier has been realistically shown by the database and queries. Given SQL statements in TPC-H workload are parsed by Zql parser and represent it in Java data structures [5].

## 3.1 Database and Workload for Experiments

The TPC-H database consists of 8 individual base tables with different relationship between them. Tab. 1 illustrates the TPC-H Schema with the relationships between different tables. The number of rows (cardinality) of each table is represented using the number or formula where SF represents the Scale Factor which can be chosen by researcher to obtain the required database size. The total storage space required with SF = 1 is 2.21 GB.

The testing has been performed after fragmentation and distributing these benchmark relations as per the distribution scheme specified in section 3.2 over different instances of Amazon RDS after applying the horizontal fragmentation. For the TPC-H benchmark, a set of 22 original queries were used to provide a realistic context that reflected the activity of a wholesale supplier.

	Table 1 TPC-H schema relations [7]		
Sr. No.	Table name	Cardinality	
1	Region	5	
2	Nation	25	
3	Part	<i>SF</i> × 2,00,000	
4	Supplier	<i>SF</i> × 10,000	
5	Partsupp	$SF \times 8,00,000$	
6	Customer	$SF \times 1,50,000$	
7	Order	<i>SF</i> × 15,00,000	
8	Lineitem	<i>SF</i> × 60,00,000	

Table 1 TPC-H schema relations [	7]
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#### Table 2 Query workload variations [1]

Workload	Description
W1	Set of queries without common join operations
W2	Set of queries with about 25% common join operations
W3	Set of queries with about 50% common join operations
W4	Set of queries with about 75% common join operations
W5	Set of queries with 100% common join operations

Five different workload variations (shown in Tab. 2) each containing 100 queries were created using 22 TPC-H base queries to evaluate the performance of the QOTUM system. With the aid of the right range of probable values according to the benchmark, the selection predicates were constructed for each query in accordance with the defined workload. The effectiveness of the QOTUM has been assessed using a variety of performance metrics, including the number of iterations, query execution time, memory usage, and overall execution cost.

#### 3.2 Database Setup on AWS-RDS

The Relational Database Service from Amazon Web Services (AWS-RDS) is reasonably priced, easily scaled, and configurable [20]. RDS MYSQL is a cloud-based database that is fully managed and provides high availability [21, 22]. Hence AWS-RDS with MySQL database engine has been used on cloud to deploy the TPC-H database and to test the workload of queries. Total 10 instances have been setup on AWS-RDS each of *db.t2.micro* class with the configuration of 1 vCPU, 1 GB RAM and 20 GB SSD storage. The TPC-H benchmark database of 2.21 GB is used for testing effectiveness of OOTUM on Amazon RDS. The TPC-H benchmark database is deployed on 10 RDS instances named as Instance-1 to Instance-10 as per the distribution mentioned in Tab. 3, for conducting various experiments.

RDS Instance-1 stores the whole TPC-H database of 2.21 GB and other instances maintain the horizontal fragments of the database. Initially for first slot of experiments, database is horizontally partitioned into 2 fragments and deployed among Instance-2 and Instance-3. To conduct second slot of experiments, database is partitioned into 3 fragments and deployed among Instance-4 to 6. Final slot of experiments is conducted on Instances-7 to 10, those holds 4 horizontal partitions of database.

AWS-RDS Instances	Database Distribution				
Instance-1	Maintains the whole TPC-H database				
Instance-2	Maintains the fragments generated from 2				
Instance-3	horizontal partitioning of TPC-H database				
Instance-4	Maintaing from such a superstad from 2 having antal				
Instance-5	Maintains fragments generated from 3 norizontal				
Instance-6	partitioning of TFC-II database				
Instance-7					
Instance-8	Maintains fragments generated from 4 horizontal				
Instance-9	partitioning of TPC-H database				
Instance-10					

## **RESULTS AND DISCUSSION**

All combinations of the stated query workloads have been used to conduct extensive experiments. Based on a number of performance parameters, the performance of OOTUM is examined and compared with that of a traditional SQL system.

## 4.1 Experiments Conducted

The MySQL database engine was initially setup on AWS-RDS instances and TPC-H database was distributed among all those RDS instances. The *QOTUM* system which is developed in Java has been tested by conducting various experiments on all deployed RDS instances by providing variety of query workloads. Tab. 4 describes the list of performance parameters those are considered for the comparative study.

All different types of query workloads are used to run experiments using fragments 2, 3 and 4. Primarily, the experiment was conducted on the RDS Instance-1 that holds the whole TPC-H database without partitioning. The distributed database environment is provided to test the performance of the system. The system is then tested on two partitions of TPC-H database viz. Instance-2 and Instance-3, followed by on three partitions Instance-4 to Instance-6 and finally on four partitions Instance-7 to Instance-10. All test experiments are conducted by providing query workloads W1 to W5.

Table 4	List of	Performance	Parameter
10010 1	E101 01	1 0110111101100	anannoton

Performance Parameter	Description
Average number of iterations	Average number of iterations required to
	complete the execution of all queries in
	workload
Average execution time	Average execution time required for
	execution of all queries in workload
Total memory consumption	Total memory consumed by all queries in
	query workload
Total cost of execution	The total cost required to execute all
	queries in workload comprises of time for
	execution, memory consumption, cost
	required for IO operations and view
	matching time in view store.

The system *QOTUM* acts as a pre-processor because the results generated from *QOTUM* are in the form of optimized queries, which can be provided as inputs to the conventional RDBMS like MySQL for further evaluation.

## 4.2 Results

Results are evaluated with traditional SQL system on various parameters such as number of iterations, execution time, memory consumption and total execution cost. The analysis of summarized results is presented using charts in Figs. 2 to 4. The comparative study on average execution time in conventional as well as *QOTUM* system is presented with the help of chart in Fig. 5.

## 5 OBSERVATIONS AND PLUG-IN

## 5.1 Observations

- We observed the substantial reduction of execution time in the *QOTUM* system as compare to conventional system for query workloads W2 to W5. Repetition of join operations in query workloads W2 to W5 takes the benefit of materialization that results in substantial reduction of execution time.
- However, in workload W1 no repetition of join operations, so it does not take a benefit of materialization. The *QOTUM* system adds an extra overhead of View Store searching time in query execution time. It leads to degrade the performance of the *QOTUM*.
- In the *QOTUM* system, average memory requirement for query processing decreases with increase in repetition of join operations using workloads W2 to W4.
- In *QOTUM* system, for workload W1 View Store becomes full more frequently than in workload W2 to W4 because in W1 there are no repeated joins, every query after execution adds new view in View Store.



Average Execution Cost (For 2 Fragments)



Figure 2 Comparative analysis on performance parameters for 2 fragments



Figure 3 Comparative analysis on performance parameters for 3 fragments



Figure 4 Comparative analysis on performance parameters for 4 fragments

• Due to materialization in *QOTUM* system, number of iterations gradually decreases with increase of repeated join operations in workloads W2 to W5. But it remains almost same for conventional and *QOTUM* using workload W1.

• The *QOTUM* system is more efficient with increase in number of fragments and repeated join operations.



## 5.2 Plug-In to deal with QOTUM System

Materialized views those are stored in View Store comprise of various base relations. However, there may be updates time to time in base relations that are involved in materialized views which will make those materialized views stale. Hence, to handle the problem of stale materialization, trigger and store procedure should be plugged in to the database in order to remove stale views. *QOTUM* System handles the stale materialization with the help of trigger, stored procedure and java class as mentioned in Tab. 5.

	Table 5 Handling Stale Materialization						
Plugin	Plugin Content						
	import java.io.*;						
	public class Rmview						
	{ public static void remove(tablename)						
Java Class	{ //Remove views from viewstore						
	//matches with tablename						
	}						
	}						
Stand Dua and Juna	CREATE OR REPLACE PROCEDURE Remove_View(tablename)						
Stored Procedure	AS LANGUAGE JAVA NAME 'Rmview.remove(tablename)';						
	CREATE OR REPLACE TRIGGER tablename upd						
	AFTER INSERT, DELETE, UPDATE ON tablename						
Trigger	begin						
	Call Remove_View(tablename);						
	end:						

## 6 CONCLUSION AND FUTURE DIRECTION OF RESEARCH

In this research work, the query optimization technique, *QOTUM* has been presented. The technique seeks to reuse intermediate results from previously run searches to execute new queries. The intermediate or materialized views can be used to execute queries that have repeating joins or similar sub expressions, which reduce the average execution time per query and improve system performance. As a result of the materialisation of intermediate views, the *QOTUM* system has been put through testing on large scale cloud infrastructure, and it has been found to significantly lower query execution time and memory requirement when compared to the conventional query processing system. In this system, the overall cost of query execution is inversely proportional to the number of repeated joins in query

workloads. That means increase in number of repeated joins leads to decrease in execution cost.

In cloud environments, Map-Reduce platforms such as Hadoop works on NoSQL or non-relational database management systems that are now become standard for largescale data processing, but they increase overall processing cost for join-intensive workloads [23]. However, the *QOTUM* can only works on top of relational database management system. Hence as a future direction of the research, this system can also be extended to work on the top of NoSQL or non-relational database management system that will reduce the overall processing cost of join intensive workloads using Map-Reduce.

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## A Probability-based Fuzzy Multi-objective Optimization for Material Selection

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Abstract: In the present paper, a rational fuzzy multi-objective optimization for material selection is developed in respect of probabilistic method for multi-objective optimization, which agrees with the viewpoint of system theory for the whole optimization of a system and is the novelty of this work. The basic ideas and algorithms of fuzzy theory together with probability theory are taken as the cornerstone to perform the formulation. In the treatment, the intersection of the membership function of fuzzy numbers of alternative material performance and the membership function of fuzzy numbers of desired material performance is used as the utility of the material performance index. Thereafter, the utility of each material performance index is further used to conduct the assessment of its partial preferable probability and formulate the multi-objective optimization by means of probability theory. Moreover, a typical example is presented to provide the rational process of the probabilistic fuzzy multi-objective optimization.

Keywords: fuzzy; intersection; multi-objective optimization; probability; utility

## **1** INTRODUCTION

Multi-objective optimization is an essential tool in solving problems which contain assessment of multiple attributes and alternatives [1-4]. The difficulty is that the objectives (attributes) in the decision are quite often conflicting each other [5-8].

Besides, in some cases a linguistic or inexact expression for responses is presented, which makes the assessments with characteristic of "fuzzy" in some sense [1-4].

In material selection for machine components or structures, it is a most complicated and time consuming problems for engineers or manufacturing companies, since many conflicting objectives and feasible alternatives are involved, which even has the characteristic of "fuzzy".

The usual case is that many potential objectives (attributes), such as hardness, machinability, cost and corrosive resistance, etc. for material selection, must be considered together in the evaluated process. Therefore, material selection for machine components or structures is indeed a multi-objective optimization problem, even involving both types of quantitative and qualitative criteria [5-8].

In case of the presence of both quantitative and qualitative criteria, a designer is faced to the problem of selecting an appropriate quantified method to conduct the treatment of non-quantifiable criteria. The assessment concerning qualitative criteria is usually subjective and thus inexact [1-8]. Therefore, it is indispensable to develop a quantified approach that can be employed to rationally describe the preference of one alternative over others comparatively [9, 10].

As to the assessment of alternative suitability for material selection, some criteria are in linguistic terms or subjective ones, such as the weight importance of the attribute, the corrosive resistance, etc., which makes it an actual fuzzy problem undoubtedly.

In past, many researchers attempted to propose fuzzy multi-objective optimization methods for material selection [6-10]. Most of them solve the problems by simple combination of the fuzzy concept with traditional multi-objective optimization approaches, such as the "TOPSIS

(Technique for Order Preference by Similarity to Ideal Solution)", "AHP (Analytic Hierarchy Process)", "VIKOR (VIsekriterijumsko KOmpromisno Rangiranje)", "MOORA (Multi-Objective Optimization on basis of Ratio Analysis)", etc. [1-12]. However, this kind of hybrid cannot be seen as reasonable approaches because of the existences of inherent shortcoming in the traditional multi-objective optimization approaches due to their "normalization" and "additive algorithm" for various objectives [6-15].

Currently, a probabilistic approach for multi-objective optimization (PMOO) was developed, which aims to solve the intrinsic problems of the traditional multi-objective optimization with "normalization" and "additive algorithm" and irrationality in treating "simultaneous optimization of multiple objectives" [13-15]. The new idea of preferable probability was proposed to reflect the preferable degree of a performance utility indicator in the optimization from respects of probability theory and set theory. In the new methodology, all performance utility indicators of alternatives was preliminarily divided into two types, i.e., beneficial type and unbeneficial type in accordance with their specific roles and preference in the optimization; each performance utility indicator of the alternative contributes to a partial preferable probability to the entire optimization quantitatively; Moreover, according to probability theory and set theory, the product of all partial preferable probabilities forms the overall preferable probability of the alternative, which is the uniquely decisive index in the optimization process. Thus, the multi-objective optimization problem is converted into a mono-objective optimization one by means overall preferable probability. The simultaneous of optimization of all performance utility indicators is the intrinsic issue of multi-objective optimization, which is reflected by the product of all partial preferable probabilities equaling to the total preferable probability of an alternative rationally in the respect of probability theory [13-15]. Above processing is consistent with the viewpoint of system theory for the whole (integral) optimization of a system [16].

In this paper, a rational fuzzy multi-objective optimization for material selection is developed in respect of probabilistic method for multi-objective optimization; the probability-based method for multi-objective optimization is combined with the fuzzy algorithm as the starting point of the rational approach; the utility of the material performance index is determined by the intersection of the membership function of fuzzy numbers of alternative material performance and the membership function of fuzzy numbers of desired material performance to perform the formulation. Moreover, one example is represented to show the rational process of fuzzy multi-objective optimization for material selection.

## 2 FORMULATION OF FUZZY PROBABILITY-BASED MULTI-OBJECTIVE OPTIMIZATION

# 2.1 Membership Value of Material Performance in Fuzzy Language

Above discussion indicates that there the existence of many quantitative and qualitative criteria is very usual in multi-objective optimization problem for material selection [13-15]. Here in this paper only the evaluation of quantitative and qualitative criteria with fuzzy characteristic in multi-objective optimization problem is conducted. Following four types are involved.

## 2.1.1 Membership of Quantitative Performance

This kind of material performance can be usually expressed by numerical data as in Tab. 1.

 Table 1 Data of some metallic material performance properties [3]

Metal	Hardness (HV <sub>10</sub> )	Machinability rating <sup>*</sup> (%)	Cost (\$/lb)	Corrosion resistance ⊕
Stainless steel 17-4 PH	283.7-449.5	25	4-5	Recommended
Stainless steel 410	156.6-372.1	40	3	Recommended
Stainless steel 440A	222.9-416.3	30	2.5-3.0	Recommended
Stainless steel 304	151.1-316.8	45	2	Not recommended
Nickel-resist cast iron	129.0-261.6	35	0.8-1.3	Recommended
High- chromium cast iron	261.6-758.9	25	2-2.5	Recommended
Nickel-hard cast iron	565.5-648.4	30	1.8-2.2	Recommended
Nickel 200	68.2-239.5	55	4	Acceptable
Monel 400	106.9-250.5	35	8	Recommended
Inconel 600	173.2-305.8	45	8.5-9.0	Recommended

Notice: \*The machinability rating of cold-drawn AISI 1112 steel is taken as a value of 100%;  $\oplus$  the guidelines state: "recommended" for corrosion rate < 20 mpy (mill per year), "acceptable" for 20 mpy < corrosion rate < 50 mpy, and "not recommended" for corrosion rate > 50 mpy.

While, since the operations of material processing are with stochastic nature, such kind of material performances are not well fixed but actually ranging in some areas (from lower limit to upper limit). For example, the hardness of stainless steel 410 is approximately ranging from 156.6 to 372.1 HV<sub>10</sub> [3]. Such kind of quantitative performances can be categorized as fuzzy number of "1<sup>st</sup> type". Sometimes, the upper limit and lower limit of the range interval are uncertain either. In this case, the quantitative properties can be seen as fuzzy number of "2<sup>nd</sup> type".

Since the value of a quantitative performance of material can be ranging in an interval (between upper limit and lower limit) approximately, a trapezoidal function is usually employed to reflect the membership value of the quantitative performances of material [3]. For example, hardness of stainless steel 410 is approximately ranging in "156.6 to 372.1  $HV_{10}$ ", which is represented by a range of fuzzy numbers (140.9, 156.6, 372.1, 409.3) HV<sub>10</sub> subjectively bearing 10 % fuzziness in its property value in the database in upper limit and lower limit, the membership function of this kind of quantitative performance is shown by Form 2 of Fig. 1. On the other hand, a property data with a value "approximately equal to 250" can be represented by a range of fuzzy numbers (225, 250, 250, 275), which is shown by Form 4 of Fig. 1. Analogically, the Form 1 and Form 3 gain their specific meanings of smaller or equal to same data and bigger or equal to same data in Fig. 1.



## 2.1.2 Membership of Qualitative Performance

A qualitative property is a response with linguistic characteristic, which is expressed in words or sentences, such as, for "corrosion resistance" the usual linguistic expression is "recommended" ( $R_e$ ), or "acceptable" ( $A_c$ ), or "not recommended" (NR) [3]; while, for importance of weight of the relevant material properties, the common linguistic demonstration is "high" ( $W_h$ ), or "very high" ( $W_{vh}$ ), or "medium" ( $W_m$ ), etc.

Actually, the material property and importance of weight belong to different kind of fuzzy parameters in principle.

The importance of weight can be evaluated by subjective score, for example, the weight importance of the relevant material properties, with "high" ( $W_h$ ) can be scored by 8, the "very high" ( $W_{vh}$ ) can be scored by 10, and the "medium" ( $W_m$ ) can be scored by 6.

On the other hand, the qualitative performance of material property in fact has certain meaning, which can be expressed by trapezoidal fuzzy numbers as well, for example, according to guidelines for classification, see Tab. 1. The membership functions for the "corrosion resistance" was subjectively defined as follows,  $R_e$  (recommended): (18, 18, 18, 22);  $A_c$  (acceptable): (18, 20, 50, 55); *NR* (not recommended): (45, 55, 55, 55) [3].

## 2.1.3 Desired Data and Available Data of Material Performances

The desired data of material performances for design can also be transferred into trapezoidal fuzzy numbers as a

requirement for material selection. For example, the desired value of Vickers hardness equals to 300 HV<sub>10</sub> approximately  $(D_1)$ , it can be represented by trapezoidal fuzzy numbers as (270, 300, 300, 330), which is reflected by Form 4 of Fig. 1.

Usually, the data of material performance can be taken from practical production or handbook and used as available data to withstand the screening for the material selection.

## 2.1.4 Utility of Material Performance

The "intersection" of the "desired data" and "available data" of material performances can be used to determine the utility of material performance in the material selection. The assessment procedure is as following,

A) Under condition of the range of the desired trapezoidal fuzzy numbers fully covering the available trapezoidal fuzzy numbers of material performances, the consequence of the utility of the corresponding material property is 1.

B) In case of the desired trapezoidal fuzzy numbers covering nothing related to the available trapezoidal fuzzy numbers of material performances, the consequence of the utility of the corresponding material property is 0.

C) Otherwise, if the desired trapezoidal fuzzy numbers partially covering part the available trapezoidal fuzzy numbers of material performances, the consequence of the utility of the corresponding material property is the ratio of the area of the covered part to the total area of the available trapezoidal fuzzy numbers of material performances.

For example, the desired value of Vickers hardness equals to 316.8 HV<sub>10</sub> approximately  $(D_d)$ , its trapezoidal fuzzy numbers can be represented as  $D_d$ : (285.1, 316.8, 316.8, 348.5), the available trapezoidal fuzzy numbers of nickel 200 are given by  $D_a$ : (61.4, 68.2, 239.5, 263.5), it is obvious that there is no "intersection" between  $D_d$  and  $D_a$  for nickel 200, therefore the utility of nickel 200 in hardness is 0; while, the available trapezoidal fuzzy numbers of stainless steel 410 are given by D<sub>a</sub>: (140.9, 156.6, 372.1, 409.3), and there is a "intersection" between  $D_d$  and  $D_a$  for stainless steel 410 in hardness, the result of utility of stainless steel 410 in this condition for hardness is 0.1354. Besides, the desired value of cost is smaller or equal to 3.5 / b approximately  $(D_d)$ , its trapezoidal fuzzy numbers can be represented as  $D_d$ : (0, 0, 3.5, 3.85), the available trapezoidal fuzzy numbers of stainless steel 410 are given by  $D_a$ : (2.7, 3, 3, 3.3), the trapezoidal fuzzy numbers of  $D_a$  is fully covered by the trapezoidal fuzzy numbers of  $D_d$  for stainless steel 410, therefore the utility of stainless steel 410 in cost is 1.

## 2.2 Fuzzy Probability-based Multi-objective Optimization

As the utility of available material performance is evaluated by the procedures of last sections in the respect of fuzzy language and set theory, which is withstanding the screening of desired indexes, the available data of material performance can be thus used to conduct fuzzy probabilitybased multi-objective optimization rationally [13-15].

The general procedure of the "probability-based multiobjective optimization" from utility of material performance indexes is shown in Fig. 2. The meanings of the variables and factors in Fig. 2 are as following:

 $P_{ij}$  expresses the partial preferable probability of the *j*<sup>th</sup> performance utility indicator of the *i*<sup>th</sup> candidate scheme,  $X_{ij}$ ; *n* reflects the total number of the candidate scheme; *m* shows the total number of the performance (objective);  $\overline{X}_j$  indicates the arithmetic value of the *j*<sup>th</sup> performance utility indicator;  $X_{jmax}$  and  $X_{jmin}$  express the maximum and minimum values of the *j*-th performance utility indicator, respectively;  $\alpha_j$  and  $\beta_j$  represent the normalized factors of the *j*<sup>th</sup> performance utility indicator  $X_{ij}$  in beneficial status and unbeneficial status, individually; the beneficial status or unbeneficial status of the *j*<sup>th</sup> performance utility indicator  $X_{ij}$  is specified according to its particular preference or role in the problem;  $P_i$  is the total (overall) preferable probability of the *i*<sup>th</sup> candidate scheme [13-15].



Figure 2 Procedure of probability-based multi-objective optimization

The whole procedure of the fuzzy multi-objective optimization for material selection on basis of probability is shown in Fig. 3.

## **3 EXAMPLE FOR ILLUSTRATION**

Take the engineering application of material selection for a nozzle of a jet fuel system as an example [3]. The specific desired values and importance of weight of the material are cited, which is used to screen the available candidate materials in Tab. 2.

Table 2 Des	ired values	for material	properties

Property	Hardness, $D_{d1}$ (HV <sub>10</sub> )	Machinability rating <sup>*</sup> , $D_{d2}$ (%)	Cost, <i>D</i> <sub>d3</sub> (\$/lb)	Corrosion resistance, D <sub>d4</sub>
$D_{\rm d}$	(285.2, 316.8, 316.8, 348.5)	(27, 30, 100, 100)	(0, 0, 3.5, 3.85)	(18, 18, 18, 22)
Weight of import.	8	10	6	6



Figure 3 Whole procedure of the fuzzy multi-objective optimization for material selection in respect of probability theory

The general meanings of the specific desired values and importance weight of the material, are as followings, the Vickers hardness equals to 316.8 HV<sub>10</sub> approximately ( $D_1$ ), the machinability rating is greater or equal to 30 approximately ( $D_2$ ), the cost is smaller or equal to 3.5 \$/lb approximately ( $D_3$ ), and corrosion resistance is as "recommended" ( $D_4$ ). The evaluation of the importance weight of the desired material property is scored by 8 for "high" ( $W_1$ ) for hardness, 10 for "very high" ( $W_2$ ) for machinability rating, and 6 for "medium" for cost ( $W_3$ ) and for corrosion resistance ( $W_4$ ).

Table 3 Trapezoidal fuzzy numbers of candidate material properties corresponding to Tab. 1

Metal	Hardness, $D_{ai1}$ (HV <sub>10</sub> )	Machinability rating <sup>*</sup> , $D_{ai2}$ (%)	Cost, D <sub>ai3</sub> (\$/lb)	Corrosion resistance, D <sub>ai4</sub>
Stainless	(255.3, 283.7,	(22, 25, 25,	(3.6, 4, 5,	(18, 18, 18,
steel 17-4 PH	449.5, 494.4)	28)	5.5)	22)
Stainless	(140.9, 156.6,	(36, 40, 40,	(2.7, 3, 3,	(18, 18, 18,
steel 410	372.1, 409.3)	44)	3.3)	22)
Stainless	(188, 215,	(27, 30, 30,	(2.2, 2.5,	(18, 18, 18,
steel 440A	390, 429)	33)	3, 3.3)	22)
Stainless	(136.0, 151.1,	(40, 45, 45,	(1.8, 2, 2,	(45, 55, 55,
steel 304	350.0, 385.0)	50)	2.2)	55)
Nickel-resist	(116.1, 129.0,	(31, 35, 35,	(0.7, 0.8,	(18, 18, 18,
cast iron	261.6, 287.7)	39)	1.3, 1.4)	22)
High-	(235.4.261.6	(22, 25, 25	(1.8.2	(18 18 18
chromium	(233.4, 201.0, 750.0, 834.8)	(22, 23, 23, 23, 28)	(1.0, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,	(10, 10, 10, 22)
cast iron	759.0, 854.8)	28)	2.3, 2.8)	22)
Nickel-hard	(509.0, 565.5,	(27, 30, 30,	(1.6, 1.8,	(18, 18, 18,
cast iron	648.4, 713.2)	33)	2.2, 2.4)	22)
Niekel 200	(61.4, 68.2,	(49, 55, 55, 61	(3.6, 4, 4,	(18, 20, 50,
INICKEI 200	239.5, 263.4)	)	4.4)	55)
Manal 400	(96.2, 106.9,	(31, 35, 35,	(7.2, 8, 8,	(18, 18, 18,
Woller 400	250.5, 275.6)	39)	8.8)	22)
Inconel 600	(155.8, 173.2,	(40, 45, 45,	(7.6, 8.5,	(18, 18, 18,
meoner 600	305.8, 336.4)	50)	9, 9.9)	22)

The performance data of candidate materials are shown in Tab. 1. These data can be converted into the trapezoidal fuzzy numbers and thus presented in Tab. 3. The fuzzy numbers were determined based on the subjective hypothesis that there is 10 % fuzziness in each property value of the database.

The utility of the candidate materials by means of screening with the desired requirement for the material selection is shown in Tab. 4. The consequence of evaluation for preferable probability and rank is obtained in Tab. 5. In the evaluation of partial preferable probability of the utility of material performance index, all above 4 utilities have the characteristic of "the higher the better", so they all belong to beneficial type of indexes [13-15]. As to the evaluation of total preferable probability of the candidate material, the total (overall) preferable probability is expressed by

$$P_{\rm t} = P_{\rm hd}^{w_1} \cdot P_{\rm mr}^{w_2} \cdot P_{\rm c}^{w_3} \cdot P_{\rm cr}^{w_4}.$$
 (1)

The symbols  $P_{hd}$ ,  $P_{mr}$ ,  $P_c$  and  $P_{cr}$  in Eq. (1) represent the partial preferable probabilities of hardness, machinability, cost and corrosion resistance, respectively;  $w_1$ ,  $w_2$ ,  $w_3$  and  $w_4$  indicate the corresponding importance weight individually.

It can be seen that stainless steel 440A is ranked first in Tab. 5, which is closely followed by stainless steel 410.

Table 4	Utility of the	he candidate	materials	by means	of screening	with the	desired
		requireme	ent for the	material se	election		

Metal	Hardness (hd), U <sub>ai1</sub>	Machinability rating (mr), $U_{ai2}$	Cost (c), <i>U</i> <sub>ai3</sub>	Corrosion resistance (cr), $U_{ai4}$
Weight of importance	8	10	6	6
Normalized importance weight	0.2667	0.3333	0.2	0.2
Stainless steel 410	0.1354	1	1	1
Stainless steel 440A	0.1442	1	1	1
Stainless steel 304	Unavailable			
Nickel-resist cast iron	0.0016	1	1	1
High-chromium cast iron	0.0603	0.0278	1	1
Nickel-hard cast iron	Unavailable			
Nickel 200	Unavailable			
Monel 400	Unavailable			
Inconel 600	Unavailable			

Table 5 Consequence of evaluation for preferable probability and rank

Metal		Partial preferable probability				Total preferable probability	Rank
		$P_{\rm hd}$	$P_{\rm mr}$	$P_{\rm c}$	$P_{\rm cr}$	$P_{\rm t}$	
	Stainless steel 410	0.3965	0.3303	0.25	0.25	0.3102	2
	Stainless steel 440A	0.4223	0.3303	0.25	0.25	0.3155	1
	Nickel-resist cast iron	0.0047	0.3303	0.25	0.25	0.0950	3
	High-chromium cast iron	0.1766	0.0092	0.25	0.25	0.0757	4

#### 4 DISCUSSION

Previously, researchers tried to develop fuzzy multiobjective optimization methods by directly combining the fuzzy concept with traditional multi-objective optimization approaches [6-10]. However, the traditional multi-objective optimization approaches, for example, TOPSIS, AHP, VIKOR, MOORA, etc. [1-12], involve "normalization" and "additive algorithm" of the multiple objectives. This kind of "additive algorithm" is in fact the union of **objective A** and **objective B** for example in some sense in respect of set theory [13-15]; while the intrinsic essence of the optimization of multiple objectives is the "simultaneity" of the optimization of these multiple objectives, while the "simultaneous optimization" of these multiple objectives is the "intersection" of these multiple objectives in some manner in the respect of set theory, so the previous approaches for multi-objective optimization cannot be seen as reasonable approaches [6-15].

In order to reflect the intrinsic characteristic of "simultaneous optimization" of these multiple objectives, a probabilistic approach for multi-objective optimization (PMOO) was proposed, which employs the "intersection" of partial preferable probabilities of utilities of the multiple objectives to indicate "simultaneous optimization" of these multiple objectives rationally in respects of probability theory and set theory [13-15], this processing coincides with the viewpoint of system theory for the whole (integral) optimization of a system [13-16]. Therefore, a rational fuzzy multi-objective optimization can be developed by combining fuzzy theory together with PMOO in this article, which is undoubtedly the novelty of this work. Of course the consequence of the new approach here is incomparable with those of the previous approaches due to their inherent shortcomings in respects of set theory and probability theory [13-15].

## 5 CONCLUSION

From above discussion, it can be seen that the fuzzy multi-objective optimization in respect of probability theory for material selection is well proposed. It is reasonably to determine the utility of the material performance index by using the intersection of the membership function of fuzzy numbers of candidate material performance and the membership function of fuzzy numbers of desired material performance. The utility of each material performance index can be naturally used to formulate the fuzzy multi-objective optimization in respect of probability theory, which is the obvious novelty and superior of this work to other previous approaches. The developed fuzzy multi-objective optimization is with the rationality in the viewpoint of system theory for the integral (overall) optimization of a system as well.

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## Enhancing Fault Identification, Classification and Location Accuracy in Transmission Lines: A Support Vector Machine Approach with Positive Sequence Analysis

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Abstract: This research paper presents a proposed system for fault identification, classification and location in transmission lines using a Support Vector Machine (SVM)-based technique in conjunction with a Positive Sequence Analyzer. The objective is to develop an accurate and reliable method for identifying, classifying and locating different fault types in transmission lines. The proposed system leverages the capabilities of SVMs in handling high-dimensional feature spaces and the fault signature extraction capabilities of the Positive Sequence Analyzer. Experimental evaluations are conducted to assess the performance and effectiveness of the proposed system, comparing it with existing fault identification and classification methods. The results demonstrate the superior performance and robustness of the SVM-based technique utilizing the Positive Sequence Analyzer, providing a valuable contribution to fault management and system reliability in transmission line networks.

Keywords: electrical fault detection; fault classification; fault identification; machine learning; Positive Sequence Analyzer; Support Vector Machine (SVM); transmission lines

## **1 INTRODUCTION**

Power transmission systems must be able to accurately diagnose and classify faults to minimize interruption and restore power supply. Fault classification and location estimation are essential tasks in power transmission systems [1]. Support vector machines (SVMs) have been successfully used for fault detection and classification in transmission lines, although these techniques have limitations, including high computational burden and memory requirements for classification, that limit their real-time implementation [2, 1]. SVM combined with feature extraction techniques, including wavelet transform (WT), synchro-squeezing transform (ST), principal component analysis (PCA), empirical mode decomposition (EMD), and Hilbert-Huang transform (HHT), has been widely used for fault detection and classification on transmission lines [2]. In addition, positive sequence analyzer can be used for fault detection and classification in power systems as it extracts features related to the positive sequence component of line currents, which can be used to identify the fault zone [1, 3]. The combination of SVM-based technique and positive sequence analyzer can improve the accuracy of fault detection and classification in power systems [3]. One proposed algorithm includes the use of PCA and SVMs for fault diagnosis in power system transmission lines, with SVMs used for fault classification and positive sequence analyzer used to determine the location of faults. This approach has been tested on a 300 km, 400 kV series compensated transmission line for all eleven types of faults through digital simulation, with promising results after testing on more than 800 fault cases with varying parameters [3, 4]. These techniques and algorithms demonstrate that SVM-based technique is a popular approach for fault detection and classification in power systems and can accurately detect and classify transmission line faults.

## 1.1 Background and Significance of the Study

Transmission lines are critical components of electrical power systems, and their protection is of utmost importance to ensure the stability and reliability of the power grid. One of the most common causes of transmission line failure is the occurrence of faults, which can cause a cascade of failures leading to power outages and damage to the system. Fault detection and classification are crucial for the prompt and effective protection of the transmission lines. [5]

The traditional methods of fault detection and classification involve the use of time-domain and frequencydomain techniques, which are computationally expensive and often require significant computational resources. In recent years, machine learning-based techniques have gained popularity due to their ability to provide faster and more accurate fault detection and classification. In this study, we propose the use of the Support Vector Machine (SVM) method to develop a positive sequence analyzer for the protection of transmission lines. [6]

## 1.2 Objectives and Research Questions

The main objective of this research is to develop a positive sequence analyzer using SVM for the protection of transmission lines. The specific research questions are as follows:

- Can SVM be used to accurately detect and classify faults in transmission lines?
- What are the performance metrics of the proposed positive sequence analyzer using SVM in comparison to existing methods?
- What are the limitations of the proposed method and how can they be addressed in future work?

## 1.3 Methodology Overview

The proposed methodology involves the following steps is shown in Fig. 1.

The proposed methodology will be validated through simulation results, and the performance of the proposed method will be compared with existing methods.



Figure 1 Methodology steps of proposed system

## 2 PROPOSED SYSTEM

## 2.1 Simulation Model

The proposed system simulation model is shown below Fig. 2.



## 2.2 Detection of External Fault

The prediction of external fault is illustrated in Fig. 3.

## 2.3 Detection Internal Fault

The proposed fault detection scheme can accurately distinguish different fault types. For the internal short-circuit fault, the proposed SVM-based detection scheme can identify the fault inception swiftly for any position along the protected line. During the internal fault, the fault breaker is located internal of long transmission line is shown in Fig. 4

## 2.4 Type and Configuration

The single line diagram of proposed simulation model is illustrated in Fig. 5.











Table 1 Specification of transmission line

Tuble T opeon						
Type of transmission line	Overhead transmission line					
Configuration of Transmission	Three-Phase Symmetrically Spaced					
line	Transmission line					
Voltage Level and Rating	400 kV					

Table 2 Transmission line-1 parameters

Number of phases	3
Line length (km):	200 and 100 km
Frequency used for RLC specification (Hz):	50 Hz
Resistance per unit length (Ohms/km)	[0.01273 0.3864]
[N×N matrix] or [r1 r0 r0m]	
Inductance per unit length (H/km)	[0.9337e-3 4.1264e-3]
[N×N matrix] or [11 10 10m]:	
Capacitance per unit length (F/km)	[12.74e-9 7.751e-9]
$[N \times N matrix]$ or $[c1 c0 c0m]$ :	

Table 3 Transmission line-2pa	rameters
Number of phases	3
Line length (km):	200 and 100 km
Frequency used for RLC specification (Hz):	50 Hz
Resistance per unit length (Ohms/km)	[0.01273 0.3864]
[ N×N matrix ] or [ r1 r0 r0m ]	
Inductance per unit length (H/km)	[0.9337e-3 4.1264e-3]
[ N×N matrix ] or [ 11 10 10m ]:	
Capacitance per unit length (F/km)	[12.74e-9 7.751e-9]
[ N×N matrix ] or [ c1 c0 c0m ]:	_

Table 4 Fault scenarios detail				
Type of Fault	AB, AC, BC, ABG, ACG, BCG, ABC, ABCG, AG,			
- JF	BG, CG,			
Fault Resistance	0.001Ω,10 Ω, 20 Ω, 30 Ω,40 Ω,50 Ω,60 Ω			
X/R RATIO	$\mathbf{V}/\mathbf{P}$ ratio shange to 20			
Variation	A/K ratio change to 20			
Source Power	SOURCE POWER change to 1500 MVA			
Variation	SOORCE TO WER change to 1500 MVA			
Load Variation	LOAD VARIATION to 150 MW			
Line Length	Line 1 Length change to 100 km			
	Line 2 Length change to 50 km			
variation	Changing both Line1 & Line2 length at same time			

## 2.5 Monitoring and Measurement

In this experimental setup we have considered the various conditions of fault resistance and other parameters as described in table-IV. To identify types of fault like internal or external, we have first created the different types of fault models near to bus-I and measured the 3-phase voltage and current at bus -1 and Bus -2, also we have considered positive

sequence analyzer to increase the accuracy and precision of fault detection technique. By utilizing a positive sequence analyzer we have recorded the positive sequence voltage and current at Bus-2 by generating training data we are able to train the SVM for detecting internal faults. By simulating each type of fault condition model in Matlab and recording the following six values to identify both Internal and External fault.

- 1) Voltage at Bus1 (V1)
- 2) Current at Bus1 (I1)
- 3) Voltage at Bus 2 (V2)
- 4) Current at Bus 2 (I2)
- 5) Positive Sequence Voltage
- 6) Positive sequence Current.

Three phase Voltage and current at bus 1 is measured by using three phase VI Measurement model and recorded readings for all condition mentioned in above Tab. 4 this recorded readings are used to train the SVM to detect the fault and classify the type of fault, Similarly Three phase Voltage and current at bus 2 is measured by using three phase VI Measurement model and recorded readings for all condition mentioned to generate training data to train SVM

Positive sequence voltage current is measured at bus-2 using a Sequence analyzer, training the data for detecting the type of faults for the transmission line.

By simulating all conditions mentioned in above Tab. 4 we get training data with total 14 parameters shown in below Tab. 5.

Table 5 Sample Data to train SVM

Voltage at Bus-1	Current at Bus-1	Voltage at Bus-2	Current at Bus-2	+ve Seq. Voltage at bus-2	+ve Seq. Current at bus-2	Type of Fault (I/E*)	Phase-A Fault	Phase-B Fault	Phase-C Fault	Ground Fault	Line-1 Length	Line-2 Length	Fault Resistance
7.06E-01	9.30E-04	8.23E-01	1.71E-03	7.68E-01	1.27E-03	0	1	1	0	0	200	100	0.01
7.06E-01	3.02E-04	9.25E-01	1.32E-03	8.08E-01	1.27E-03	0	1	1	1	0	200	100	10
7.06E-01	5.61E-04	5.83E-01	7.62E-04	7.70E-01	1.24E-03	0	1	1	1	1	200	100	20
7.06E-01	1.22E-03	6.37E-01	1.07E-03	7.80E-01	1.22E-03	0	1	1	0	1	200	100	30
7.06E-01	1.18E-03	7.03E-01	1.38E-03	8.15E-01	1.13E-03	0	1	0	1	0	200	100	40

## 2.6 Control and Protection Systems

In this implementation we have used two three phase breaker near to Transmission line-1 and Bus-2 respectively. The three phase breaker parameters are shown in below Tab. 6.

|--|

Number of phases	3
Initial status:	Closed
Switching of:	Phase-A, Phase-B and Phase-C
Switching times (s):	[5/60]
Breaker resistance Ron (Ohm):	0.001
Snubber resistance Rs (Ohm):	1e5
Snubber capacitance Cs (F):	Inf

In this project we have implemented a two series compensation devices one is connected near to transmission line 1 and second is connected near to transmission line 2.

Series compensation devices are utilized in transmission lines to enhance the efficiency and reliability of power transmission. Here are some of the benefits of using series compensation devices:

- Increased Power Transfer Capability: Series compensation devices, such as series capacitors, can increase the power transfer capability of transmission lines by improving their voltage stability and reducing voltage drops. By injecting reactive power into the line, series compensation reduces the reactive power flow and allows for more active power transfer. [7-9]
- Voltage Profile Improvement: Series compensation helps to mitigate voltage drops and improve the voltage profile along the transmission line. It compensates for the line's inherent inductive reactance, reducing the line's overall impedance and enhancing the voltage regulation at the receiving end. [10]
- Improved System Stability: Series compensation devices contribute to system stability by damping out power oscillations and improving the transient stability of the transmission line. They help in suppressing subsynchronous resonances and enhancing the overall dynamic response of the power system. [11]
- Increased Efficiency: By reducing the reactive power flow, series compensation devices minimize line losses,

resulting in improved overall transmission line efficiency. The reduced reactive power flow also leads to lower transmission line voltages, reducing the need for voltage support from other devices in the system. [12]

- Expanded Transmission Capacity: Series compensation allows for increased transmission capacity without the need for costly infrastructure upgrades or the construction of new transmission lines. It provides an economical solution to enhance the capacity of existing transmission infrastructure and meet growing demand for electricity. [13]
- Enhanced Voltage Control: Series compensation devices provide effective voltage control by regulating the line voltage and reducing voltage fluctuations. This is particularly beneficial in long transmission lines, where voltage drop and instability can occur due to high reactive power requirements. [14]
- Increased Grid Flexibility: Series compensation enhances the flexibility and controllability of the power grid. By manipulating the reactive power flow, system operators can adjust the power flow distribution, optimize the utilization of existing transmission lines, and effectively manage network congestion. [15]
- Reduced Environmental Impact: By improving transmission line efficiency and capacity, series compensation devices can help reduce the need for constructing new transmission infrastructure, thereby minimizing land use and environmental impact associated with new line construction.

## 2.7 Communication and Data Acquisition

To implement fault detection, location, and classification in a long transmission line using an SVM-based technique and positive sequence analyzer, we follow below steps:

- Data Acquisition: Collect data from the long transmission line using sensors or measurement devices placed at various points along the line. The data may include current and voltage measurements, which are crucial for fault detection and analysis.
- Pre-processing: Pre-process the acquired data to remove noise, normalize the values, and prepare it for further analysis. This step ensures that the data is suitable for training and testing the SVM classifier.
- Feature Extraction: Extract relevant features from the pre-processed data that can be used to differentiate between normal and fault conditions. Features could include the magnitudes, angles, and harmonic content of the voltage and current signals.
- Positive Sequence Analysis: Perform positive sequence analysis on the collected data to obtain the positive sequence components of the voltage and current signals. Positive sequence analysis helps in characterizing the behaviour of the transmission line during normal and fault conditions.
- Fault Labelling: Label the collected data based on the presence or absence of faults. This step is crucial for supervised learning algorithms like SVM, as they require labelled data for training.

- Training SVM Classifier: Use the labelled data to train an SVM classifier. SVM is a popular machine learning algorithm suitable for binary classification tasks. It learns to distinguish between normal and fault conditions based on the extracted features.
- Testing and Validation: Evaluate the trained SVM classifier on a separate set of test data to assess its performance. This step helps in determining the accuracy, precision, recall, and other evaluation metrics of the classifier.
- Fault Detection, Location, and Classification: Once the SVM classifier is trained and validated, we can use it to detect, locate, and classify faults in real-time data from the long transmission line. By applying the trained classifier to new data samples, we can identify the type and location of faults accurately.

# 3 RESULT FOR FAULT IDENTIFICATION AND CLASSIFICATION

# 3.1 Effect of Fault Resistance (*Rf*) on Positive Sequence Voltage and Current

Separating internal from external faults and classifying the fault as symmetrical or unsymmetrical fault is one of the key goals of this research project. This is done by considering the positive sequence voltage and current value at bus-2.

Using positive sequence current and voltage values is important for fault classification and detection in transmission lines because they provide valuable information about the system's behavior during a fault condition. Here are a few reasons why positive sequence quantities are preferred:

- Symmetrical Faults: Positive sequence quantities represent the symmetrical component of the fault current and voltage. During a balanced fault, where the fault impedance is purely resistive, the fault current and voltage have a positive sequence component only. By analyzing the positive sequence values, it becomes easier to identify and classify symmetrical faults such as line-to-line and line-to-ground faults.
- Simplified Analysis: Positive sequence analysis simplifies fault calculations by considering only the symmetrical component. This simplification reduces computational complexity and allows for efficient fault detection algorithms.
- Fault Discrimination: Positive sequence quantities help in distinguishing between internal and external faults. Since internal faults predominantly affect the positive sequence values, they exhibit significant changes compared to the healthy system. On the other hand, external faults may cause minor perturbations in positive sequence values but have a more pronounced impact on negative and zero sequence components. Analyzing positive sequence values aids in distinguishing between different fault types and their location within the transmission line.
- Fault Localization: Positive sequence information can be utilized to determine the location of the fault within the transmission line. By comparing the positive sequence voltage and current phasors at different locations along

the line, engineers can estimate the fault position based on the phase angle and magnitude differences.

• Protection System Design: The design of protective relaying systems relies on positive sequence quantities. Protective relays are responsible for detecting faults and isolating faulted sections of the transmission line. By focusing on positive sequence values, relays can make quick and accurate decisions, improving the selectivity and speed of fault detection. [15, 16]

Overall, positive sequence current and voltage values play a crucial role in fault classification and detection in transmission lines due to their simplicity, discriminative power, and ability to aid in fault localization and protection system design. Below Figs. 6 and 7 shows a graph for behavior of positive sequence current and voltage for LG, LL, LLG, LLLG faults for internal condition and Figs. 8 and 9 shows a graph for behavior of positive sequence current and voltage for LG, LL, LLG, LLLG faults for external condition respectively.







Figure 7 Variation of positive sequence voltage for Internal (a) SLG fault, (b) LL fault, (c) LLG fault, (d) LLLG fault and (e) LLL fault



Figure 8 Variation of positive sequence current for external (a) SLG fault, (b) LL fault, (c) LLG fault, (d) LLLG fault and (e) LLL fault



fault, (c) LLG fault, (d) LLLG fault and (e) LLL fault

#### 3.2 Result for Fault Identification and Classification

The classification of fault in both Internal and external condition for LG, LL, LLG, LLLG and LLL fault is shown in Tab. 6 respectively. It shows that it will identify fault with good accuracy and precision compared with the Fuzzy system as shown in Tab. 7 below for the same Transmission line configuration.

Eault	Fault location	Fault	Outp	ut of the	SVM c	lassifier
Taun	(Distance from	resistance	Phase	Phase	Phase	Ground
type	the relay in km)	(in Ohms)	Α	В	С	G
No			0	0	0	0
fault	-	-	0	0	0	0
AG	100	10	1	0	0	1
AB	80	20	1	1	0	0
AC	50	30	1	0	1	0
BC	70	40	0	1	1	0
BG	90	50	0	1	0	1
CG	150	60	0	0	1	1
ABG	200	0.001	1	1	0	1
ACG	270	20	1	0	1	1
BCG	300	60	0	1	1	1
ABC	180	50	1	1	1	0
ABCG	210	40	1	1	1	1

#### Table 7 Fault classification result

#### 3.3 Result for Fault Location

of fault from line-1 and line2 to resolve the fault within a

The second aim of this research is to identify the location

short time for maintaining the continuity of supply. Fig. 10 show the result for fault location which is near about 99% accurate.



#### 3.4 Effect of Line Length Variation

The line length has been altered to 50% of its nominal value, which is 200 km, to test the validity of the proposed design under various line length conditions. All type of fault has been simulated in line connected between Bus-1 and 3 with different ranges of fault resistance i.e. Rf = 0.01, 10, 20,30, 40, 50, 60  $\Omega$ . Fig. 11 shows accuracy of the proposed system for detecting, classifying and locating the SLG, LL, LLG, LLLG and LLL faults. The average accuracy of proposed system is shown in below Fig. 13 it proves that proposed system is having near about 84% accuracy during line length variation.



Figure 11 Average Accuracy of SVM system during Line Length Variation

#### 3.5 Effect of Source Impedance(X/R Ratio) Variation

In some conditions the source impedance get varied, in this proposed system the X/R ratio get increased by double of given value i.e. to 20 ohm. Below Fig. 12 result shows

accuracy of proposed system during Source impedance variation from that we can say that proposed system has 96% accuracy in internal fault and 87% in external fault.



Figure 12 Average Accuracy of SVM system during X/R Ratio Variation

## 3.5 Effect of Source Power Variation

Below Fig. 13 shows the accuracy of the proposed system when source power varied from 1000 MW to 1500 MW. Result shows that the proposed system has overall 97% internal and 81% external fault accuracy.



Figure 13 Average accuracy of SVM system during source power variation



Figure 14 Average accuracy of SVM system during load variation

## 3.6 Effect of Load Variation

Practically when the load on the system gets varied, the proposed system should have greater accuracy for fault identification and classification. Accuracy of proposed system during load variation is shown below Fig. 14; it shows that proposed system has greater accuracy during load variation.

#### Δ COMPARISONS OF RESULTS WITH EXISTING METHODS

Support Vector Machines (SVM) is known for their excellent classification accuracy, especially when dealing with high-dimensional datasets and complex decision boundaries. SVM can handle both linear and non-linear classification problems effectively.

ANN systems are capable of handling imprecise and uncertain data.

In some cases, the accuracy of ANN systems may be slightly lower compared to SVM.

Below Tab. 8 shows the overall accuracy of both SVM and ANN system for proposed system. It is clear that SVM has greater accuracy than ANN system.

	Internal fault	classification	External fault classification		
Name of	accu	iracy	accu	iracy	
fault	ANN	SVM	ANN	SVM	
	technique	technique	technique	technique	
AG	100%	100%	100%	100%	
BG	71%	100%	86%	100%	
CG	100%	100%	86%	100%	
AB	100%	100%	0%	100%	
AC	57%	100%	57%	71%	
BC	43%	86%	43%	71%	
ABG	71%	100%	71%	100%	
ACG	14%	100%	29%	100%	
BCG	57%	100%	100%	71%	
ABC	71%	100%	71%	100%	
ABCG	0%	86%	100%	43%	
Average	62%	97%	68%	87%	

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## 5 CONCLUSIONS

In this study, a novel technique for fault classification and defective phase identification is introduced, utilizing a single-ended mixed Support Vector Machine (SVM). The technique focuses on analyzing the approximation coefficients of current signals, which are exclusively measured at one end of the line. The proposed SVM-based approach offers several advantages, including the ability to identify faults in both primary and backup protection systems, covering up to 92% of the entire line length. Furthermore, the suggested SVM-based relay demonstrates remarkable performance with minimal training patterns.

The proposed method exhibits a high level of accuracy in locating various types of shunt faults, achieving a success rate of 92% across different fault locations. Extensive testing confirms the reliability and selectivity of the approach, providing satisfactory performance for three-phase transmission lines. Although the training process is performed offline, it should be noted that the training time for constructing the SVM network increases with larger training data sizes resulting from system configuration changes.

The effectiveness of the proposed scheme is demonstrated through successful detection and classification of different types of faults, including symmetrical and unsymmetrical faults, as well as unique cases involving High Impedance Faults (HIF), evolving faults, current transformer (CT) saturation, capacitive voltage transformer (CVT) transients, close-in faults, swing conditions, and source strength variations. A comparative analysis conducted against recently proposed techniques highlights the scheme's potential and robustness.

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# Regression Approach in the Evaluation of White's Effect Magnitude in Comparison to Lightness

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Abstract: In the achromatic White's grid, the grey patches between the grey lines are perceived as darker while the same elements inserted between white lines are perceived lighter than their true measured values. A number of authors attempted to calculate the magnitude and direction of this effect using mathematical models based on multiple spatial filters. This paper uses different mathematical model, based on regression analysis, which has shown itself as an excellent tool for prediction of direction and magnitude of White's effect. The psychophysical visual experiment was conducted on 38 subjects of both genders. The differences in lightness perception  $\Delta L_{00}$  were calculated in CIE  $\Delta E_2000$  system. This paper determined the functional dependence of White's effect magnitude  $\Delta L_{00}$  to the lightness L of rectangular elements in White's achromatic grid. The results gave the square polynomial of very high quality ( $R^2 = 0.974$ ). Regression polynomials were also found. The gave numerical values  $\Delta L_{00}$  of difference in perception of left and right elements in comparison to their physical values (left  $R^2 = 0.943$ , right  $R^2 = 0.938$ ) in dependence to variation of lightness parameter L. Results of the research clearly show the mathematical pattern of White's effect based on the lightness of rectangular elements.

Keywords: assimilation; induction; lightness; regression analysis; White's effect

## **1** INTRODUCTION

White's effect illustrates a variation in the lightness of grey elements when juxtaposed with black and white lines [1-4]. This can be characterized as the grey elements assimilating with the color of the solid lines. Grey-black lines are perceived darker in comparison to grey-white lines which are perceived as lighter (Fig. 1). Numerous scientific research attempted to interpret the appearance of the effect and its magnitude.



Research conducted by Anderson [5, 6] showed that White's effect has the opposite effect from simultaneous contrast. The author defined new illusions containing layer dims, which are similar to White's effect in order to evaluate elements of organizational forces influencing the calculation of surface lightness.

Blakeslee and McCourt proved that mathematical tools such as a multiscale array of two-dimensional difference-of-Gaussian (DOG) filters represent a very successful tool for the prediction of a lot of psychophysical visual effects such as grating induction, induction, assimilation and Herman's grating [7]. However, Todorović [8, 9] determined that the DOG models can't be connected to a significant group of effects that include White's effect.

Blakeslee and McCourt [10-13] attempted to interpret effects like White's and others, for example simultaneous brightness contrast and grating induction using multiscale spatial filtering). They also determined that the effect also appears in the early stage of cortical filtering operations in the human visual system.

Robinson, Hammon and de Sa, developed and modified ODOG models. Their re-search produced locally normalized ODOG or LODOG model [14] LODOG model enables the interpretation of a range of effects like White's zig-zag effect [15] and radial White stimulus [16]. Their results increased the efficiency of lightness prediction models. Robin-son, Hammon & de Sa developed frequency-specific locally normalized models or FLODOG models [14]. Blakeslee, Cope and McCourt generated ODOG models by using software Mathematica based on Wolfram's research [17].

White's and other psychophysical visual effects are often researched with T-junctions. T-junctions are formed at the intersection of grey rectangular element, black and white parallel lines. Margaret S. Livingstone and Piers D. Howe researched White's effect samples without T-junctions and radial samples. The magnitude of the effect is similar in samples with or without T-junctions [18]. Authors used the results to explain White's effect on Gestalt theory. They also confirm the hypothesis by Gilchrist [19] that states that the illusion can be defined with Gestalt grouping laws and the anchoring theory of lightness perception.

Lin and Chen [20] found similarities in magnitudes of White's chromatic effect on bull's eye radial and grated samples. They determined that there is a common mechanism influencing the appearance of chromatic assimilation and White's effect. The research made by Altschuler and others [21] showed that the chromatic White's effect is not dependent on the geometric structure of the stimuli. Their results show the possibility of defining chromatic White's effect using the influence of background colour or lightness on the perception of test disc colour. They also determined the possibility of simultaneous colour contrast, afterimages, metameric intransitivity and chromatic White's effect being caused by identical neurological mechanisms. According to Clifford and Spehar [22], the appearance of chromatic White's effect can be explained by the contrast of rectangular elements in the grate with the colour of the same grate as the assimilation effect on neighbouring grates. Their research was made in DKL colour space, and the qualitative value of the magnitude was calculated on results gained with classical achromatic White's samples.

Budimir, Mrvac and Matijević used nonlinear regression models to research regularities in defining White's effect in dependence on the percentage of grate coverage [23, 24]. Results represent a mathematical description of laws that define White's effect regarding grating coverage percent.

In order to determine regularities shown in White's effect, this paper researches different curves that show the dependence of magnitude to the lightness of the effect [25, 26]. Application of different numerical methods used in psychophysical research based on different interpolations was discussed.

Monte-Carlo simulation and parameter assessments with the method of maximal credentialing [27-29]. Methods of nonlinear regression analysis were chosen and gave excellent results [30, 31]. Results presented in this paper give analytical expressions for assessment of White effect magnitude for different lightness values of rectangular elements. The applied method differs from previously described and offers new possibilities for the study of many visual effects.

## 2 EXPERIMENTAL PART

## 2.1 Research Description

The experiment consists of two components: the instrumental (or measured) and the visual. The selected instrumental component involves the spectrophotometric measurement and the representation of CIE  $L^*a^*b^*$  values. The visual component was employed to identify the pertinent fields utilizing the method of simultaneous binocular harmonization [32].

## 2.2 Research Description

Test sheet was designed in compliance to research methodology. Test sheet consisted of 9 achromatic variations (cards) of White's effect of identical 50% coverage, different lightness ( $L^*$ ) of grey rectangular elements (Tab. 1) and reference sheet (Fig. 3). During print values of chromatic components,  $a^*$ ,  $b^*$  varied, but in minute values which did not influence the research.

Table 1 Measured physic	al Lab values of the test sample
-------------------------	----------------------------------

Sample number	$L^*$	a*	$b^*$
1.	93,21	3,40	-7,93
2.	90,36	3,27	-8,32
3.	86,49	3,00	-6,68
4.	81,30	3,03	-7,41
5.	75,03	2,63	-6,88
6.	66,41	1,92	-6,30
7.	55,29	1,52	-6,23
8.	44,95	1,22	-5,90
9.	34,38	0,79	-5,65

Dimensions of test sheets in  $183 \times 110$  mm (width×height) and the value of parallel white and black lines is identical x = y = 6 mm (Fig. 2).



Test sheet size was created in compliance with standard observer conditions for graphic industry and professional photography (ISO 3664:2009). Conditions include 10° viewing angle and viewer distance of 60 cm according to the formula [33].

$$\tan\frac{VA}{2} = \frac{H}{2D} \tag{1}$$

VA stands for the viewing angle, H for test sample height and D for distance of the sample form the observer.



Test sheets and reference sheets of achromatic grey were constructed in Adobe Photoshop 2020, utilizing Lab colour mode (as seen in Fig. 3). The sheet was devised to represent a variety of perceptible features in the Lab colour mode, spanning the entire perceptual range with incremental changes of 2%. Individual fields were accurately matched with the appropriate CIE  $L^*a^*b^*$  values from spectrophotometric measurement.

The samples were printed using a calibrated Canon Pixma pro-100s printer. The rendering process occurred in Adobe Photoshop 2020, wherein the Lab colour mode was converted specifically for the Canon Pixma pro-100s. The conversion intent chosen was perceptive, and the conversion engine used was Adobe (ACE). Standardized Canon photo paper, with a matte finish and a weight of 170 g/m<sup>2</sup>, served as the printing material. The paper underwent conditioning in a room for two days, under standardized environmental conditions with a temperature of 23 °C and a relative humidity of 55%. Finally, the samples were produced in a batch of 10 pieces.

## 2.3 Instrumental Analysis

In the visual segment of the experiment, 38 participants, encompassing both genders and averaging 20 years of age, were involved. Every participant had previously cleared the Ishihara test, employed to identify potential color vision impairments. Visual assessments were conducted in adherence to ISO 3664:2009 – utilizing a 10° viewing angle, maintaining a 60 cm distance between the observers and the test samples, set within natural grey surroundings, and under lighting conditions set to CIE D75 (7500K).

Visual assessment was carried out following the simultaneous binocular harmonization method. Both the test

and reference sheets were positioned within the visual field concurrently. The participants were tasked with identifying the field on the test card that most closely matched the sample on the reference sheet (refer to Fig. 4).

Perceived lightness of left and right rectangular elements on the individual sheet was defined as the arithmetic centre of perceived lightness values of all subjects. Those values gave the lightness values of standard CIE observer [34].



**Figure 4** Visual matching principle with the reference sheet

Table 2 Descriptive statistic of perceived lightness L, a	and b values of observed elements (	left)
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	Descriptive statistics (left rectangular elements)										
Nr. Ligi	Lightness	Lightness	Variable	Expectation	Int. conf.	Int. conf.	Median Min	Min	Max V	Varianaa	Std. dev.
	Lightness	numerical	variable		-95%	95%	wieulali	IVIIII.	Iviax.	variance	
			L	93,897	93,633	94,16	94,15	91,91	94,78	0,643	0,802
1. 10	10	93.21	а	3,581	3,547	3,614	3,6	3	3,64	0,01	0,102
			b	-7,889	-8,52	-7,259	-8,13	-8,53	3,6	3,682	1,919
			L	89,854	89,195	90,513	90,1	84,66	93,5	4,02	2,005
2.	20	90.36	а	3,456	3,425	3,486	3,44	3,26	3,64	0,009	0,092
			b	-8,501	-8,554	-8,447	-8,495	-8,8	-8,18	0,027	0,164
			L	84,286	83,131	85,441	84,535	76,17	91,38	12,338	3,513
3.	30	86,49	а	3,293	3,257	3,328	3,3	2,85	3,45	0,012	0,108
			b	-8,046	-8,141	-7,95	-7,9	-8,57	-7,45	0,084	0,289
		81,3	L	74,666	73,204	76,127	74,67	67,72	81,89	19,769	4,446
4.	40		а	2,8	2,685	2,915	2,85	2,1	3,32	0,123	0,35
			b	-7,744	-7,832	-7,657	-7,83	-8,14	-7,41	0,071	0,267
	50	75,03	L	63,947	61,641	66,252	64,15	39,87	74,67	49,182	7,013
5.			а	1,901	1,738	2,064	1,9	0,4	2,93	0,246	0,496
			b	-7,307	-7,465	-7,148	-7,315	-8,14	-5,92	0,232	0,482
			L	55,434	53,35	57,519	52,99	41,98	67,72	40,21	6,341
6.	60	66,41	а	1,37	1,259	1,48	1,17	0,99	2,1	0,113	0,336
			b	-6,745	-6,864	-6,626	-6,7	-7,53	-6,18	0,131	0,362
			L	46,139	44,208	48,071	47,43	34,88	60,17	34,524	5,876
7.	70	55,29	а	0,916	0,815	1,018	0,99	0,4	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	0,309	
			b	-6,35	-6,434	-6,265	-6,275	-7,1		0,257	
		44,95	L	37,642	36,152	39,131	37,59	30,65	49,35	20,536	4,532
8.	80		а	0,692	0,592	0,792	0,46	0,4	1,13	0,093	0,304
			b	-5,91	-6,097	-5,724	-6,11	-6,57	-4,66	0,322	0,568
			L	30,324	28,396	32,253	30,65	20,65	41,98	34,411	5,866
9.	90	34,38	а	1,253	1,03	1,477	1,13	0,4	2,5	0,461	0,679
			b	-4,072	-4,695	-3,45	-4,66	-6,29	-0,04	3,588	1,894

## 3 RESULTS

Statistical analysis of experimental data was made with program Statistica 14. The statistical analysis contains descriptive statistic of all experiment results, correlative and regressive analysis. All data was gained from the psychophysical visual experiment of 38 subjects.

## 3.1 Descriptive Sample Statistic

Descriptive statistic contains medium values or arithmetic middle, reliability intervals, median, minimum, maximum, variance and a standard deviance of perceived L, a and b of left and right analysed samples from the data gained from the experiment.

Considering the relatively low variance values and standard deviation, descriptive statistic shows the high quality of analysed subject (Tab. 2 and 3). All reliability intervals have a diameter less than 2, which means that statistical deviations are not visually perceivable.

Table 3 Descriptive statistic of perceived lightness L, a and b values of observed samples (right	ht)
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	Descriptive statistics (right rectangular elements)										
Nr.	Lightness	Lightness numerical	Variable	Expectation	Int. conf. _95%	Int. conf. 95%	Median	Min.	Max.	Variance	Std. dev.
			L	93,587	93.309	93,864	93.92	90.65	94.78	0.715	0.845
1. 10	10	93.21	a	3,583	3.572	3,593	3.58	3.45	3.64	0.001	0.032
			<i>b</i>	-8.203	-8.259	-8,147	-8.13	-8.8	-8.05	0.029	0.17
			L	92,096	91,66	92,531	92,52	89,35	94,38	1,755	1,325
2.	20	90.36	а	3,539	3,519	3,56	3,56	3,43	3,64	0,004	0,062
			b	-8,437	-8,495	-8,378	-8,46	-8,8	-8,05	0,032	0,179
			L	88,851	87,964	89,738	89,725	80,83	91,91	7,282	2,699
3.	30	86,49	а	3,408	3,378	3,439	3,43	3,21	3,57	0,009	0,175 2,699 0,093 0,245 4,133 0,141 2,533 4,037 0,239
			b	-8,408	-8,489	-8,327	-8,445	-8,8	-7,79	0,06	0,245
		81,3	L	84,592	83,233	85,95	86,04	74,67	90,65	17,08	4,133
4.	40		а	3,25711	3,211	3,304	3,26	2,93	3,57	0,02	0,141
			b	-7,648	-8,48	-6,815	-8,18	-8,8	7,41	6,414	2,533
			L	79,173	77,846	80,5	79,74	69,35	88,42	16,296	4,037
5.	50	75,03	а	3,117	3,039	3,196	3,22	2,5	3,41	0,057	4,133 0,141 2,533 4,037 0,239 0,264 3,566 0,388 0,304
			b	-7,773	-7,86	-7,686	-7,835	-8,51	-7,41	0,07	
			L	72,905	71,733	74,077	72,56	64,14	80,83	,42         16,296         4,037           41         0,057         0,239           ,41         0,07         0,264           ,83         12,719         3,566           31         0,151         0,388	3,566
6.	60	66,41	а	2,609	2,482	2,737	2,51	1,58	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	0,388	
			b	-7,662	-7,762	-7,562	-7,5	-8,14	-7,14	0,093	$\begin{array}{r} 0,032\\ 0,17\\ 1,325\\ 0,062\\ 0,179\\ 2,699\\ 0,093\\ 0,245\\ 4,133\\ 0,141\\ 2,533\\ 4,037\\ 0,239\\ 0,264\\ 3,566\\ 0,388\\ 0,304\\ 7,336\\ 0,536\\ 2,357\\ 5,82\\ 0,443\\ 0,498\\ 7,647\\ 0,405\\ 0,428\\ \end{array}$
			L	64,717	62,306	67,129	66,05	41,98	74,67	53,823	4,037 0,239 0,264 3,566 0,388 0,304 7,336
7.	70	55,29	а	1,957	1,781	2,134	1,91	0,77	2,93	0,288	0,536
			b	-6,983	-7,758	-6,208	-7,37	-8,14	6,83	5,556	2,357
			L	56,827	54,913	58,74	55,94	45,64	69,35	33,876	5,82
8.	80	44,95	а	1,479	1,333	1,624	1,26	0,86	2,6	0,196	0,443
			b	-6,815	-6,979	-6,651	-6,7	-8,14	-6,26	0,248	0,498
			L	46,096	43,582	48,609	46,535	30,65	72,56	58,481	7,647
9.	90	34,38	а	0,892	0,759	1,025	0,86	0,4	2,5	0,164	0,405
			b	-6,283	-6,424	-6,143	-6,25	-7,83	-4,66	0,183	0,428

## 3.1.1 Descriptive Sample Statistic

The perceptual discrepancy induced by specific presentations of visual effects is represented as the lightness deviation  $\Delta L_{00}$  between the reference sheet and the test sample [35, 36].

Difference values in perception are shown in Tab. 4.

Tab	le 4 Difference	values in l	lightness	perception	of analysed.
	<b>x</b> • • • ·				

Lightness	Lightness numerical	$\Delta L_{00}$ (left)	$\Delta L_{00}$ (right)	$\Delta L_{00}$ (between)
10	93,21	0,42	0,23	0,19
20	90,36	-0,32	1,02	-1,4
30	86,49	-1,44	1,51	-2,95
40	81,3	-4,69	2,21	-6,89
50	75,03	-8,62	2,95	-11,56
60	66,41	-11,51	5,05	-14,52
70	55,29	-11,01	8,29	-17,48
80	44,95	-7,8	11,85	-18,78
00	3/ 38	47	10.34	13.54

## 4 DISCUSSIONS

## 4.1 Correlative Sample Analysis

Pearsons correlation coefficient  $\rho$  was used to perform correlative analysis of numeric lightness variable values and  $\Delta L_{00}$  (left),  $\Delta L_{00}$  (right) and  $\Delta L_{00}$  (between). Marked correlations are significant, with significance levels p < 0.05(Tab. 5).

#### Table 5 Results of correlative analysis

Variables	Numerical lightness values, L	$\Delta L_{00}$ (left)	$\Delta L_{00}$ (right)	$\Delta L_{00}$ (between)	
Numerical lightness Values, L	1			-	
A. L. (1-£)	<i>p</i> =	1			
$\Delta L_{00}$ (left)	p = 0,102	p =	-	-	
$\Delta L_{00}$ (right)	-0,9724	-0,5737	1	-	
	p = 0,000	p = 0,106	<i>p</i> =		
$\Delta L_{00}$ (between)	0,8638	0,8878	-0,8816	1	
	p = ,003	p = 0,001	P = 0,002	<i>p</i> =	

Statistically significant correlation value of (p < 0,05) was determined among the variables L,  $\Delta L_{00}$  (right) and  $\Delta L_{00}$ (between) and among variables  $\Delta L_{00}$  (left) and  $\Delta L_{00}$ (between) and among variables  $\Delta L_{00}$  (right) and  $\Delta L_{00}$ (between) (Tab. 5). Other correlations are not statistically significant. High positive correlation values of  $\rho = 0,8638$ was determined between L and  $\Delta L_{00}$  (between). High negative correlation values of  $\rho = -0,8816$  were determined between  $\Delta L_{00}$  (between) and  $\Delta L_{00}$  (right).  $\Delta L_{00}$  (between) and  $\Delta L_{00}$  (left) are also highly correlated with  $\rho = 0,8878$ . This shows that the Munker-White effect whose heading in visible in arable value  $\rho = 0,8878$  acts according to physical values
of grate L and perceived difference  $\Delta L_{00}$  (left) and their opposite values  $\Delta L_{00}$  (right).

#### 4.2 Regression Analysis of Elements

For conducting polynomial regression analysis, CIE  $\Delta E_{00}$  differences in the lightness of the samples under consideration were calculated, as depicted in Tab. 4. Numerical values of magnitude shift lightness appearance in White's grate are presented as difference  $\Delta L_{00}$ .  $\Delta L_{00}$  is defined as dependent variable for regressive analysis, and physical lightness values *L* as independent variable. Analysis of different regression models showed that the polynomial models as most suited for available data. Left analysed elements and the difference between left and right models were described with squared regression models. For the analysis of right elements linear regression model was used.

Results of the analysis are shown in Tabs. 6, 7 and 8. The  $R^2$  value is nearing its maximum value of 1 for all three models. Their values are 0,978, 0,972 and 0,990, which

means that they are representative. Namely, models can interpret 97,8%, 97,2% and 99,0% of squared errors. Regression levels are read from *p*-values which for those models are p = 0.00008, 0.00001 and 0.00001. All three pvalues are below 0.01 and that marks them as high quality. Adjusted  $R^2$  determination coefficients have values of 0,943, 0.938 and 0.974 which is another confirmation of model quality. This parameter is contingent on the degrees of freedom. The standard error (SE) quantifies the average deviation of the data points from the regression curve. Standard error value for all three models (1,702, 1,075, 1,144) also shows their quality. Standard error of specific coefficients (Tabs. 6, 7 and 8) are relatively low and show high quality. Test shown very low p-values empirical or noticed significance) of variable coefficient P and  $P^2$  (Tabs. 6, 7 and 8) Stated *p*-values are below significance level (0,001) and this model also shows the quality of regression models.

**Table 6** Results of regression analysis of variable  $\Delta L_{00}$  or analysed elements in dependence to lightness (left)

N = 9	Regression a	analysis of left rectangular e Adjusted $R^2 = 0$	square model; dependence va 078, $p < 0.00008$ , Std. error a	ariable L (lightness); R = assessment: 1,702	$= 0,978 R^2 = 0,957,$	
	b*	Std. error of $b^*$	b	Std. error of b	<i>t</i> (6)	<i>p</i> -value
Free coefficient			26,603	4,56	5,834	0,00112
L	-5,924	0,7016	-1,271	0,15	-8,444	0,00015
$L^2$	6,55	0,7016	0,011	0,001	9,337	8,60E-05

Table 7 Results of the re-	gression analysis of $\Delta L_{00}$	or analysed samples	in dependence to I	ightness (righ	ť
					- 1

	Regression analysis of right rectangular elements lightness; linear model; dependence variable L (lightness); $R = 0.972$ , $R^2 = 0.946$ ,							
N = 9	$N = 9$ Adjusted $R^2 = 0.938$ , $F(1,7) = 121,66$ , $p < 0.00001$ , Std. error assessment.: 1,075							
	$b^*$	Std. error of $b^*$	b	Std. error of b	<i>t</i> (7)	<i>p</i> -value		
Free coefficient			18,798	1,316	14,281	0,000002		
L	-0,972	0,088	-0,2	0,018	-11,03	0,000011		

Table 8 Results of reg	gression analy	sis of variable $\Delta L_{00}$ or analy	ysed elements in de	pendence to lig	htness (	between)	)
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	Regression ana	lysis of elements light	model; dependence variable L (lightness); $R = 0,990, R^2 = 0,981,$				
N = 9	Adjusted $R^2 = 0,974, F(2,6)=151,61, p < 0,00001$ , Std. error assessment: 1,144						
	$b^*$	Std. error of $b^*$	b	Std. error of b	<i>t</i> (6)	<i>p</i> -value	
Free coefficient			9,538	4,864	1,961	0,0976	
L	-3,128	0,472	-1,063	0,161	-6,623	0,000571	
$L^2$	4,021	0,472	0,01	0,001	8,514	0,000144	

As a result, of regression analysis regression polynomials give functional dependence of the intensity of the effect shift the incidence of the lightness of the lightness of analysed elements.

Squared regression polynomial (Fig. 5) was used to describe perception deviation  $\Delta L_{00}$  for left elements.

$$\Delta L_{00}(L) = 26,610 - 1,276L + 0,011L^2$$
<sup>(2)</sup>

Perception deviations of right elements from their physical values are calculated with linear regression polynomial (Fig. 6):

$$\Delta L_{00}(L) = 18,798 - 0,200P \tag{3}$$

Mutual deviations of perceived lightness between left and right rectangular elements (White's effect) are calculated with squared regression expression (Fig. 7):

$$\Delta L_{00}(L) = 9,538 - 1,063L + 0,010L^2 \tag{4}$$

Graphical display of regression curves and their 95% reliability intervals is shown in Figs. 5, 6 and 7.

Analysis of extreme regression polynomial for left analysed elements was calculated as:

$$\min\left\{26,610-1,276L+0,011L^2\right\} = 11,2258 \text{ in } L = 59,2983 (5)$$

The deviation is largest at lightness value L = 59.3. At that value the degree of deviation is 11.23. That value shows high deviation at those levels of lightness.

After At interval L < 59,3 deviation intensity grows on absolute value while it shrinks at interval L > 59,3.

Zero points of this polynomial are  $L_1 = 27,0$  and  $L_2 = 91,6$ . That means that there is no deviation in perception at those values.



Figure 5 Polynomial regression of left elements (lightness influence)



**Figure 6** Polynomial regression of right elements (lightness influence)



The linear function describing lightness difference of right perceived elements falls on entire domain. The

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coefficient of this heading is -0.2. This means that an enhancement of lightness of rectangular elements for 1 unit can be expected to cause a perception shift of -0.2. Zero point of this heading is 93,81. Right rectangular elements are perceived in accordance with their physical values for that value.

Analysis of extreme polynomial difference in perception of left and right rectangular elements give the result:

$$\min\left\{9,538 - 1,063L + 0,010L^2\right\} = -17,4702 \text{ in } L = 50,8136 \text{ (6)}$$

According to that, White's effect has the highest intensity at lightness L = 50,814. In this case the intensity of White's effect, calculated through difference in perception of left and right elements is 17,47.

Intensity deviation enlarges at absolute values at interval L < 50,814, while it shrinks at interval L > 50,814.

Polynomial zero-points are:

$$L_1 = 9,95 \text{ and } L_2 = 91,65$$
 (7)

This White's effect is not present at lightness of rectangular elements of  $L_2 = 91,65$ .

#### 5 CONCLUSIONS

The paper presents regression models of very high quality obtained from experiment data. Results show in what way the lightness of rectangular elements influence the magnitude of appearing psychophysical visual effect on lightness shift in White's grating. Obtained polynomials connect the shift of lightness appearance  $\Delta L_{00}$  and physical lightness L of analysed elements.  $\Delta L_{00}$  is defined as variable dependable of independent variable L. It is ascertainable that polynomials facilitate precise forecasts of the direction and magnitude of White's effect. The findings illustrate the principle governing the visual perception of White's effect relative to lightness. The mentioned principle reveals a notable intensity of White's effect that amplifies as the lightness of the rectangular elements nears the value L =50.814. At this level of lightness, it is anticipated that a standard observer would perceive a lightness shift valued at  $\Delta L = -17.4702$ , a value considered to be relatively high. It was also determined that the effect itself has a much lower, but still rather high intensity in very low and very high values of lightness of rectangular elements. This is an exact, mathematical description of the White's effect, what offers many possibilities of estimating rather precisely the results of this effect for all lightness variations of the achromatic grev color of rectangular elements. It is to be expected that the effect would have similar results also in the case of coloured patterns.

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# Corrosion Enhancement of PM Processed Magnesium by Turning Native Oxide on Mg Powders into Carbonates

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Abstract: In addition to its use as a lightweight material, pure magnesium is a promising candidate for prospective bioimplants considering its excellent biocompatible properties. Regardless of what Mg application is used, the ultimate goal is to improve magnesium's mechanical properties and degradation behaviour. Because of the high affinity for oxygen native oxide layer of gas-atomized powders is naturally formed in contact with the atmosphere. S/TEM investigation of the native oxide of the Mg powder particles revealed a nonhomogeneous nano-crystalline MgO layer. MgO is relatively soluble in water and does not provide sufficient corrosion protection. Among various surface treatment methods, conversion of the non-protective magnesium oxide to carbonate products is possible depending on the environmental conditions. This work used a simple experimental method using CO<sub>2</sub> and water vapour to achieve surface carbonation of Mg powders. Two carbonates samples and pure magnesium were prepared by direct extrusion. The samples after carbonation goal mechanical properties and the layer of carbonates had a significant impact on corrosion resistance. 1 day carbonation resulted in transformation of native oxide to crystalline nesquehonite structure.

Keywords: corrosion; magnesium powder; native oxide; surface modifications

#### **1 INTRODUCTION**

In recent years, an intensive effort was made to solve the main problems which limited the application of magnesium. Magnesium has become recognized as a structural material, which delivers, on the one hand, the essential advantages of reduced mass while retaining the suitable mechanical, thermal, and biodegradable properties that make it a desired candidate for advanced engineering in the aerospace industry, electronic devices or implant applications [1-3]. Still, on the other hand, pure magnesium's high susceptibility to corrosion holds it from fulfilling all possibilities.

Magnesium is a reactive metal, and under humid conditions, its corrosion resistance is strongly influenced by its high affinity for oxygen [4, 5]. Consequently, oxygen uptake from the surrounding atmosphere leads to the formation of a thermodynamically stable native MgO-layer with a thickness of 3 - 5 nm on the surface of the magnesium particles. In humid air, hydration of naturally grown magnesium oxide (MgO), uniformly adhering to the Mg surface, results in hydroxide (MgOH)<sub>2</sub> formation [6, 7]. Several studies characterized the oxidation of magnesium and the surface structures, including usually a dense upper layer of Mg(OH)<sub>2</sub> on top of a porous layer of MgO on the Mg core [8-10].

Understanding and improving the corrosion behaviour of magnesium is vital for increasing its potential application. While the possibilities of enhancing the corrosion resistance by alloying are limited, a number of modification and coating methods have been developed [11, 12]. Surface modifications, among which the most frequently used, are chemical conversion coating [13], organic coating [14], and micro-arc oxidation coating [15] are an efficient way to isolate the metal core of magnesium from external environments.

Carbonate coatings fabricated by reacting with excited  ${\rm CO}_2$  or combining processing and heat-treatment of Mg-

based materials are promising methods for enhanced corrosion stability [16, 17]. MgCO<sub>3</sub> coating can be an effective barrier because it is sparingly soluble in water. However, the high thermodynamic equilibrium and the kinetics of the reaction at atmospheric pressure are very slow and require an extra excitation, such as heating to at least 400 °C [18, 19] or high energy electron beam [16]. Many different ways of preparing MgCO<sub>3</sub> are described in the literature. Recently most studies have focused on the reaction between CO<sub>2</sub> and metal oxides at low-temperature levels. Moreover, if water and CO<sub>2</sub> co-exist in the environment, MgCO<sub>3</sub> can be produced at atmospheric pressure [20].

Great effort has also been put into enhancing the strength of magnesium-based materials. Among various methods, powder metallurgy (PM) processing, in combination with severe plastic deformation (SPD) techniques, can be used to improve the microstructural and mechanical properties of magnesium. Compared with the casting process, the powder metallurgy (PM) route can positively affect the hardness, tensile and yield strength, and the development of a crystallographic texture [12, 21].

#### 2 MATERIALS AND METHODS

The experiments were performed on pure Mg (99.98 %) atomized powder (IMR Metalle, Austria) with a size fraction value of 20 - 40  $\mu$ m. Particle size distribution (PSD) was determined by a laser diffraction system (Fritsch Analysette 22 MicroTec device) with d<sub>50</sub> powder particle size values of 30  $\mu$ m. The microstructure of the powders was studied by scanning electron microscopy (SEM, JEOL JSM-7600F) equipped with EDS, WDS, and EBSD detectors. The analysis was focused on the surface morphology and the microstructure of the samples after forward extrusion processing. The detailed microstructure of the native MgO and the extruded samples was examined using transmission electron microscopy (TEM, JEOL 1200FX) operated at 80

kV and a probe-corrected FEI/Thermofisher Scientific Titan Themis 300 transmission electron microscope in scanning mode (STEM) at a 200 kV accelerating voltage. Direct observation of the native MgO surface layer on initial Mg powders was done using support Cu grids with lacey carbon film. For a more detailed characterization of the interface, standard preparation of bulk material was done using grinding, polishing, and final ion polishing (GatanPIPS-Cryo holder).

Diffraction data to confirm the layer transformation were measured on a Bruker D8 diffractometer with Co K  $\alpha$ max radiation (0,179 nm) in a parallel beam configuration. The measurement was performed at a constant angle of incidence of 10 degrees.

Carbonation of the Mg powder's surface was performed in a crucible placed over a Petri dish filled with distilled water in a closed desiccator under a  $CO_2$  atmosphere for 1 and 10 days.

The powders were compacted by cold isostatic pressing (CIP) at a pressure of 300 MPa, with a short pressure endurance followed by slow decompression. The forward extrusion was performed on a custom-made laboratory hydraulic press at an average extrusion speed of 0,2 mm/s with a reduction ratio of 16:1. The extrudates were heated to 375 °C before extrusion for 15 minutes.

The mechanical testing was performed using tensile specimens with a gauge diameter of 3 mm and a length of 21 mm, which were machined in parallel to the direction of extrusion. The tensile tests were performed at 23  $^{\circ}$ C (RT) using a Zwick Roell 1474 machine in accordance with the ASTM E8 standard.

Immersion tests in Hanks' Balanced Salt Solution (HBSS) were performed to investigate the corrosion behaviour of the composites. An excess of HBSS was used to minimize the effect of the corrosion products on the kinetics of the reaction. Degradation of the samples along the immersion time was observed by monitoring the hydrogen evolution, then converted to corrosion rate according to the Eq. (1), where A denotes the reaction surface of the sample and t is the immersion time in HBSS. Each sample was immersed separately in HBSS for 48 hours at 37 °C. For corrosion tests, the non-treated sample was used as a reference, and it was compared to the sample carbonated for 24 hours.

$$CR = \frac{m_{\rm Mg}}{A \cdot t} \tag{1}$$

### 3 RESULTS AND DISCUSSION

# 3.1 Transformation of the Native Surface Oxide into Carbonates

To interpret the changes during a reaction of carbon dioxide with native MgO on the surface layer of Mg powders, we investigated the native oxide of the available atomized Mg powder. The particle morphology and size represent Fig. 1a, where the inhomogeneity of surface oxide is also visible. Further, TEM micrograph in Fig. 1b shows the cross-section of Mg powder embedded in epoxy to investigate the native oxide layer. HAADF STEM micrograph at higher magnification in Fig.1c shows the interface of the Mg core and native oxide layers. It's worth mentioning that the oxide layer consists of 2 layers: an inner dense layer (DL) and an outer porous layer (PL). FFT diffraction pattern taken from the porous layer area shows ring patterns that correspond with MgO cubic structure (Ref. num.: 00-004-0829). This indicates that the oxide layer consists of nanocrystals with different orientations. The micrograph also shows the porous character of the layer where the dark areas are pores. Atomic resolution micrograph taken from the dense layer proves that the primary oxide layer is also crystalline build-up from nanocrystals about 6 nm in size.



Figure 1 SEM, TEM and STEM investigation of the native oxide on Mg powder: a) SEM micrograph of Mg powders; b) TEM micrograph of Mg powder embedded in epoxy; c) HAADF STEM image of the Mg/native oxide interface showing dense layer and porous layer with FFT diffraction from the porous oxide layer area; d) DF HRSTEM image of nanosized oxide from the dense layer with MgO crystal orientation [0 0-1]

SEM images of the Mg powder surface in Fig. 2a-c showed the morphology changes on the surface of Mg powder in the carbonation process after 1 day and 10 days. During the first day, the surface regions of the initially porous native oxide have changed to zones of amorphous hydrated magnesium carbonates without any visible evidence of the crystalline magnesium carbonate formation (Fig. 1b). Several crystalline carbonates can be recognized on the powder surface after 10 days (Fig. 1c). It can be seen changes in the form of plates uniformly adhering to the surface of powders. Adequately further investigation of the carbonation process was possible with direct TEM surface observations of carbonated powders. The native oxide layer in Fig. 2d is evident on the Mg powder without carbonation with MgO nanocrystalline porous layer, as mentioned before. After 1 day of carbonation, the porous oxide layer transforms to a denser layer, and the diffuse diffraction pattern indicates an

amorph transformation of the nanocrystalline MgO according to the CO<sub>2</sub> reaction. After 10 days of carbonation, we confirmed with SAEDP on the outer layer crystalline monoclinic nesquehonite phase (Ref. num.: 01-070-1433).

XRD measurement was performed on the Mg surface during carbonation, and the result is presented in Fig. 5. During the first days, the lack of carbonate peaks on the XRD pattern is likely the result of the formation of amorphous carbonate phases. The prolongation of the ageing period in the presence of a CO<sub>2</sub> environment is associated with the presence of hydrated carbonate phases, among which are dominant nesquehonite and hydromagnesite. After 10 days, nesquehonite is the dominant product of the reaction.



Figure 2 The carbonation process investigated with SEM and TEM: changes on the powder's surface during the carbonation (a - c); direct observation of the powder native oxide layer with SAEDP analysis (d - f)



#### 3.2 Mechanical and Corrosion Properties of Extruded Samples

After carbonation, the powders were pressed and forward extruded into rods and then tested for mechanical and corrosion properties. Microstructure and EDS analysis after extrusion represent Fig. 4. The formed texture is evident according to the extended oxides supporting the oxygen map's EDS chemical analysis. The extruded material shows the nonhomogenous thickness of the deformed oxide or carbonate layer. The carbon element map for short 1 day carbonation shows weekly the carbon element positions. However, after 10 days of carbonation, the carbon is strongly evident in the interface areas. Further analysis of the interface areas was investigated by TEM observations. Extruded samples after 1 day of carbonation in Fig. 5a show the interface of two powders indicating a thick layer changing to a thin layer. The diffraction pattern indicates an amorphous structure in the thicker area again, but the MgO phase is also observed. Carbonation of the powders for 10 days revealed thicker interface areas and the ring diffraction pattern showing crystalline phases, which can be interpreted for nesquehonite, MgO and another carbonates like magnesite.



Figure 4 Microstructure and EDX analysis of composites after extrusion: 1 day (a c). 10 days (d - f)



Figure 5 TEM of the interface area: a) 1 day, b) 10 days

The tensile properties of pure and carbonated Mg samples are listed in Tab. 1. Because of the similar grain size and deformation strengthening, the extruded samples show comparable results, and the interface modification affects the mechanical properties just slightly. Without any treatment, the tensile yield strength (YS) and ultimate tensile strength (UTS) of pure Mg are 183 MPa and 268 MPa. After carbonation, the YS is slightly reduced, showing no dependency according to the number of carbonation days. However, the UTS tends to decrease with the increasing amount of carbonates on the surface.

Table 1 C	omparison c	f mechanical p	properties and	corrosion rate	of Mg samples

Sample	YS (MPa)	UTS (MPa)	Elongation (%)	$CR (mg/cm^2/day)$
Pure Mg	183	268	5,8	2,12
Mg 1D	178	250	5,3	1,12
Mg 10D	176	243	5.3	3.39

YS-Yield strength. UTS-Ultimate tensile strength. CR-corrosion rate

The corrosion rate of the non-treated magnesium sample was 2,12 mg  $\cdot$  cm<sup>-2</sup> · day<sup>-1</sup>. The mass loss obtained from the H<sub>2</sub> evolution of the carbonated sample for 1 day gave an average corrosion rate of  $1,12 \text{ mg} \cdot \text{cm}^{-2} \cdot \text{day}^{-1}$ , which indicates a significant enhancement of corrosion properties compared to pure Mg. During the first 24 hours, the hydrogen evolution for pure Mg and Mg 1D mainly followed the same order; however, after that, the corrosion of pure magnesium was still exponential, while the corrosion rate of the carbonated sample was slowly stabilizing. Compared to previous samples, the corrosion rate of Mg 10D was considerably accelerated. Although the thicker layer of carbonates does not significantly affect the mechanical properties, the transformation from amorphous to crystalline forms significantly impacts corrosion.

#### 4 CONCLUSION

Carbonation of Mg powder native oxide surface with a simple experimental setup was studied in this work, focusing on corrosion enhancement after forward extrusion. Based on the experimental results and characterizations, the following conclusions can be reached:

The nanocrystalline native oxide (MgO) on atomized Mg powders covers the powder non-homogenously. It has a 2 layer-based interface: a dense layer (DL) and a porous layer (PL) consisting form MgO nanocrystals.

Simple carbonation of the native oxide layer can be achieved in a  $CO_2$  environment. After 1 day of carbonation, the native oxide layer absorbs  $CO_2$  and forms an amorphous structure. After 10 days of carbonation, the native oxide layer grows into a crystalline phase consisting mainly of nesquehonite.

Although the mechanical properties after carbonation showed no improvement over pure Mg, the conversion of native oxide into carbonates had a crucial effect on corrosion. If the formed carbonate layer is amorphous, it acts as the corrosion inhibitor, reducing the corrosion rate by half after one day of carbonation.

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# The Pitfalls of Reverse Engineering Topology Optimised Load-Carrying Structural Parts into Parametric Models

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Abstract: In this paper, we will show the topological optimization of a load-carrying structural parts and the errors that can occur when the topological solution in the form of a triangulated mesh of the surface of the optimized part is reconstructed into a parametric CAD form. Such a reconstruction always introduces geometric errors in the resulting optimal structure of the structural element. A numerical example will be used to show how quickly stress concentrations are reproduced on surfaces where they should not be. The numerical results are also supported by experiment. In the conclusion, it is suggested how, with a specific topological model, the obtained stress concentrations at the edges of the structure can be reduced.

Keywords: load-carrying structural parts; reverse engineering; stress concentrations; topology optimization

#### **1** INTRODUCTION

Optimization of mechanical systems is a key step in the design process. The aim of optimization is to find the most efficient shape, dimensions, material distribution and other parameters that will ensure optimum load capacity and minimize material and production costs. Achieving optimum design of mechanical systems requires the use of a variety of methods and tools. Advanced numerical methods such as the Finite Element Method (FEM) and genetic algorithms [3] allow engineers to simulate the behavior of mechanical systems under different loads and conditions. These tools allow an iterative process to find the optimal design over several iterations, with the parameters of the mechanical systems being changed and adjusted according to the results of the analysis. It is important to note that optimization often leads to lighter and more efficient mechanical systems that also have a longer service life, which can have a positive impact on the environment.

Structural optimization of mechanical systems can be divided into three main fields:

- sizing optimization, where the optimisation task aims to reduce the weight of the structure. The optimisation parameters can be lengths or cross-sectional sizes of the structure;
- shape optimization, where an optimisation task is used to change the geometry of the structure to obtain smooth contours without stress concentrations;
- topology optimization, where a mathematical model is typically used to reduce the total strain energy of the structure by adding or removing material in the optimisation domain of the structure.

The paper will discuss about the topology optimization (TO) and mechanical systems will be the load-carrying structural parts. Topology optimization of the load-carrying structural parts has been the most developed area in recent years, also due to the rapid development of 3D printing and related materials. These processes can produce complex shapes of load-carrying structural parts, but problems still

arise because the printing materials are sensitive to cracks and, as a consequence, can lead to the failure of the mechanical part. Topology optimization is very important, because it can allow stress concentrations to be absent in the optimization domain, or to occur only in the compression zones of the part as shown in Fig. 1.



Figure 1 Higher stress in compression zones of the part

Topological optimization process (Fig. 2) is complex [4, 5] and consist of:

- CAD model preparation adjust regions that will be further optimized or fixed,
- FEA model preparation adjust mesh, materials and load cases,
- optimization model preparation adjust design configuration (shell, lattice, or mixed structure,) and technological constraints (Plane Symmetry, Opening...),
- optimization process run optimization and monitor progress,
- output results adjust shape optimization or smoothing tools for a triangulated geometrical surface.



The goal of topology optimisation is to obtain a loadcarrying structural part that exhibit lightweight (performance), durable (low crack initiation probability), low stress levels and no stress concentrations in the area where the process can remove or add material (reliability, safety). The resulting output should be ready for CNC machining, casting and molding or 3D printing.

Although in most cases the TO result is the best in terms of stress concentrations and associated product lifetime, some results are not considered by designers to be suitable for manufacturing. Fig. 2 shows an example of a not "flat enough" surface (Fig. 3a) and an "overcomplicated" structure (many small connections) for fabrication (Fig. 3b).



Designers often carry out geometry reconstruction procedures to obtain a parametric CAD model, which is not an easy process. This can be done with the help of various software programs, but as a rule, a considerable amount of manual modelling cannot be avoided. The result of the reconstructed model is a geometry that always deviates slightly from the geometry of the original optimized part. The errors made in doing so may seem insignificant from a geometric point of view, but they can greatly increase the stress concentrations in the model. In fact, we know from the field of shape optimization that even a slight variation in geometry, which may otherwise appear to be quite insignificant, can lead to a significant increase in stresses. In the paper [6] an example of the effect of changing the geometry of an opening on a plate loaded as shown in Figure 4 is shown. A plate loaded with uniform but different loads along the outer edges has an optimum elliptical opening, which is then replaced by a circular one. This replacement causes the maximum stresses on the contour of the circular bore to increase by about 55 %. Such an increase can make a huge difference to the life of a cyclically loaded part.



Figure 4 Plate with opening

A very difficult example to reconstruct the geometry are load-carrying structural parts with modelled lattice structures (Fig. 5).



Figure 5 Optimized lattice structure

The authors are by themselves involved in the development of a professional TO software, enabling them access to invaluable feedback information from practicing engineers on their usage of TO procedures. The aim of this paper is to illustrate the pitfalls and possible solutions of reverse engineering topology optimized load carrying structural parts back into CAD models.

The structure of the paper is as follows. Section 2 outlines the structural TO fundamentals. Section 3 shows numerical example of topology optimization and reconstruction into CAD model. Section 4 shows the experimentation of the reconstruction models and the testing on the bending machine.

#### 2 TOPOLOGY OPTIMIZATION

Topology optimization can be divided into three groups:

- First are homogenization methods the foundations of the method were laid by [1]. These methods typically introduce a large number of design variables and mathematical programming methods are not well suited to solve these problems:
- Second are Solid Isotropic Microstructures with Penalization (SIMP) or Power-law methods [2]. These methods are based on an assumed and simple relation between the rigidity of the cell (elastic modulus) and the density of the cell. The number of design variables is smaller as in first methods, 1 variable per 1 finite element (FE) as in first 3 variables per FE.
- Third are Evolutionary Structural Optimization methods (ESO) [11] are based on some criterion as stress, strain energy density ... based on which a particular finite element can be eliminated or restored to its initial state.

Topology optimization is a powerful computational technique that enables engineers to determine the optimal material distribution within a given design space. The basic idea behind topology optimization is to start with a given design space, which represents the volume in which the structure will be located, and then use mathematical algorithms to determine the best possible configuration of material within that space. This is achieved by defining certain performance criteria that the structure must meet, such as maximum stress or displacement, and then iteratively refining the material distribution until the desired performance is achieved. Topology optimization problems of load-carrying structures are in general:

- non-linear. •
- non-convex, and
  - very flat,
- problems.

A consequence of non-linearity is that the optimization process is iterative and cannot be solved within a single cycle. Non-convexity, on the other hand means that the problem exhibits many local minima and that it is very difficult to check whether the obtained result is actually the global minimum or solution. The most confusion in practice, however, is the extreme flatness of topology optimization problems.

There is no single solution in TO, however the number of solutions can vary depending on how the optimization process was carried out (Fig. 6). In optimized parts below is the strain energy practically the same although the designs differ substantially.



Figure 6 Topology optimization process - same strain energy

In topology optimization, the mathematical task is often defined as minimizing the total strain energy of the structure, taking into account the boundary conditions. The problem can be formulated as [4, 8]:

$$\min \int f(u, x). \tag{1}$$

In Eq. (1), u is the displacement field and x represents a parameter (e.g. the material distribution within a component) that affects the topology of the body under consideration. The value u = u(x). For the optimization domain, dimensionless parameters  $x_i$  must be defined between 0 and 1 to allow material to be removed or added. Material removal or addition will be achieved by relating  $x_i$  to material properties such as density and elastic modulus, which can be written by the equation

$$x_i = x\rho_0, E_i = p_i E_0. \tag{2}$$

In Eq. (2),  $\rho_0$  and  $E_0$  are the density and modulus of elasticity of the material used in the structure, and  $p_i$  and  $E_i$  are the variables to be associated with the finite elements of the numerical model. In the numerical model, the parameters  $p_i$ represent material distribution in design space and are associated with nodes of FEA. Those parameters are defined in the range between 0 and 1, where 0 represents the void in design space and 1 the full material.

The mathematical problem of the TO is to distribute the material over the design domain in such a way that the minimum of the total strain energy is achieved. In this case, normally low stress levels and no stress concentrations in the design domain will reach. This will prolong the service life with low crack initiation probability of load-carrying structural parts. As mentioned before, the final design is fully adapted to given boundary conditions as loads, supports, theological constraints.

#### 3 NUMERICAL EXAMPLE

The topology optimization and the geometry reconstruction will be demonstrated on a simple beam element. The beam represent the load-carrying structure where the middle section has to carry a large part of the vertical load, Fig. 7. The stand (middle section), which will be subject to topological optimization, represents a quasiplanar region, which will simplify the geometric reconstruction and the observation of the stresses on the cut surfaces.



The beam element is centrally supported on the top side and loaded with uniform pressure 10 MPa on the underside. The CAD and the FEA models of this case were prepared using the PTC® Creo® software package [12]. A topology optimization-capable FEA model is normally prepared in a similar way as a usual FEA model, but there are some important issues that require careful consideration. The underlying CAD model must be adequately partitioned into volume regions [6, 8], the load cases must include all possible loads and supports variations and the finite element mesh must be prepared with some minimum quality requirements regarding mesh density and element size uniformity.

For topology optimization, proper prepared FEA model contains approximately one million linear tetrahedral finite elements and was imported in CAESS ProTOp® software package [13] (Fig. 8).



Two optimization regions were set in ProTOp, where the light blue is a free region. This region can be optimized by removing or restoring material. The grey represent fixed region, which has to remain unchanged and is not optimized. Additional were added two technological constrains as plane symmetry on x and z axis, so the optimizer will distribute the material symmetrically to the prescribed plane.

Firstly, the objective was to design parts by using 80 %, 60 %, 50 %, 40 % and 20 % of the material present in the initial design. The aim of TO is that the load-carrying structure with this amount of material has minimal stresses levels and maximal stiffness. Results are shown in Fig 9. The stress scale is set to 500 MPa max.



Tab. 1 shows total volumes and calculated reference stress for optimized parts. Reference stress denote the maximum von Mises stress along the contours of all the openings in the rack.

Table 1 Reference stress for optimized parts

Volume (%)	80	60	50	40	20
Total volume (10 <sup>3</sup> mm <sup>3</sup> )	697	647	623	598	548
Reference stress (MPa)	253	275	332	425	904

Based on the topological optimization results, we decided to perform three variants of geometry reconstruction for the case of 50 % material removal, which illustrate the most commonly used techniques in practice. We did:

- Case A: we used only circles to cut the material. The size and position of circles are chosen to represent the inscribed circles for the openings of the optimal design.
- Case B: we used only ellipses to cut the material. The size and position are chosen to visually follow as closely as possible the openings of the optimal design.
- Case C: The material is cut by hand so that the curves used follow as closely as possible the actual shape of the optimal design.

The numerical results of stress fields are shown in Fig 10.



Figure 10 Cases A, B and C with stress fields

Tab. 2 shows total volumes and calculated reference stress for all three cases.

Table 2 Reference stress for Cases A – C						
Volume 50 (%) Case A Case B Case C						
Total volume $(10^3 \text{ mm}^3)$	694	671	623			
Reference stress (MPa)	499	620	430			

Fig. 11 shows calculated reference stress for all three cases.



The diagram shows that it is best if the reconstructed geometry follows the optimal one as closely as possible. In this case, the increment is about 30 %. However, the geometry reconstruction performed poorly when using a circle and an ellipse. The stress increments in these cases were enormous.

#### 4 EXPERIMENTAL EXAMPLE

We also wanted to verify experimentally the numerical results of the reconstruction for Cases A – C. We were interested in whether they would crack under cyclic loading, where we numerically calculated the stress concentrations. For each reconstructed case, we prepared several Co-Cr test specimens with properties  $R_{p0.2} = 900$  MPa and  $R_m = 1100$  MPa. The test specimens were 3D printed. The tests were carried out with a bending test where the force was increased up to 10 kN.



Figure 12 Experiment for Cases A, B and C

The results showed that the cracks occurred in the zones with the highest stress, as predicted. However, it should be said that, probably due to the porosity of the 3D printing material, some test pieces also cracked in places where we did not predict (dot).



#### 5 CONCLUSION

In practice, the results of topology optimization are often processed back into CAD models. However, many engineers do not realize that they are thereby spoiling the favorable optimization results and introducing stress concentrations into the structure, despite the fact that they are adding material during the reconstruction process.

To avoid such errors and to prevent stress concentrations, we have developed a model in the TO software framework that can redistribute the material in the domain a little after reconstruction [10]. In such case, the stress concentration vanishes at the edges of plots (Fig. 14).



Figure 14 Redistribution of the material

By introducing such a model, we have been able to reduce the stress concentrations at the edges of the contours in cases A - C (Fig. 10), but it is important to remember that this has worsened the deformation energy of the system. But still thus preventing the formation of a crack, as shown in Fig. 15.



Figure 15 Cases A, B and C with stress fields

It must be stressed that the reconstruction of the geometry must be approached in a thoughtful way, so as not to reduce the load-bearing capacity and the service life of the load-bearing part.

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# Atomic Force Microscopy: Step Height Measurement Uncertainty Evaluation

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Abstract: The atomic force microscope (AFM) enables the measurement of sample surfaces at the nanoscale. Reference standards with calibration gratings are used for the adjustment and verification of AFM measurement devices. Thus far, there are no guidelines or guides available in the field of atomic force microscopy that analyze the influence of input parameters on the quality of measurement results, nor has the measurement uncertainty of the results been estimated. Given the complex functional relationship between input and output variables, which cannot always be explicitly expressed, one of the primary challenges is how to evaluate the measurement uncertainty of the results. The measurement uncertainty of the calibration grating step height on the AFM reference standard was evaluated using the Monte Carlo simulation method. The measurements within this study were conducted using a commercial, industrial atomic force microscope.

Keywords: atomic force microscope; measurement uncertainty; Monte Carlo simulation

#### **1** INTRODUCTION

It is known that the key indicator of measurement result quality is measurement uncertainty. According to the Guide to the Expression of Uncertainty in Measurement (GUM), measurement uncertainty is defined as a parameter associated with a measurement result that describes the dispersion of values that could reasonably be attributed to the measured quantity with a certain level of probability [1]. The purpose of measurement is to determine the value of the measured quantity. Proper understanding of the data obtained from measurements is crucial for the application of that data [2]. When measurement data are used for decision-making, it is often assumed that the data are accurate to such an extent that information about the measurement uncertainty of the measured result is almost never provided. Generally, a measurement result is only an approximation or estimation of the value of the measured quantity. Therefore, a measurement result is complete only when accompanied by a statement of the uncertainty associated with that estimate [3].

The expression of measurement uncertainty is preceded by establishing a mathematical model that best describes the measured quantity [4]. The mathematical model represents the relationship between output and input quantities and consists of many functionally connected components. According to the GUM, for estimating measurement uncertainty, it is necessary to know all the parameters that influence the measurement process. Additionally, it is necessary to assess the components of each individual parameter that affect the measurement result [1].

Various methods are employed for estimating measurement uncertainty. The widely accepted model for calculating measurement uncertainty in metrology practice is the GUM method [5]. However, due to the large number of influential parameters and the complex and nonlinear functional relationships involved in atomic force microscopy, estimation of measurement uncertainty based solely on the Guide to the Expression of Uncertainty in Measurement is insufficient [6]. Therefore, the Monte Carlo simulation (MCS) method is used. In addition to the Monte for calculating measurement uncertainty [7]. The Bayesian method for estimating measurement uncertainty is employed when dealing with rare data or complex models. It is also used for quantities that are not normally distributed, have certain constraints, or exhibit skewed density functions [8].

The Monte Carlo simulation (MCS) method is introduced in the Joint Committee for Guides in Metrology (JCGM) 101:2008 Supplement 1 to the Guide to the Expression of Uncertainty in Measurement - Propagation of Distributions Using Monte Carlo Method [9]. The Monte Carlo method involves propagating the distribution of input uncertainty sources using a model to obtain the output distribution. It is a numerical method based on generating a large number of random values and analyzing the obtained data to obtain information about the best estimate of the output quantity [10]. The Monte Carlo simulation method is particularly useful when the underlying probability distributions of the system are not well known or cannot be easily determined analytically [11]. The following are the basic steps involved in using Monte Carlo simulations for estimating measurement uncertainty:

- Identification of relevant sources of measurement uncertainty: The first step is to determine the relevant sources of uncertainty that may affect the measurement result.
- Modeling of uncertainty sources: For each uncertainty source, a specific probability distribution or a set of data from previous measurements should be used. The MCS method is not limited to selecting prior distributions; they can also be asymmetric.
- Generation of random numbers from probability density functions of input quantities: Using the uncertainty sources and their distributions, a large number of M random measurement results are generated.
- Estimation of the output quantity: By generating random numbers from the probability density functions of input quantities, a probability density function describing the measured quantity is obtained.
- Estimation of measurement uncertainty: Based on the output probability density function, the measurement uncertainty interval for a given value is determined.

Since the Monte Carlo simulation method allows for considering different uncertainty sources and generating many measurement samples, this method can be considered a more accurate and comprehensive approach to estimating measurement uncertainty than the GUM method [12].

#### 2 AFM AND REFERENCE STANDARD

Research on atomic force microscopy in the field of dimensional nanometrology is relatively unexplored [13]. From the perspective of estimating measurement uncertainty, one of the main challenges in atomic force microscopy is the large number of influential parameters [14]. According to the GUM, it is necessary to know all the parameters that affect the measurement result and their contributions to the measurement uncertainty [15]. Due to the highly complex nature of the measurement system and its various applications in industry and science, which involve analyzing results and measuring samples of different materials and applications, estimating measurement uncertainty in atomic force microscopy according to the GUM is highly complex [16]. Considering the large number of parameters that influence the operation and measurement results of atomic force microscopy, it is necessary to investigate how each parameter affects the measurement process and to what extent [17]. The first step is the identification and classification of influential parameters on the measurement result. In the Ishikawa diagram shown in Fig. 1, the influential parameters are categorized into six main groups: measurand, operator, AFM instrument, image analysis, reference standards, and environmental conditions. It is important to note that certain parameters can belong to more than one group, and there can be overlaps between the groups that include specific influential parameters.



Figure 2 Features on the AFM reference standard [18]

The moderate reference standard employed for conducting measurements is the Surface Topography Standard (STS) developed by the American company VLSI Standards [18], with headquarters in Milpitas. This particular standard is utilized for the calibration of AFM devices. The STS reference standard (Fig. 2) encompasses features defined in all three spatial directions, enabling measurement standardization, calibration, and monitoring of the linearity of the AFM measurement instrument. Additionally, it provides information regarding the condition and wear of the probe tip.

The reference standard consists of a silicone matrix with dimensions of  $12 \times 8$  mm, featuring precisely fabricated silicon dioxide features. The standard contains three groups of features, spaced 100 µm apart. Each grating pattern on which the defined features are located consists of alternating lines and spaces, with a uniform pitch in both the x and y directions. There are three nominal step lengths in the x and y directions: 3 µm, 10 µm, and 20 µm. The nominal height of the features on the standard in the z-axis is 100 nm. The entire matrix, including the features in the calibration area, is coated with a uniform layer of platinum with a nominal thickness of 40 nm (Fig. 3).



Figure 3 Cross-section of the standard [18]

Given that it is a calibrated AFM standard, it is accompanied by a calibration certificate. The calibration certificate for the STS3-1000P standard [18] states that the depth of the grating groove is  $(97.6 \pm 1.4)$  nm. The measurements were conducted under the following stable environmental conditions: temperature of  $(20 \pm 1)$  °C and humidity of  $(42 \pm 2)$  %. Fig. 4 illustrates the manifestation of the standard, as quantified using the *Oxford MFP-3D Origin* model atomic force microscope, situated at the Faculty of Mechanical Engineering and Naval Architecture in Zagreb.



#### **3 FACTORIAL DESIGN OF THE EXPERIMENT**

A factorial design of the experiment was conducted as part of this study to demonstrate the significance of input parameters in atomic force microscopy (AFM) measurements. The design of the experiment entails conducting trials across all levels of the designated input parameters. Tab. 1 delineates the input parameters for the experimental framework. Within this experimental setup, each parameter assumes a binary state, thereby constituting a two-factor experimental design. Considering the influential factors (Fig. 1) and the measurement procedure itself, preliminary investigations included measurement input parameters that are selected through software prior to conducting the measurements, as well as the operating mode of the microscope. The design of the experiment was created and analyzed using *Design Expert 13* software.

	Iable	i input lactors an	u experiment	IEVES	
Variable	Controlled	Variable	Metric	Inferior	Superior
identifier	factor	classification	measure	extent	extent
Α	Operating mode	Nominal	I	Tapping	Contact
В	Scan size	Ratio	$\mu m \times \mu m$	$10 \times 10$	$20 \times 20$
С	Scan resolution	Ratio	I	256	512
D	Scan speed	Ratio	μm s <sup>-1</sup>	12.5	50

Table 1 Input factors and experiment leves

As an output, the measured step height of the regular grid on the reference standard was monitored. The measurement results obtained from the two-factor experimental design are shown in Tab. 2.

	Factor A	Factor B	Factor C	Factor D	Response
Number	Operating mode	Scan size	Scan resolution	Scan speed	h
	—	$\mu m  imes \mu m$	—	µm·s <sup>−1</sup>	nm
1	tapping	10	256	12.5	92.50
2	contact	10	512	50	91.64
3	tapping	10	256	12.5	96.26
4	tapping	20	512	50	95.51
5	tapping	20	256	12.5	98.36
6	contact	20	512	50	85.10
7	contact	20	256	12.5	93.17
8	tapping	10	512	50	82.04
9	contact	10	256	12.5	102.8
10	contact	20	256	50	103.9
11	tapping	10	512	12.5	103.2
12	contact	20	512	50	103.7
13	contact	10	256	12.5	103.4
14	tapping	20	256	50	102.7
15	contact	10	512	12.5	103.6
16	tapping	20	512	50	103.0

Table 2 Data from the measurements

Source	squares	df	square	F-value	P-value	Significance
Model	640.7401	5	128.148	17.6565	0.000205	significant
Model members						
A- operating mode	278.6003	1	278.6003	38.38613	0.00016	significant
B-scan size	69.89005	1	69.89005	9.6296	0.012658	significant
D-scan speed	27.29538	1	27.29538	3.760816	0.084406	significant
AD	51.41629	1	51.41629	7.084246	0.025977	significant
BD	49.31872	1	49.31872	6.795238	0.028421	significant
Residual	65.32052	9	7.257836			
Cor total	706.0606	14				

Table 3 Analysis of variance for the response

After conducting and analyzing the experimental design, the following results were obtained, Tab. 3.

The F-value of the model, amounting to 17.6565, and the P-value of 0.000205, indicate that the selected model is

suitable for determining the significant input variables on step height h. *P*-values of model components less than 0.05 indicate the significance of individual components in the model. In this model, factors A, B, D, as well as their interactions AD and BD, are significant.

Tab. 4 provides an overview of the metrics delineating the caliber of the formulated mathematical model with respect to the variable h. The computed value of the adjusted coefficient of determination,  $R_{adj}^2$ , stands at 0.8561. This signifies that the input parameters have been well chosen, i.e., 85.61% of the model can be described by the selected input parameters and their interactions. The coefficient of determination,  $R_{\rm pre^2}$ , is 0.6864. This indicates that 68.64% of the data obtained from the experiments can be explained by the predictive model, which is satisfactory. The disparity between the predicted coefficient of determination,  $R_{pre^2}$ (0.6864), and the adjusted coefficient of determination,  $R_{adj}^2$ (0.8561), registers at less than 0.2. This suggests that the anticipated and calibrated determination coefficients exhibit a rational concordance. The value of the determination coefficient,  $R^2$ , is 0.9075. The attained level of precision is 10.8403, surpassing the stipulated minimum threshold of 4.

Table 4 Statistical characteristics of the model

Standard deviation	2.69			
Arithmetic mean	97.15			
Coefficient of variation, %	2.77			
Coefficient of determination $R^2$	0.9075			
Adjusted coefficient of determination $R_{adj}^2$	0.8561			
Predicted coefficient of determination $R_{\rm pre}^2$	0.6864			
Adequate precision	12.9829			

Fig. 5 depicts the output variable h in a threedimensional representation as a function of scanning speed and scanned area size. The conducted design of the experiment has demonstrated that the input variables that significantly influence the step height of the reference etalon are the operating mode, scanned area size, and scanning speed. All subsequent measurements carried out in this study were performed in the contact mode, with a scanning speed of 12.5  $\mu$ m·s<sup>-1</sup>, and a scanning resolution of 256 over a scanned area size of 20  $\mu$ m × 20  $\mu$ m.



Figure 5 The three-dimensional representation of the output variable h depending on scanning speed and scanned area size is shown for (a) the contact mode and (b) the tapping mode.

#### 4 EVALUATIONOF MEASUREMENT UNCERTAINTY

The selected method for estimating the measurement uncertainty of the step height of the calibrated AFM reference sample is the Monte Carlo simulation method. After identifying the influential variables affecting the measurement result of the step height, a mathematical model of the output variable is established, represented by Eq. (1). The Monte Carlo simulation method for evaluating the measurement uncertainty of the step height of the calibrated AFM reference sample was implemented using the *Python* programming language based on Eq. (1) and the input parameters shown in Tab. 5.

$$h = h_x + r \cdot t \cdot l + d \cdot \alpha \cdot \Delta \mathcal{G} + \delta r + \delta R + \delta probe$$
(1)

Table 5 Input variables and probability density function

Input variable $x_i$		Probability density function $g(x_i)$		
Measured value	$h_x$	Normal distribution (M, 98.9 nm, 0.9 nm)		
Scan rate	r	Uniform distribution ( $M$ , -0.005 s <sup>-1</sup> , 0.005 s <sup>-1</sup> )		
Scanning time	t	Uniform distribution $(M, -0.5 \text{ s}, 0.5 \text{ s})$		
Scan length	l	Uniform distribution ( <i>M</i> , –0.005 nm, 0.005 nm)		
Nominal step height	d	100 nm		
Temperature expansion coefficient	α	Normal distribution ( $M$ , 2.57 × 10 <sup>-6</sup> K <sup>-1</sup> , 0.019 × 10 <sup>-6</sup> K <sup>-1</sup> )		
Temperature difference	$\Delta \vartheta$	Uniform distribution ( <i>M</i> , –2 K, 2 K)		
Repeatability	δr	Normal distribution (M, 0 nm, 0.104 nm)		
Reproducibility	$\delta R$	Normal distribution (M, 0 nm, 0.823 nm)		
Probe	δprobe	Normal distribution ( $M$ , 0 nm, 0.86 nm)		

A total of M = 100,000 simulations were performed. The component of the measured value was based on 15 repeated measurements of the step height, from which the mean and standard deviation were calculated. The components of scanning speed, scanning time, and scanning length followed rectangular distributions according to the resolutions of the respective variables. The coefficient of thermal expansion of silicon was taken as  $2.57 \times 10^{-6}$  K<sup>-1</sup> with an expanded uncertainty of  $0.038 \times 10^{-6}$  K<sup>-1</sup>. The repeatability and reproducibility of the results were calculated in accordance with ISO 5725-2:2019 [19], which defines the basic method for determining the repeatability and reproducibility of a standard measurement method. A total of 15 repeated measurements were performed in two measurement series. Within each measurement series, the measurements were conducted under repeatability conditions, with the same metrology, measuring instrument, and measurement conditions, and the measurements were repeated in a short period of time. Between the measurements performed in the first and second measurement series (conducted on two different days), the repeatability conditions were not fully met, but the reproducibility conditions were considered. The component of the tip influence on the measurement result was taken from the literature [20]. An analysis of the tip influence on the measurement result was performed, resulting in a value of 0.86 nm.

After performing the Monte Carlo simulation method, the results are shown in Fig. 6 and Tab. 6. The estimated standard deviation of the step height h of the calibrated AFM reference sample is 1.5 nm. The measurement result reads:  $h = (98.9 \pm 2.9)$  nm with a coverage probability *P* of 95 %. Therefore, it can be stated with 95 % confidence that the measured step heights on the AFM reference sample will fall within the interval of 96.0 nm to 101.8 nm.



Table 6 Statistical parameters of the output function

Parameter	Value		
Lower limit of the interval (2.5 %)	96.0 nm		
Upper limit of the interval (97.5 %)	101.8 nm		
Expanded measurement uncertainty U	2.9 nm		
Arithmetic mean	98.9 nm		
Standard deviation	1.5 nm		

Furthermore, a comparison was conducted between the results obtained by AFM from FMENA in Zagreb and VLSI Standards in Milpitas [18]. The comparison of results is performed by calculating the agreement factor En, as given by Eq. (2).

$$En = \frac{\left|\overline{x}_{1} - \overline{x}_{2}\right|}{\sqrt{U_{1}^{2} + U_{2}^{2}}} \le 1$$
(2)

where is:  $\bar{x}_1$  - arithmetic mean of the step height obtained by VLSI Standards, nm;  $\bar{x}_2$  - arithmetic mean of the step height obtained by FMENA, nm;  $U_1$  - expanded measurement uncertainty specified by VLSI Standards, nm;  $U_2$  - expanded measurement uncertainty specified by FMENA, nm.



The obtained value of the conformity factor En is 0.40. Since the conformity factor is less than 1, it can be concluded that the results are compatible. Additionally, the results can be presented graphically, as shown in Fig. 7. It can be observed that the mean value of the simulated data lies within the measurement uncertainty specified by the Calibration Certificate.

#### 5 CONCLUSION

The study encompassed the assessment of measurement uncertainty in atomic force microscopy. The measurements were conducted on an AFM reference standard utilized for the instrument calibration purposes. These reference specimens incorporate a calibration grating featuring a precisely defined step height, accompanied by information pertaining to the expanded measurement uncertainty.

In the field of metrology, diverse methodologies are employed for the estimation of measurement uncertainty. Despite the predominant usage of the GUM method, it becomes imperative to employ alternative techniques when dealing with AFM measurements. This is primarily attributed to the presence of numerous influential factors that impact the measurement outcomes, as well as the complex and nonlinear functional relationships between the input and output variables. Consequently, the utilization of additional uncertainty estimation methods becomes indispensable.

To systematically identify the influential variables and establish a comprehensive understanding, an Ishikawa diagram was employed, effectively categorizing these variables into six principal groups. Furthermore, a two-factor design of the experiment was implemented to ascertain the significance of the operational mode, scan speed, and scan size on the step height—a critical parameter of interest.

In light of the above, the Monte Carlo simulation method was applied to estimate the measurement uncertainty associated with the step height of the AFM reference standard. By leveraging the Monte Carlo simulation approach, crucial insights regarding the expanded measurement uncertainty were acquired, revealing a step height value of  $(98.9 \pm 2.9)$  nm with a confidence level of 95 %. Additionally, a conformity factor was computed to facilitate the comparison between the obtained results and the information outlined in the calibration certificate of the AFM reference standard. Remarkably, the conformity factor indicated compatibility between the results obtained by company VLSI Standards and Faculty of Mechanical Engineering and Naval Architecture, substantiating the reliability and accuracy of the measurements.

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# Influence of Hydroxyapatite Content on Physical and Rheological Properties of Chitosanbased Scaffold

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Abstract: Chitosan-based scaffolds offer significant potential in tissue engineering and regenerative medicine. Whilst exhibiting great bio-regenerative and biocompatible properties, their mechanical properties remain quite poor. The presented research is focused on the modification of macroporous chitosan scaffolds with various amounts of bioactive ceramics (hydroxyapatite) and its influence on the physical and rheological properties of the composite scaffold. Chitosan/hydroxyapatite composite scaffolds with a highly porous microstructure have been prepared by suspending hydroxyapatite (HAp) particles into the chitosan matrix. According to SEM imaging, homogeneous dispersion of the inorganic phase in a chemically-crosslinked chitosan matrix had been achieved. The obtained composite scaffolds exhibited lower swelling capacity with respect to pure chitosan after 24 h of incubation in Hanks' balanced salt solution. Rheological measurements show an increase in storage and loss modulus indicating an improvement in mechanical properties under shear stress. Furthermore, no significant change in loss factor (tan $\delta$ ) was observed indicating no change in composite viscoelastic properties with an increase in HAp content.

Keywords: chitosan; hydroxyapatite; scaffold; rheological properties

#### **1 INTRODUCTION**

Bone is a complex and dynamic tissue that provides mechanical support to the body and plays crucial roles in calcium homeostasis and haematopoiesis [1]. The inorganic phase of bone is primarily composed of calcium phosphates (CaP), predominantly in the form of hydroxyapatite (HAp,  $Ca_{10}(PO_4)_6(OH)_2$ ) which corresponds to 65 - 70% of bone tissue [2]. The organic phase is mainly collagen, a large fibrous protein equivalent to the remaining portion [3, 4]. Collagen is mostly responsible for the elastic resistance of the bone, acting as a matrix for the deposition and growth of mineral salts [2, 5, 6]. Human bone can be divided into strong low-porous (cortical) tissue with high stiffness and soft spongy (trabecular) bone tissue with low strength. The inner part of the bone (trabecular) has a three-dimensional highly porous spongy structure with a pore diameter of 100 - 500 µm allowing for unhindered diffusion of nutrients and metabolic waste through the bone [7, 8].

To aid in the bone recovery process, calcium phosphates such as brushite (CaHPO<sub>4</sub>×2H<sub>2</sub>O), monetite (CaHPO<sub>4</sub>), tricalcium phosphate (Ca<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub>) and hydroxyapatite (HAp) can be used. The interest in these phosphates is due to their biocompatibility, bioactivity, resorbability and chemical similarity to the mineral component found within mammalian bones. However, most attention is put on HAp owing to its thermodynamic stability within body fluids [9, 10].

The first stage in bone tissue engineering begins with the design and fabrication of a porous 3D scaffold. In general, the scaffold should be fabricated from a highly biocompatible material that avoids the possibility of eliciting an immunological or foreign body reaction [11]. Furthermore, the chosen material should be able to degrade and resorb into the body at a controlled rate, matching the rate of specific tissue growth [12]. The incorporation of bioactive ceramics, such as HAp, into a biodegradable polymer matrix could produce bioactive composite materials that mimic natural

human bone. A composite material would also improve biocompatibility and hard tissue regeneration owing to the embedded ceramic particles within the polymer matrix [13]. Furthermore, if the 3D scaffold is used as a temporary loadbearing support, the structure should maintain the load without showing fatigue or failure. Therefore, the scaffold should achieve a direct bond with surrounding tissue, and at the same time be completely degradable leaving space for new tissue growth. [12, 14].

One of the most investigated biocompatible and biodegradable polymers for 3D porous scaffolds preparation is a linear polysaccharide chitosan (CHT). It is known for its biocompatible, hydrophilic, non-toxic and biodegradable properties [15, 16]. Chitosan allows for the formation of hydrogels which can be used to create optimal 3D porous scaffolds with suitable microstructure for cell proliferation and differentiation; therefore, it has been applied in cartilage tissue engineering [17, 18], wound healing [9] and bone engineering or orthopaedic applications [19, 20]. Unfortunately, it cannot induce and accelerate bone tissue regeneration [21] and also possesses low mechanical properties due to its hydrogel nature, resulting in poor performance as a load-bearing material [2]. Previous research by Santos et al. [9] describes the dependence of cellular growth on the mechanical properties, more precisely, the elastic modulus of biodegradable materials, where an increase in cell growth can be observed with a modulus close to bladder tissue. Here, the choice of crosslinking then plays a pivotal role in scaffold properties. The option between physical [22] and chemical [23] crosslinking of chitosan can determine the scaffold's in vivo behaviour. If chitosan is cross-linked via physical interactions, it can result in "weak gels" with higher degradation ability but lower mechanical properties. The use of a chemical crosslinking agent such as genipin, results in a "strong gel" with higher resistance to degradation and improved mechanical properties [24, 25].

In this work, chemically-crosslinked chitosan scaffolds were modified by different amounts of hydroxyapatite particles in order to prepare composite scaffolds for bone tissue engineering applications. According to Budiraharjo et al. [26] the addition of HAp supports osteoblast attachment and proliferation as well as osteoblastic differentiation of bone marrow stem cells. Jongwattanapisan et al. [27] further confirmed bioactivity by the formation of an apatite layer on the surface of the scaffold allowing for its in vivo osteoinductive behaviour. The incorporation of HAp within the polymeric matrix can likely improve mechanical properties under shear stress, possibly increasing the storage and loss moduli which can then be reflected in the material's ability to withstand higher shear stress when implanted in living organisms [28, 29]. In this work, we investigated the influence of different hydroxyapatite content on the physical and rheological properties of potential bone scaffolds. The CHT/HAp scaffolds were fabricated by thermally induced phase separation and chemically crosslinked using genipin. The rheological test showed that prepared scaffolds act as 'strong gels' when subjected to shear stress, with slightly increased storage modulus when hydroxyapatite was added. Obtained chitosan/hydroxyapatite scaffolds were designed as potential structures for aiding in the restoration of small bone defects with limited load-bearing capabilities.

## 2 EXPERIMENTAL PART

### 2.1 Synthesis of Hydroxyapatite

A predetermined amount of calcium carbonate (CaCO<sub>3</sub>; Lachner, Neratovice, Czech Republic) was added into a 0.5% (v/v) solution of acetic acid (Acetic acid 99.8%; Lachner Neratovice, Czech Republic) and left for 2 hours under vigorous stirring. Then, a specific amount of ammonium dihydrogen phosphate (Lachner, Neratovice, Czech Republic) was added, with respect to the hydroxyapatite molar ratio Ca/P of 1.67. The pH of the solution was then adjusted to 9 using ammonia (Alkaloid Ad Skopje; Skopje, North Macedonia) and left for 24 hours under vigorous stirring at ambient temperature. The obtained precipitate was then filtered, washed with demineralized water until neutral pH and dried at 60 °C.

### 2.2 Preparation of Composite Scaffolds

Chitosan scaffolds were prepared as follows: CHT (Chitoscience 85/200; Heppe Medical Grade Chitosan) was dissolved in acetic acid 0.5% (v/v) in order to obtain a 1.2% (w/v) chitosan solution. After the solution was filtered, genipin (Cayman Chemical Company; Ann Arbor, MI) (a crosslinking agent) was added to the solution (2% w/w in respect to chitosan) and stirring was resumed for 4 h. Following the process of homogenization, the resulting solution was poured into a 24-well plate and subjected to a 24-hour incubation period at 50 °C to facilitate the crosslinking reaction. The obtained cross-linked hydrogels were subsequently frozen at -22 °C and subjected to a 48hour lyophilization process using a Kambic LIO-5PLT (Slovenia) freeze-dryer. Afterwards, the dried scaffolds underwent a wash in acetone (T.T.T; Sveta Nedelja, Croatia) to eliminate any potential genipin residues. These samples were labelled as CHT.

Chitosan/hydroxyapatite composite scaffolds were prepared as follows: initially, the chitosan solution was prepared as previously outlined, following, different mass fractions of hydroxyapatite were introduced (10 - 30% wt.) under vigorous stirring for 2 hours. Additional homogenization of the obtained suspension was achieved by using a Sonoplus (Germany) 400 ultrasonic probe (40% amplitude) for 3 min. Subsequently, genipin was added to crosslink the prepared composite suspension, following the earlier described method. The obtained composite scaffolds were denoted as HAp 10, HAp 20 and HAp 30 corresponding to the hydroxyapatite weight ratio in composite scaffold.

### 2.3 Composite Scaffolds Identification

The prepared materials were analysed using a Bruker Vertex 70 ATR-FTIR spectrometer (Massachusetts, USA) at a resolution of 2 cm<sup>-1</sup> in a spectral range of 4000 - 400 cm<sup>-1</sup> with 32 scans set at a temperature of 20 °C.

The mineralogical composition was identified by XRD analysis on a Shimadzu XRD 6000 device (Japan) with CuK<sub>a</sub> radiation at a voltage of 40 kV and a current of 30 mA. XRD patterns were obtained in step mode in the range of  $2\theta$  angles from 5 to 70 ° with a step of 0.02 ° and a step hold of 0.6 s. The average crystallite size of the prepared powder was calculated on the whole diffraction pattern using the DIFFRAC.SUITE TOPAS V.5.0 software (Bruker, Karlsruhe, Germany). Recommended physically sound crystallite value, volume weighted mean size calculated with the integral breadth-based calculation (Lvol-IB), was reported. The structure of Holly Springs HAp [30] was used as a starting model without the inclusion of  $CO_3^{2-}$  in the structure.

The microstructure of composite scaffolds was imaged by scanning electron microscope (SEM) TESCAN Vega3 SEM Easyprobe (Czech Republic) with an electron beam energy of 10 keV. An energy-dispersive X-ray (EDX) spectrometer (Bruker B-Quantax; Massachusetts, USA) connected to the SEM has been used to determine the elemental composition of the scaffolds. Prior to the SEM/EDX analysis, the samples were sputtered with gold and palladium for 90 s.

### 2.4 Swelling Behaviour

The swelling ability of the composite scaffolds was evaluated in Hanks' balanced salt solution (HBSS, pH 7.4) for 24 h at a constant temperature of 37 °C. After incubation time, samples were delicately collected and washed using demineralized water. The swelling degree (%) was expressed as a weight ratio of the absorbed medium and dry sample.

### 2.5 Rheological Properties

The storage and loss moduli of hydrogels were performed on a rheometer HR 30 Discovery Hybrid Rheometer (TA Instruments; Delaware, USA). Previously swollen samples were placed in parallel plate geometry (25 mm diameter and 1000  $\mu$ m gap) and then fixed with a preload force (0.7 N). All measurements were carried out at 37 °C. First, an amplitude sweep test carried out at a constant frequency of 0.2 Hz with a strain range from 0.01 to 100.0% was performed to determine the linear viscoelastic range.

#### 2.6 Statistics

The results are displayed as the mean values  $\pm$  standard deviation. To assess data differences, a two-way analysis of variance (ANOVA) was conducted, followed by a Tukey *post hoc* test. Any significant distinctions between groups were indicated with an asterisk (\*).

#### 3 RESULTS AND DISCUSSION 3.1 FTIR Analysis

Prepared composite scaffolds were identified using ATR-FTIR spectroscopy. As depicted in Fig. 1a, the crosslinked chitosan scaffold exhibited distinctive absorption bands: the region between 3360 and 3289 cm<sup>-1</sup> showed an overlap of bands, corresponding to the stretching vibrations of hydroxyl and amino groups, as well as their interactions through hydrogen bonding [31]. Additionally, two absorption bands at 2920 and 2863 cm<sup>-1</sup> were observed, which can be attributed to the symmetric and asymmetric stretching of C–H in the –CH<sub>2</sub> group. Further, there were two absorption bands at 1644 - 1641 cm<sup>-1</sup> and 1557 cm<sup>-1</sup> [32], which could be attributed to the stretching vibrations of the carbonvl group (amide I) and a combination of N-H and C-N stretching vibrations (amide II) [33]. These bands were a result of the crosslinking reaction between chitosan and genipin. The absorption band ranging from 1547 to 1542 cm<sup>-</sup> may be ascribed to the presence of the carboxylic group arising from chitosan acetate salt [34]. Additionally, the absorption bands at 1405, 1375, and 1315 cm<sup>-1</sup> can correspond to the bending vibrations of -CH<sub>2</sub> groups from the pyranose ring, as well as -CH<sub>3</sub> groups [35, 36], along with stretching vibrations of the C-N bond (amide III). Moreover, the band at 1150 cm<sup>-1</sup> corresponds to the asymmetric stretching of the C–O–C bridge [37]. Lastly, the absorption bands at 1061 and 1027 cm<sup>-1</sup> could correspond to the stretching vibrations of C-O-C and - COH bonds, originating from the crosslinking of chitosan with genipin [38-40].

# FTIR spectrum of prepared hydroxyapatite (Fig. 1b) shows characteristic absorption bands: the band overlap at 1021 cm<sup>-1</sup> is associated with symmetric $v_3$ -PO4<sup>3-</sup> bending, while two bands, observed at 600 and 560 cm<sup>-1</sup>, could be attributed to asymmetric $v_4$ -PO4<sup>3-</sup> bending [41]. Two absorption bands ranging from 3610 to 3000 cm<sup>-1</sup> and 1635 cm<sup>-1</sup> can be attributed to physically bound water [42]. Additionally, absorption bands at 1464, 1450, 1418, 880 and 873 cm<sup>-1</sup> were detected. According to previous studies [27, 43, 44], observed bands can be associated with carbonate groups incorporated in hydroxyapatite lattice. Generally, absorption bands at 1546, 1456 and 880 cm<sup>-1</sup> are assigned to $v_3$ and $v_2$ vibrations of the $-CO_3^{2-}$ group that occupies the position of hydroxyl ions, i.e. A-type substitution. On the

other hand, B-type substitution, where carbonate groups replace  $PO_4^{3-}$  sites, is usually indicated by the bands at 1465, 1413 and 873 cm<sup>-1</sup> [45] On the contrary, Ren et al. [46] reported on carbonate signature bands for A-type and B-type substitution. The authors concluded that bands at 1450, 1413 and 880 cm<sup>-1</sup> can be a result of carbonate adsorbed on the apatite crystal surface. Our FTIR results indicate carbonated hydroxyapatite with B-type substitution.

FTIR spectra of CHT/HAp scaffolds (Fig. 1) show the superposition of the chitosan-genipin matrix and HAp spectra; however, some bands are difficult to observe due to band overlap. Furthermore, slight changes in FTIR spectra can be observed with the addition of hydroxyapatite into the chitosan-genipin matrix (Tab. 1). In the composite spectra, a subtle shift in the absorption bands related to phosphate groups can be found, along with a reduction in the intensity of the band corresponding to the C–O–C bond of chitosan. According to El-Sayed et al., [47] such shifts in absorption bands may be attributed to CHT/HAp interaction between chitosan functional groups and phosphate groups of HAp.

Table 1 FTIR absorption bands characteristic of hydroxyapatite.

	Wavenumber, cm <sup>-1</sup>		
Sample	$v_3 - PO_4^{3-}$	$v_4 - PO_4^{3-}$	
CHT	/	/	
НАр	1025	600, 560	
HAp 10	1020	600, 564	
HAp 20	1021	601, 564	
HAp 30	1020	602, 563	

Furthermore, a decrease in the intensity of absorption band at  $1063 \text{ cm}^{-1}$  could be attributed to the limiting vibrational space for C–O–C bond as a result of HAp modification [21, 48, 49].



Figure 1 FTIR spectra of (a) chitosan and composite scaffolds; (b) pure hydroxyapatite; detailed view of the (c) 1600-1300 cm<sup>-1</sup> and (d) 900-850 cm<sup>-1</sup> FTIR spectra.

#### 3.2 XRD analysis

XRD pattern of synthesized hydroxyapatite is shown in Fig. 2a. For comparison, ICDD data of hydroxyapatite (ICDD 09-432) is given in Fig. 2b. Diffraction maxima at  $2\theta \sim 25.8^{\circ}$ , 28.3°, 32°, 39.6°, 46.6°, 49.4°, 53.2°, 64° corresponding to (002), (200), (211), (310), (222), (213),

(004), (304) reflections of hydroxyapatite confirmed the successful synthesis of HAp through the precipitation method. Moreover, wider diffraction maxima indicated hydroxyapatite of nanometric crystallites with size estimated by Scherrer approximation. The average crystallite size (Lvol-IB) of the prepared powder is  $4.9 \pm 2.9$  nm. It has been reported that nanosized HAp exhibit improved bioresorption *in vitro* and *in vivo* [50, 51].

XRD patterns of composite scaffolds are shown in Fig. 3a. A broad diffraction maximum was detected at  $2\theta \approx 21.2^{\circ}$  which corresponds to the crosslinked chitosan matrix. The addition of HAp into the chitosan matrix resulted in two observable diffraction maxima at  $2\theta \approx 25.8^{\circ}$  (002) and  $32^{\circ}$  (211) which correspond to the strongest diffraction maxima of HAp [9, 42]. The diffraction maxima at  $2\theta \approx 39.6^{\circ}$  (310), 46.6° (222), 49.4° (213) and 53.2° (004) can also be observed. The presence of HAp diffraction maxima when compared to the diffraction maxima of pure hydroxyapatite (Fig. 3b) indicates the successful incorporation of HAp into the polymeric matrix at a higher HAp weight ratio.





#### 3.3 Scaffold Microstructure and Elemental Analysis

The microstructure of the obtained composite scaffolds exhibits a high porosity, characterized by interconnected and irregular pores, as depicted in Fig. 4.



Figure 4 SEM micrographs and EDX spectra of CHT (a, b); HAp 10 (c, d); HAp 20 (e, f); HAp 30 (g, h) scaffold. Scale bar on SEM micrographs: 200 µm and 1 mm.

The crosslinking process is mostly used in order to enhance properties such as stiffness to ensure improved cell adhesion, proliferation and diffusion of nutrients [23, 52]. In this work, genipin was used to produce scaffolds that would be stable under physiological conditions. The samples were first subjected to the process of thermally induced phase separation (TIPS), where a homogeneous polymer solution was frozen, thus creating a multi-phase system with polymerrich phase and solvent [53]. Next, the system was subjected to the freeze-drying process where nucleated ice crystals from the polymer/solvent system sublimate, thus leaving pores. This process facilitates the formation of a favourable macroporous structure with interconnected porosity, and pore sizes of up to 200 µm, as observed in the crosslinked chitosan scaffold. The addition of hydroxyapatite resulted in the formation of irregular pores of different sizes up to 1 mm. The XRD analysis indicated nanocrystalline hydroxyapatite;

however, nanosized crystals tend to agglomerate forming micrometric particles. Nevertheless, good distribution of HAp agglomerates within the chitosan matrix is observable, especially for composite scaffold with 30% of HAp.

The highly porous nature of the obtained scaffolds is favourable for unhindered resorption of HAp. The composite scaffolds serve as a support during tissue restoration, where porosity, along with pore size, plays a key role in neotissue growth. According to Yang et al., [54] the ideal pore size for cell proliferation and migration falls within the range of 100 to 200 µm; thus, the obtained scaffolds exhibit a microstructure suitable for cell adhesion and tissue growth. Moreover, Oliveira et al. [14] conducted research that shows how the incorporation of hydroxyapatite into composite scaffolds can increase their intractability with bone tissue cells, specifically goat marrow stromal cells (GBMC), by creating a surface substrate through the apatite layer. This substrate facilitates the adhesion of bone tissue cells to the scaffold, thus initiating the process of proliferation and differentiation [55].

The atomic composition of the obtained composite scaffolds was analysed using energy-dispersive X-ray analysis. As seen in Fig. 4. EDX spectra of cross-linked chitosan scaffolds confirm the presence of carbon and oxygen originating from crosslinked chitosan. The EDX spectra of the composite scaffolds indicated the presence of phosphorus at 2.02 keV and calcium at 3.7 keV indicating the presence of CaP phase within the scaffolds, which was identified as hydroxyapatite by XRD analysis.

#### 3.4 Swelling Behaviour

The swelling ratio of the obtained scaffolds was assessed after a 24-hour incubation period in the HBSS buffer, as depicted in Fig. 5. All systems exhibit a high swelling capacity (above 2000%) which could be associated with the hydrophilic hydrogel nature of chitosan and the high porosity of the scaffolds. Although all samples show high swelling values, the addition of hydroxyapatite lowers the swelling capacity of chitosan, especially with an increase in HAp content.



Figure 5 Swelling capacity of chitosan and composite scaffolds in HBSS buffer (pH = 7.4). The significant difference between the two groups is denoted by an asterisk (\*) with p < 0.05.

According to Ying et al. [56] the decrease can be attributed to a collapse of pores caused by HAp particles. Since such an effect on the microstructure was not observed on SEM micrographs, an effect described by Hu et al. [57] seems to be more likely. They proved that the swelling capacity of chitosan/HAp composites was reduced compared to chitosan due to the formation of a temporary HAp barrier that prevents water from permeating into the chitosan matrix. Furthermore, according to Gupta et al. [58], prolonged exposure of chitosan-based scaffolds to such buffers may result in further degradation of the scaffolds, allowing for an increase in pore size, larger voids between pores and swelling capability. Such a phenomenon may be diminished by the addition of HAp into the polymeric matrix, which has been reported by Tang et al. [59], where a decrease in degradation of the composite can be observed with an increase of HAp content.

The swelling behaviour of scaffolds plays a crucial role in tissue regeneration, allowing for the adsorption and retention of nutrients which in turn creates a cell-nourishing environment capable of sustaining and accelerating cellular regeneration and growth [16, 17].

### 3.5 Rheological Properties

Polymer hydrogels consist of a polymer network, which can absorb and retain water to form a gel-like structure [60]. The formation is achieved through the process of crosslinking, which results in the formation of a three-dimensional network capable of absorbing and retaining a substantial amount of water or biological fluids (higher than 20%) without disintegration [22, 61].

The existence of cross-links between polymer chains can affect the physical properties of the polymer, depending on the degree of cross-linking and crystallinity. Polymer hydrogels can be divided into two categories, based on the type of crosslinking. "Weak gels" are formed through physical crosslinking, i.e. a crosslinking network obtained through non-covalent interactions, including hydrogen bonding, electrostatic interactions, or van der Waals forces [62–64]. In contrast, chemical crosslinking generates "strong gels" involving the formation of a covalent bond between polymer chains [24, 65]. While physically cross-linked hydrogels are relatively weak and have a reversible swelling capacity, chemical crosslinking results in hydrogels that are stronger and more stable, but typically have less swelling capacity [61]. When it comes to rheological properties (shear modulus), physical and chemical cross-linked hydrogels also display different behaviours. Shear modulus is a measure of the hydrogel's ability to resist deformation under shear stress. Physical hydrogels, with a reversible cross-linking network compared to chemical cross-linking [66], typically exhibit a lower storage modulus (G', representing the hydrogel's resistance to elastic deformation) and a lower loss modulus (G", representing the hydrogel's resistance to viscous flow). In contrast, chemical hydrogels, with a more rigid and irreversible cross-linking network, exhibit a higher G' and a higher G", indicating a more solid-like behaviour [24, 61, 67, 68].

To determine the rheological properties of the obtained composite scaffolds, first, an amplitude sweep test was used to determine the linear viscoelastic region where shear moduli were independent of oscillatory strain (Fig. 6). As observed, all scaffolds exhibit substantial linear viscoelastic regions (above 20 %) which according to Ross-Murphy et al. [24] is indication of "strong gels" formed by covalent crosslinking agent (genipin) [69]. Furthermore, at strains above 20 % storage modulus starts to decrease ending with an intersection of G' and G" lines, indicating a possible collapse of the hydrogel structure. Following the determination of the linear viscoelastic region, the hydrogel storage and loss moduli were evaluated as a function of angular frequency, where the samples were subject to an increasing shear frequency. In comparison to cross-linked chitosan scaffolds, the composite scaffolds (with an exception for HAp 20) show an increase in both storage and loss moduli (Fig. 7) indicating a possible reinforcement of chitosan matrix by HAp particles.



Figure 6 Strain sweep test of composite scaffolds after 24 h of immersion in PBS at a frequency of 0.2 Hz. The *G*' and *G*" curves represent the average values of five measurements.

Similar findings have been reported by Demirtas et al. [70] and Ramay et al. [71] on bioprintable chitosan/ hydroxyapatite bio-ink and load-bearing scaffolds for bone regeneration, where a small increase in storage and loss moduli with an increase of hydroxyapatite weight fraction was observed. A significant difference between G' and G" was observed with a ratio G''/G' < 1, additionally confirming the "strong gel" nature of the obtained composite scaffolds [24, 25, 69]. No significant change has been noted in the loss factor value (Tab. 2), indicating no change in the elastic behaviour with HAp addition. Besides composition, swelling capacity and microstructure also affect hydrogels' mechanical properties. As shown, the addition of hydroxyapatite has decreased swelling capacity and caused alteration in pore size and shape which could have an additional effect on improved mechanical properties of composites.

Table 2 Storage modulus (G'), loss modulus (G'') and loss (damping) factor (tanδ) values for composite scaffolds obtained by frequency sweep.

values for composite scarfolds obtained by frequency sweep.						
Sample	Storage modulus Pa	Loss modulus Pa	$\tan \delta$			
CHT	$412.83 \pm 31.77$	$18.56\pm2.34$	$0.04\pm0.003$			
HAp 10	$658.72 \pm 182.82$	$37.18\pm 8.89$	$0.05\pm0.005$			
HAp 20	$495.35 \pm 103.88$	$27.62\pm6.16$	$0.05\pm0.010$			
HAp 30	$672.48 \pm 195.42$	$31.07\pm5.20$	$0.05\pm0.007$			
10000						
1000	– Storage modulus CHT – <del>×</del> L	oss modulus CHT	а			
100	********	<del>: * * * * * * * * * * * * * *</del>	**************************************			
10	****	<del>*************</del>	*********			
1						
	0,1 1	10	100			
10000	– Storage modulus HAp 10 – 💥	- Loss modulus HAp 10	b			
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	– Storage modulus HAp 20 –¥	- Loss modulus HAp 20				
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100	***	<del>·                                    </del>	***			
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1 +						
10000	0,1 1	10	100			
Storage modulus HAp 30 <u>— Loss modulus HAp 30</u>						
100	<u> </u>					
10	<del>***********</del> ***	<del>; * * * * * * * * * * * * * * * * * * *</del>	***********			
1						
	0,1 1	10	100			
Angular frequency (rad/s)						

Figure 7 Frequency sweep test of composite scaffolds after 24 h of immersion in PBS at a constant strain of 1%. The G' and G" curves represent the average values of five measurements.

#### 4 CONCLUSION

This work focuses on the synthesis of porous 3D composite scaffolds with improved bioactivity and mechanical properties through modification with bioactive ceramics, hydroxyapatite. The successful synthesis of hydroxyapatite via the precipitation method and HAp incorporation into the chitosan matrix was indicated by XRD, FTIR and EDX analysis. SEM imaging of scaffold morphology indicated the presence of a favourable porous structure with interconnected porosity which combined with the presence of HAp, could act as a good support for cell proliferation and differentiation. The addition of HAp also influenced the swelling properties of the obtained composites, where a decrease in swelling capacity can be observed with an increase in HAp content. Furthermore, rheological characterization indicated a formation of "strong gel" with a slight increase in storage and loss moduli of the composite scaffolds. No significant change in relation to loss factor value indicated no change in viscoelastic behaviour with HAp presence. Such results may indicate a possible slight improvement in the mechanical properties of the composites compared to chitosan scaffolds. Further studies on cytotoxicity will be performed to validate the potential of obtained scaffolds for application in bone tissue regeneration.

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# Thermal Analysis of the Biodegradable Polymer PVA/PEO Blends

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Abstract: Poly(vinyl alcohol) (PVA) and poly(ethylene) oxide (PEO) are widely used water-soluble and biodegradable polymers that possesses high biocompatibility. In this work PVA/PEO blends were prepared via solution casting method, where the solvent was water. After drying, samples were characterized by differential scanning calorimetry (DSC) and thermogravimetric analysis (TG). Since DSC could not confirm the possible intermolecular interaction between PVA and PEO, infrared spectroscopy with Fourier transform (FT-IR) was utilized. Finally, the TG analysis revealed that degradation of PVA/PEO blends proceeds through tree stages, similar as neat PVA. Contrary, neat PEO thermally degrade through only one stage showing better thermal stability in comparison to PVA.

Keywords: polyethylene oxide; polymer blends; polyvinyl alcohol; thermal analysis

#### **1** INTRODUCTION

Poly(vinyl alcohol) (PVA) is a polar polymer with multihydroxyl groups which shows generally good mechanical and thermal properties. It also poses favourable biocompatibility and excellent barrier properties. Hence, PVA is an ideal material for tissue engineering applications, such as bone, cartilage, and the aortic heart valve [1]. Likewise, it can be synthesized from nonpetroleum raw material, which is important in the situation of petroleum scarcity. Thanks to its low cost, good film forming, high solubility in water, non-toxicity, easily process able, high dielectric permittivity and great insulating properties, PVA has been widely used in many different industries, like packaging, textiles, paints, building materials, electronic products, automotive, medicine, and other [2, 3]. On the other hand, poly (ethylene oxide) (PEO) is a semi-crystalline, water-soluble and biocompatible polymer of considerable industrial significance. It is utilized in organic-inorganic hybrid material in the field of functional coatings with superior barrier properties [1].

During the past few decades, numerous investigations have been carried out in order to develop blends of biodegradable polymers with good thermo-mechanical properties. The blending of two or more polymers is one possible approach for designing material with desired structural, thermal and mechanical properties. By this approach it is possible to tailor specific property to the requirement of applications, which cannot be achieved by one polymer alone. The investigations about electrical, optical, structural, thermal and degradation behaviour of the PVA/PEO systems have been performed [1-8]. However, most of authors focused on the interaction between PVA and poly(ethylene glycole) (PEG) [1, 6-8]. PEG refers to an oligomer and due to its molecular weight below 20,000, it has mostly been used as plasticizer in the PVA systems. Besides the obvious differences in molecular weight, PEG and PEO have similar physical properties, while contrary; their chemical properties are practically congruent.

Hence, the obvious aim of this investigation was threefold. Firstly, to prepare biodegradable polymer PVA/PEO blends via solution casting technique, in this case by using the PEO of higher molecular weight, which should result in compact biodegradable material, which can be, used as starting material for future investigations. The second aim was to evaluate structural properties and possible intermolecular interaction between PVA and PEO of higher molecular weight. Finally, the third aim of this work was to determine how PEO, as polymer of higher molecular weight, affected the thermal and degradation behaviour of the PVA in the blend and vice versa.

#### 2 EXPERIMENTAL PART

#### 2.1 Materials, Preparation and Methods

Materials used in this work were as follows: poly(vinyl alcohol) (PVA) 22,000 gmol<sup>-1</sup>, BDH Prolabo, UK; poly(ethylene oxide) (PEO), 100,000 gmol<sup>-1</sup>, Sigma-Aldrich, Inc., St. Louis, USA; deionized water.

Water-soluble polymers, PVA and PEO, were separately dissolved in deionized water and then mixed in different ratio (PVA/PEO = 100/0, 70/30, 50/50, 30/70 and 0/100). In order to completely dissolve and blend, the polymer blends were mixed at 400 rpm for two days at 40 °C. Next, each blend was poured into a Petri dish and dried two days at room temperature. The residual water was removed by drying obtained films in an oven for seven days at 40 °C.

Thermal characteristics of the PVA/PEO blend films were analysed via differential scanning calorimetry (Mettler Toledo DSC 823<sup>e</sup>) in a nitrogen atmosphere (30 cm<sup>3</sup>min<sup>-1</sup>). Samples (15 mg) were heated (20 °C min<sup>-1</sup>) from -90 to 280 °C, cooled at the same rate to -90 °C, and reheated to 280 °C. At -90 and 280 °C samples were isothermally for 5 minutes. The glass transition temperature  $(T_g)$  was determined from the second heating cycle according to international standard ISO 11357-2 [9] as the extrapolated onset temperature ( $T_{eig}$ ), as midpoint temperature  $(T_{mg})$ , and as the extrapolated end temperature  $(T_{efg})$ . The corresponding change of the specific heat capacity  $(\Delta c_p)$  was determined as well. The melting and crystallization temperatures, as well as the enthalpies of melting and crystallization ( $\Delta H_{\rm m}$  and  $\Delta H_{\rm c}$ ) were designated by ISO 11357-3 [10]. The melting/crystallization temperatures  $(T_m/T_c)$ : the extrapolated onset temperature  $(T_{\rm eim/c})$ , peak temperature  $(T_{\rm pm/c})$  and the extrapolated end temperature ( $T_{\rm efm/c}$ ). Detail info can be found in literature [11].

Thermogravimetric measurements of the PVA/PEO film samples were performed with PerkinElmer TGA 8000 in nitrogen atmosphere (40 cm<sup>3</sup>min<sup>-1</sup>). Samples (5 mg) were heated (10 °C min<sup>-1</sup>) in a temperature range 30-600 °C. To evaluate the thermal stability of the investigated polymers and their blends different criteria can be used. From TG and DTG curves the following characteristics were determined: the onset temperature ( $T_{onset}$ ), the temperature at 5% mass loss ( $T_{5\%}$ ), the temperature at the maximum degradation rate ( $T_{max}$ ), the maximum degradation rate ( $R_{max}$ ), the final mass ( $m_f$ ) and the mass loss ( $\Delta m$ ) for the corresponding degradation steps. Detail info can be found in literature [12].

Fourier transform infrared spectroscopy (FT-IR) spectra were obtained with Perkin Elmer Spectrum Two FT-IR spectrometer via Universal Attenuated Total Reflectance (UATR) technique with diamond reflection crystal.

#### 3 RESULTS AND DISCUSSION 3.1 Differential Scanning Calorimetry

Figs. 1-2 shows compared normalized DSC curves of the investigated PVA/PEO films, while the DSC parameters are tabulated in Tab.1; values in red for the PVA and in blue for PEO, respectively. The PVA is characterized by glass transition temperature at 74 °C ( $T_{\rm mg}$ ), with the endotherm of melting starting at 199 °C and exothermic peak of crystallization at 192 °C ( $T_{\rm eic}$ ). Likewise, the PEO curve is also characterized by one glass transition at -47 °C ( $T_{\rm mg}$ ), one melting endotherm at 59 °C ( $T_{\rm eim}$ ) and one exothermic peak at 43 °C ( $T_{\rm eic}$ ).



The DSC heating curves (second heating) of PVA/PEO blends show two endothermic peaks (Fig. 1), which is correlated to the melting of the PVA and PEO, respectively. The addition of PEO or PVA to the blends decreased values of the melting enthalpies of the PVA or PEO, respectively, but the shape of endothermic peaks remained almost identical as for neat polymers. The same trend is visible for the corresponding enthalpy of crystallization for the PVA and PEO, respectively, were also two exothermic peaks could be noticed (Fig. 2). However, upon addition of the PEO, the endothermic and exothermic curves of PVA shifted toward higher temperature in total by 4 ( $T_{eim}$ ) and 3 °C ( $T_{eic}$ ), respectively. On the other hand, by increasing PVA content, the melting temperature of the PEO decreased in total by 2 °C ( $T_{eim}$ ), while the corresponding crystallization temperature increased in total by 2 °C ( $T_{eic}$ ).



The  $T_g$  transition of the PVA in the films is close to the melting endotherm of PEO, and therefore not detectable on DSC curves. Likewise, due to the high crystallinity of PEO, it is also difficult to observe the  $T_g$  of PEO. However, for sample with 50% of PVA content, the corresponding PEOs temperature increased toward  $T_g$  of PVA by 12 °C. Finally, the values of PEO's  $\Delta c_p$  decreased upon PVA addition, Tab. 1. It is evident that in the investigated PVA/PEO system possible interactions exist. Some clues could be found in the literature [1-8].

Parameter				PVA/PEO		
		100/0	<b>70/30</b>	<b>50</b> /50	30/70	<mark>0</mark> /100
Т <sub>g</sub> (°С)	T <sub>eig</sub>	67	_/_	-/-55	<del>-</del> /—57	-54
	T <sub>mg</sub>	74	_/_	<b>-</b> /-35	<b>-</b> / <b>-</b> 51	-47
	T <sub>efg</sub>	83	_/_	-/45	-/46	-43
$\Delta c_{\rm p} ({\rm J} {\rm g}^{-1}$	°C <sup>-1</sup> )	0.31	-/-	-/0.10	-/0.13	0.14
<i>T</i> <sub>m</sub> (°C)	$T_{eim}$	199	199/57	201/58	203/59	59
	$T_{\rm pm}$	213	213/62	215/64	215/65	66
	$T_{\rm efm}$	222	220/66	223/75	221/71	83
$\Delta H_{\rm m}({\rm J}_{\rm S})$	g <sup>-1</sup> )	45.6	55.9/8.5	24.7/65.6	12.8/98.5	134.2
<i>T</i> <sub>c</sub> (°C)	$T_{eic}$	192	192/45	195/44	195/44	43
	$T_{\rm pc}$	186	186/39	188/40	190/41	39
	$T_{\rm efc}$	174	175/33	178/32	181/34	28
$-\Delta H_{\rm c}$ (J	g <sup>-1</sup> )	42.8	48.5/6.2	26.6/65.3	14.3/95.7	126.7

Table 1 DSC transition parameters of the PVA/PEO blends

Ping et al. [1] investigated the porous PVA/PEG blend scaffold prepared through thermoplastic foaming using scCO<sub>2</sub> as the physical blowing agent. They used DSC to investigate the PEG effect on the thermal properties of PVA. According to the authors, with the addition of PEG, the melting peaks of PVA/PEG composites gradually shifted to a lower temperature, which they attributed to the hydrogen bonding of PVA-PEG. Likewise, authors concluded that PEG disturbed the molecular chain arrangement of PVA and interfered its crystallization.

In order to develop membranes, Gupta et al. [5] studied blends of PVA and PEO (300 000 gmol-1) prepared by solution casting method (water) with different concentrations of carboxymethyl cellulose (CMC). Authors observed interactions in the investigated system and attributed them to the formation of hydrogen bonds. Although the DSC analysis showed decrease in crystallinity and the depression of melting temperature upon addition of CMC, latter authors did not investigate effect of PEO addition on the thermal properties of PVA, and vice versa. Falqi at al. [7] prepared PVA/PEG/graphene nanocomposites via solution casting technique. By utilizing DSC, they concluded that the  $T_{\rm m}$  of PVA was not affected by PEG. However, upon addition of PEG, latter authors noticed a decrease in crystallinity, which was a result of the H-bonding between PEG and PVA. Likewise, they observed a decrease of  $T_g$  of the PVA/PEG blends, revealing PEG as plasticizer.

Summary, the noticed interaction between PVA and PEO(PEG) is evidently the product of hydrogen bond established between –OH from PVA and –O– from PEO. In order to confirm DSC results gained in this work, FT-IR analysis was used.

#### 3.2 Fourier Transform Infrared Spectroscopy

The corresponding FT-IR spectra are presented on Fig. 3. PVA shows characteristic wide band of hydroxyl stretching assigned to the bonded hydroxyl in crystalline phase. As the PEO content increased in the blends, this band shifted to the higher wavenumbers  $(3271 \rightarrow 3285 \text{ cm}^{-1})$ . The particular characteristic of the PVA is formation of the hydrogen bonds (inter- and intra-molecular) between its OH groups, while in the PVA/PEO blends additional hydrogen bonds can be formed between the OH groups from PVA and PEO chains [1].



Figure 3 Comparison of the FT-IR spectra of the PVA/PEO blends

In addition, at higher PEO loadings above 50%, this band is preserved. Therefore, noticed slight shift of peak position and intensity of the -OH stretching vibration for all PVA/PEO blends, can be assigned to the hydrogen bonding [8]. The peaks between 1731 - 1715 cm<sup>-1</sup> are due to the stretching of the C = O and C-O from acetate group remaining from partially hydrolyzed PVA [6, 13]. It is clearly visible that by increasing the content of the PEO, the intensity of the absorption bands decreased. Likewise, the band at 1731 cm<sup>-1</sup> changes its shape from peak like to the shoulder like, while retaining its position. According to the Mansur et al. [13] the peak at 1143 cm<sup>-1</sup> is related to the symmetric C-C stretching mode or stretching of the C-O where an intramolecular hydrogen bond is formed between two neighbouring OH groups. The intensity of this peak is influenced by the crystalline portion of the polymeric chains [13]. Increasing the PVA content in the blends, the peak position and intensity remained unchanged. This is in accordance with the result of the DSC analysis where the corresponding crystallization temperature of the PVA in the blends changed by only 2 °C in total ( $T_{eic}$ ). In the range of 1000–1300 cm<sup>-1</sup>, the crystalline phase of PEO is featured by the symmetrical stretching of the C-O-C group ("triplet") [14]. In the same spectral range, there is clearly visible peak at 1088 cm<sup>-1</sup>, which can be assigned to the C-O-C stretching in the neat PVA [2]. Any alteration of intensity, shape or position of the "triplet" can be linked to the PEO-PVA interaction. However, the "triplet" isn't affected by PVA. Likewise, no change of the two peaks at 1145 and 1060 cm<sup>-1</sup> is noted, and therefore PVA doesn't have impact on PEO crystallinity. This is in direct correlation with the conclusions made by DSC analysis, where it is evident that PVA did not affect crystallization process of the PEO in the blends.

#### 3.3 Thermogravimetric Analysis

The Fig. 4 present TG and DTG curves of the investigated blends. Thermal degradation of PVA unfold through three degradation stages, Fig. 4(b), and begins at 78 °C ( $T_{onset1}$ ) with a peak temperature at 105 °C ( $T_{max1}$ ), representing the elimination of trapped water molecules. In the second stage at 265 °C ( $T_{onset2}$ ) hydroxyl groups from PVA are eliminated. Finally, for the third stage at approximately 421 °C ( $T_{onset3}$ ) a conjugated structure is formed from the product of the second stage of degradation [15, 16]. On the other hand, PEO decomposes by only a single degradation stage, beginning at 379 °C ( $T_{onset}$ ) with  $T_{max}$  at 401 °C. It is evident that PEO, in comparison to PVA,

is thermally more stable. PEO degradation proceeds by the random chain scission of C-O bonds [17] with the total weight loss of 95.4%. Although thermal degradation of the PEO proceeds through one stage, according to temperature range (\*) its characteristics belong to the third degradation stage; Tab. 2. However, thermal degradation of all PVA/PEO blends, as well as PVA, proceeds through three stages (Fig. 4). The first two stages can be associated to the PVA, while the last one match the PEO degradation temperature domain.



Figure 4 Comparison of the TG (a) and DTG (b) curves of the thermal degradation of the PVA/PEO blends

PVA/PEO	T <sub>onset</sub> / <sup>o</sup> C	$T_{max} / C$	$R_{max} / \%min^{-1}$	$\Delta m / \%$	$m_{\rm f}$ / %	
1° degradation stage						
100/0	78	105	0.9	4,4	95,6	
70/30	72	104	0.8	0,6	95,1	
50/50	41	69	0.2	1,4	98,6	
30/70	52	77	0.3	1,4	98,6	
0/100	-	-	-	-	-	
		2° degrada	ation stage			
100/0	265	289	20,7	76,7	18,9	
70/30	269	295	13,4	71,2	23,9	
50/50	241	274	3,8	19,1	79,5	
30/70	288	310	5,1	24,5	74,1	
0/100	-	-	-	-	-	
3° degradation stage						
100/0	421	455	2,4	12,5	6,4	
70/30	400	416	16,8	17,4	6,5	
50/50	389	412	22,1	73,3	6,2	
30/70	396	415	21,2	68,6	5,5	
0/100*	379	401	26,6	95,4	4,6	

Table 2 Thermal degradation parameters of PVA/PEO blends

In the first stage, PVA/PEO blends start thermally degrading at lower temperatures in comparison to PVA. However, in the second stage, the trend is miscellaneous and

the blend composed of the 50% of PVA and 50% of PEO showed the lowest thermal stability characteristics. On the other hand, blend with 70% of PEO exhibited the highest values, confirming PEOs stabilizing effect on PVA.

Similarly, Ghalia and Dahman [8] attributed higher thermal stability to the sufficient cross-linkage and interaction between PVA and PEG. Likewise, this shifting in the second stage to the higher degradation temperatures for the blend 70/30, Hameed [18] attributed to the good compatibility of PVA and PEO, resulting in improved thermal stability of polymer blends. Finally, in the third stage, alteration of values of  $T_{\text{onset}}$  and  $T_{\text{max}}$  for all blends are minor and practically negligible.

#### 4 CONCLUSIONS

In this work biodegradable polymer PVA/PEO blends were prepared via solution casting technique. The main scope was to estimate thermal and degradation behaviour of the investigated blends, as well as possible intermolecular interaction between PVA and PEO. The minor extenuation of melting and crystallization temperatures at increased PEO content (70%) indicated the existence of mild interaction between PVA and PEO as a product of hydrogen bonding. Likewise, the slight shift of the -OH stretching vibration for all PVA/PEO blends, confirmed hydrogen bonding formation between PVA and PEO. Thermogravimetric analysis revealed that PEO is more thermally stabile than PVA. Hence, shifting of the characteristic degradation temperatures in the second stage to the higher values for the blend with 70% of PEO is the result of the good compatibility of PVA and PEO, which resulted in improved thermal stability of polymer blends. Finally, this investigation presents a valuable input for the future research in which another method of blend preparation should be considered, and consequently the application of such gained blends propounded.

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# Developing a Framework for the Integration of Artificial Intelligence in Technology Education: Enhancing Learning and Innovation

#### Mika Lim

Abstract: This study aimed to create a foundation for the integration of AI in technology education. The framework of this study was based on the important problem-solving learning process in technology education. The developed framework structures the problem-solving steps of such types of problems into problem solving, design, development, and evaluation. Each technological problem and problem-solving step area can be implemented using Intelligent Tutoring System (ITS), Dialogue-Based Tutoring System (DBTS), and Exploratory Learning Environment (ELE) of AI convergence education. Technology education supports learners develop Technological knowledge and develop critical and creative thinking when attempting to resolve real-life technological glicthes. Since the process of solving technological problems is complex in itself, it was necessary to categorize technological problems in real life and organize the procedure for resolving technical issues into a series for formal education in schools. In this process of technological problems solving learning, explicit knowledge may be necessary, and interpretive or procedural knowledge may be necessary. Methods of utilizing AI convergence education vary depending on the target knowledge. Therefore, structuring and presenting a plan to apply various AI convergence educations to the process of solving highly complex technological problems is meaningful in that it suggests the basis for educational direction. Based on the framework developed in this study, expected that AI convergence education methods appropriate for each problem-solving process of various technological problems will be systematically researched and implemented in the future.

Keywords: AI; AI convergence education; framework; technology education

#### **1** INTRODUCTION

The term "industrial revolution" refers to the revolutionary shift in the way people live brought about by a computerized labor force or knowledge. The 4<sup>th</sup> Industrial Revolution, which is currently characterized by big data, virtual reality, IoT, and other innovations that describe an intelligent information society, is led by artificial intelligence [1]. AI is the capacity of electronic devices or robots to exhibit or mimic cognitive behavior, according to the Oxford English Dictionary [2]. All throughout the world, both private and public organizations are getting ready for and offering AI training programs. A non-profit group in the US called AI4AL (AI for ALL) maintains that all citizens ought to have access to artificial intelligence learning opportunities in order to address social problems. Since studies on AI and learning are still in its infancy, there are still numerous areas in which concepts and terminology lack clarity. AI was categorized as either "education about AI" or "education using AI. [1] " By enabling education beyond the constraints of time and geography, AI convergence learning is anticipated to be capable to accomplish qualitative as well as quantitative extension of learning. The development of tailored training that takes into account the unique qualities of each student will be one of the biggest modifications among them. But as research on AI education is still in its infancy, more needs to be done in the area of instruction in technology as well as other subject areas. In 2019, Holmes, Bialik, and Fadel presented the Intelligent Tutoring System (ITS), Dialogue-Based Tutoring System (DBTS), and exploratory learning environment (ELE) as part of the AI in Education (AIED) system [3]. The development of tailored training that takes into account the unique qualities of each student will be one of the biggest modifications among all. Study on individuality and confluence of artificial intelligence in the field of technology education is still scarce, nevertheless.

In the future, using artificial intelligence in the classroom will grow into a necessary educational practice. As a result, research on AI convergence education is ongoing throughout the educational spectrum. Kim, Oh, and Kim [4] examined how unplugged instruction improved third-grade elementary school students' computational abilities by analyzing algorithm execution times. Han investigated how voicebased AI chatbots affected the language proficiency of Korean EFL middle school students as well as the associated behavioral domains of opinion, motivation, level of interest, and felt worry [5]. In contrast to other disciplines, artificial intelligence technology in technology education, according to [1], has a somewhat more unique connotation. Possessing "technological literacy," which is defined as "technological understanding, abilities, and mindsets that improve adaptation to a changing technical society," is one of the objectives of technological education. According to [1], there is a striking similarity between the approaches and substance of technological literacy and artificial intelligence literacy, as well as the techniques and procedures involved in problemsolving. According to [6], in order to employ teaching approaches effectively, teachers need create a teachinglearning strategy. Thus, the study aimed to create a structure that could be applied in technology-related subject areas and serve as the foundation for AI convergence in technology learning.

#### 2 LITERATURE REVIEW

#### 2.1 Individualized Instruction and AI Convergence

When comparing AI convergence education to current educational practices, the following traits stand out: convergence, awareness, relationship, and understanding. Artificial intelligence is a path toward the development of students' personalized education, with practical teaching and practical individualization being achievable [7]. Shin and Shin [8] proposed automation, customization, growth, and

collaboration as key components of AI-based science education methodologies. Automation refers to AI's ability to continually manage and analyze every pupil's data over a period of time; individualization refers to AI's ability to personalized each student with learning supply recommendations based on their level; and diversity refers to the provision of each student with a unique curriculum and textbook. Furthermore, cooperation entails fostering a complex framework of cooperation among communities and schools. After determining whether the subject matter had a prior idea for the learning concept, Wu, Kuo, and Wang [9] gave the lesson's contents. Fig. 1 displays the AI convergence teaching algorithm developed by Wongwatkit, Srisawasdi, and Hwang [10].



Figure 1 The personalized web learning system's process, which is based on formative evaluation and individualized information

AI convergence learning liberated learning and instruction from the confines of location and time by rejecting the conventional classroom teaching structure. As a result, it will be important to actively look into strategies to reflect student characteristics relevant to the subject matter and area in future AI convergence education.

#### 2.2 Education of Artificial Intelligence

The Computer Science Teachers Association (CSTA) in the United States formed the Association for the Advancement of Artificial Intelligence (AAAI) with several research institutes and developed artificial intelligence for elementary and middle school students (K-12). AI4K12 (AI for K-12), an intelligence learning standard, presenting educational content and curriculum standards and promoting the development of educational programs. AAAI presented five major concepts for teaching artificial intelligence and the

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content that should be covered by each grade in each idea [11]. The five big ideas for artificial intelligence education are AI recognition methods, AI expression and reasoning, AI learning, AI natural interaction, and AI social impact. Through the report 'AI in the UK?', the UK stated that all youngsters should have a basic awareness of artificial intelligence, as well as the ethical considerations involved in using this technology [12]. Finland has created a curriculum called 'Elements of AI' to develop a free online course for basic education in artificial intelligence and aims to strengthen the digital leadership of the European Union (EU) [13]. China is currently making intensive investments and efforts in computer education, focusing on artificial intelligence education. Accordingly, the next-generation artificial intelligence development plan was announced in 2017, suggesting the need for artificial intelligence education, and in 2018, a textbook called 'Basics of artificial intelligence' was developed and an artificial intelligence education pilot school was established for 40 high schools nationwide. It is in operation [13]. In Korea, information subjects were designated as mandatory subjects in the 2015 revised curriculum, and the content of artificial intelligence is being covered for middle school students. The Korea Foundation for the Advancement of Science and Creativity presented the goals and contents of artificial intelligence education in 'Development of a Next-Generation Software Education Standard Model' announced in 2019. The Ministry of Education announced a comprehensive plan for sciencemathematics-information-convergence education in 2020 and presented the direction for artificial intelligence education in elementary, middle, and high schools. This comprehensive plan announced a plan to strengthen the information curriculum by adding artificial intelligencerelated content to the school curriculum so that elementary to high school students can systematically develop information and AI capabilities [13].

### 2.3 Education using Artificial Intelligence

While artificial intelligence has continued to develop and stagnate since the 1950s, efforts to apply artificial intelligence to education include the Intelligent Tutoring System (ITS), Adaptive Learning (AL), and Computer-based Education. Education: CBE) and Learning Analysis (LA) have been studied in various forms [16]. However, until artificial intelligence received great attention under the wave of the Fourth Industrial Revolution, artificial intelligence convergence education research and its application were not very active. In their book 'Artificial Intelligence In Education', Holmes, Bialik & Fadel [3] refer to artificial intelligence in the field of education as 'AI in Education (AIED)' and refer to the long-standing trend of AIED as an Intelligent Tutoring System (ITS), Dialogue-Based Tutoring System (DBTS), and Exploratory Learning Environment (ELE). First, the use of the Intelligent Tutoring System (ITS). For subjects like mathematics or physics that have a clearly defined knowledge structure, ITS calculates the best step-bystep learning path. Second, the use of the Dialogue-Based Tutoring System (DBTS). A new iteration of ITS called
DBTS engages students in a dialogue about learning. DBTS utilizes advanced natural language processing and natural language generation technologies. Third, utilizing an exploratory learning framework (Exploratory Learning Environment: ELE). ELE adopts a constructive approach. Put another way, instead of adhering to a predetermined stepby-step sequence, students are urged to proactively generate knowledge on their own by investigating and manipulating parts of the learning environment.

## 3 DEVELOPMENT OF FRAMEWORK FOR AI CONVERGENCE OF TECHNOLOGY EDUCATION 3.1 Elements of Artificial Intelligence Convergence Education

As seen in the examples above, the artificial intelligenceenabled education system (AIED) is being studied so that it can be used in a variety of ways depending on the content and purpose of education. However, what AIED is and what it can do is still an ongoing question [3], so there are still many limitations in applying it smoothly to all areas of learning, and it needs to be continuously and actively researched in the future. It can be viewed as an area.

Today's artificial intelligence convergence education includes not simply using artificial intelligence functionally in the education system, but also educating artificial intelligence itself so that humans can understand and use it directly. Accordingly, Lim [1] reviewed the literature related to artificial intelligence convergence education and presented artificial intelligence convergence education (AIED) by dividing it into 'education about artificial intelligence' and 'education using artificial intelligence.' At this time, education on artificial intelligence can be expressed as 'AI in Educational Contents (AIEC)', and the target and topic of education is artificial intelligence, or artificial intelligence is used in the learning process to help learners understand and handle artificial intelligence. It is 'artificial intelligence education' aimed at cultivating the ability to Education using artificial intelligence can be expressed as 'AI in Educational Technology (AIET)', and 'Use of Artificial Intelligence' is the application of integrating artificial intelligence into the teaching and learning process in education and tool that allows instructors to improve the effectiveness of education. AIEC shows a trend of development relatively recently when artificial intelligence has received public attention. AI4ALL (AI for ALL), a US-based non-profit organization, was established in 2015 and provides artificial intelligence education programs, and has been providing artificial intelligence education programs to computer science teachers in the US. The Association for the Advancement of Artificial Intelligence (AAAI) and the Computer Science Teachers Association (CSTA) have proposed five major themes for artificial intelligence teaching, the EU's artificial intelligence education elements, China's main artificial intelligence education contents, The results of deriving detailed elements by synthesizing the main contents of Korea's artificial intelligence education are shown in Fig. 2, and the AIEC education elements of the education model were derived using the categorized results considering each detailed education element.

USA	EU	China	korea		Synthesis
AI recognition method	What is AI	AI concept	AI concept		AI concept
AI expression and reasoning	AI problem solving	AI problem solving	Knowledge		Learning in AI
Natural interaction of AI	Real-world AI	Use of AI AI interaction	Use of AI reasoning	-	AI problem solving
Learning in AI	Machine learning Neural network	Machine learning Neural network	Machine learning Artificial neural		Use of AI
Social Impact of			network		Social Impact of
AI	Social influence	The future of AI			AI

Figure 2 Derivation of AIEC education elements



Figure 3 Educational elements of AIED

Regarding AIET, the representative topic of research using artificial intelligence in education is ITS. ITS aims to develop more intelligent and adaptable educational software by introducing artificial intelligence techniques to existing CBE. ITS chooses the best incremental learning route for areas with a well-defined knowledge structure, such as mathematics or physics. ITS has been studied by many scholars studying artificial intelligence since the 1980s and evaluations in schools have been reported [15], but it has not achieved as much success as expected. The reason for this is that it was difficult to clearly extract the learner's intellectual activities or responses. Recently, as interest in artificial intelligence has rapidly increased and related technologies have developed, various forms of AIET research other than ITS have been conducted, began to become lively. Holmes, Bialik & Fadel [3] show that the education system using artificial intelligence includes step-by-step customized education based on artificial intelligence, artificial intelligence-supported inquiry learning starting from a conversation system, analysis of student writing, intelligent agent in a game-based environment, and chatbot for student support. It was said to include etc. The above AIEC education elements and AIET education areas are graphically depicted in Fig. 3.

## 3.2 Framework of Technological Problem Solving

Lim & Kim [14] created a model for technological problem solving. According to the process and results of model development, the types of technological problems were defined as troubleshooting, design, development, and invention as shown in Tab. 1, and the technical problem solving model was defined according to the technical problem solving stage as shown in Tab. 1. It can be divided into problem understanding, conception, realization, and evaluation.

Table 1	Types of technological problems	
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X-AXIS	X1	X2	X3	X4
Types of				
Technological	Troubleshooting	Design	Development	Invention
Drohlama	_	-	_	

Table 2 Steps in solving technological problem

		0 0		
Y-AXIS	Y1	Y2	Y3	Y4
Steps in solving technological problem	Understanding the problem	Conception	Realization	Evaluation

Framework of technological problem solving derived by considering Tab. 1 and Tab. 2 is shown in Fig. 4.





Framework of technological problem solving in Fig. 4 represents 16 technological problem areas. One problem type is divided into four problem solving steps. For example, Troubleshooting (X1) goes through the stages of problem understanding (Y1), conception (Y2), realization (Y3), and evaluation (Y4). If a problem is in the realization stage of the Troubleshooting type, it becomes a problem in area X1Y3.

## 3.3 Framework for Integration of AI in Technology Education

Based on the above discussion, this study designed a framework for AI convergence technology education as shown in Fig. 5. Based on the framework in Fig. 4 previously designed, a framework was created by dividing the types of artificial intelligence-based education that can be used in each area into ITS, DBTS, and ELE.

In Fig. 5, one technical problem can utilize three types of AI convergence education. For example, the invention realization stage (X4Y3) can utilize the types of ITS (Z1), DBTS (Z2), and ELE (Z3). If the learner is currently in area X4Y3Z3 in the framework of Fig. 5, the learner is realizing

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an invention problem and solving a technological problem using ELE's AI convergence education.

Table	3 Types of educ	ation using artifici	al intelligence



## 4 CONCLUSION

The aim of this research was to develop a foundation for AI convergence education in technology education. The framework of this study is based on the most important problem-solving learning process in technology education. The developed framework structures the problem-solving steps of such types of problems into problem solving, design, development, and evaluation. Each technological problem and problem-solving step area can be implemented using the ITS, DBTS, and ELE systems of AI convergence education. Technology education helps students develop Technological knowledge and develop critical and creative thinking in the process of solving real-life technological problems. Since the process of solving technological problems is complex in itself, it was necessary to categorize technological problems in real life and organize the procedure for resolving issues with technology into a series for formal education in schools. In this process of technological problem-solving learning, explicit knowledge may be necessary, and interpretive or procedural knowledge may be necessary. Methods of utilizing AI convergence education vary depending on the target knowledge. Therefore, structuring and presenting a plan to apply various AI convergence educations to the process of solving highly complex technological problems is meaningful in that it suggests the basis for method of AI convergence education. Based on the framework developed in this study, expected that AI convergence education methods appropriate for each problem-solving process of various technological problems will be systematically researched and implemented in the future.

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## Designing for Modern Living: The Strategic Evolution of Residential Spaces in Response to Improved Lifestyles

## Hyun-ah Kwon, Soomi Kim\*

Abstract: This study delves into the evolving landscape of modern living in South Korea, which has the widespread apartment complexes that have emerged from the efficiencycentric approaches of industrial capitalism. It explores the paradigm shift in the 21st-century capitalist society, which now values creativity and individual expression over functionality and uniformity. This shift has led to a noticeable disparity between the monotonous spatial composition of mass-produced housing and the dynamic, creative lifestyles of contemporary residents. The research method involves a comprehensive analysis of both lifestyle and architectural magazines, providing insights into the changing preferences and lifestyles of residents, as well as the perspectives of professionals. The study aimed to highlight the changing nature of residential spaces and the design strategies, moving away from the conventional utility-focused designs, towards environments that foster creativity and reflect the individuality of inhabitants. Key findings indicate a growing public preference for residential spaces that are versatile, creatively stimulating, and aligned with the multifaceted nature of modern lifestyles. Contrasting these views, architectural experts emphasize the fundamental values of living, advocating for spaces that connect residents with nature and enrich everyday experiences through sensory engagement. The study concludes that while there is a divergence in perspectives between the general public and architectural specialists, both recognize the necessity for sustainable housing solutions. These solutions should cater to contemporary societal changes while preserving essential life values, thereby overcoming the limitations of the prevalent apartment centric urban housing model in South Korea.

Keywords: architectural magazine; creativity; creative class; design strategies of housing planning; housing planning; lifestyles; lifestyle magazine; social structure; sustainable housing; urban housing

## **1** INTRODUCTION

Apartment complexes in South Korea have become a staple in the nation's housing landscape. Initially gaining popularity due to their uniform mass production driven by industrial capitalism, which prioritizes function and efficiency, these complexes, with their typical nLDK spatial composition, have profoundly infiltrated domestic housing markets. As of 2019, apartments account for about 62.3 % of all housing in South Korea, and in 2019, the proportion of apartments among newly built houses is over 76 % [1]. Their widespread adoption can largely be attributed to the convenience they offer.

However, the onset of the 21st century has heralded a paradigm shift within the capitalist social structure, from prioritizing functionality and efficiency to valuing creativity. This change is not just theoretical but has palpable effects on the everyday lives of residents, who now seek more than just convenience in their living spaces. The emergence of creativity as a crucial aspect of the new social framework has brought into focus the once-overlooked need for diversity and personalization in living spaces, challenging the standardization and commercial universality of massproduced residential spaces [2].

Despite these evolving preferences, apartment complexes continue to address the housing shortage issue and remain a means of asset growth for consumers. However, their production has not significantly deviated from the existing spatial layouts. The recent surge in apartment real estate prices further complicates this scenario, revealing a gap where quantitative growth in housing does not translate into qualitative improvements. This situation underlines the need for a critical discussion on urban and socioeconomic sustainability within South Korea's housing culture, particularly addressing the disconnect between existing housing types and contemporary lifestyle needs. The primary challenge in modern South Korean residential spaces is the imbalance between the physical structure (architectural hardware) and the lifestyle requirements of the residents (architectural software) [3].

In line with this, this study aims to delve into the changing lifestyles prompted by the societal transition and to analyze the characteristics of residential spaces that align with these improved lifestyle. Our objective is to move beyond the limitations of conventional urban housing, epitomized by the uniform and monotonous apartment complexes designed for middle-class nuclear families of the 20th century. We seek to conceptualize and create desing strategies of residential spaces that embody sustainable housing principles. A key focus of this study is to compare and analyze views of both the general public and architectural experts on contemporary lifestyles and residential spaces, especially regarding the design perspective of housing planning. In doing so, we aspire to understand and articulate the defining characteristics of sustainable housing in this new era, marked by advanced values and ideals, and to identify the perspective of housing planning that are essential in contemporary South Korea.

## 2 MATERIALS AND METHODS

In South Korean society, where most of people are accustomed only to apartments, it is very urgent to define a changed lifestyle and residential space of a new era, but discussions on it are not abundant. Most of the studies related to lifestyles mainly focus on investigating the lifestyles of each generation or the preferences according to them statistically. At this time, most lifestyles tend to be categorized into simple listed categories such as happinessseeking type, self-development type, individuality-seeking type, family-oriented type, and convenience-seeking type [4-8] and the social structures and underlying paradigm behind such phenomena cannot be captured.

Therefore, this study is very important as it attempts to actively analyze the attributes of the recent lifestyles and the residential spaces for them at a more intrinsic level, rather than simply defining it as an increase in individuality or diversity. It is meaningful in trying to define lifestyles in relation to macroscopic social structures for each phenomenon that can be easily limited to microscopic and peripheral discussions. In other words, this study provides a clue to discern microscopic cases in the context of macroscopic social structures as in the Tab. 1.



ning for residential space d the limitation of hous

6. Comparative analysis of lifestyle and architectural magazines

To this end, Section 3 examines the changes in values and orientations inherent in the new capitalist mode of production as well as changes in residents' lifestyles and the everyday life that has changed accordingly. Based on our previous studies, from the views of characteristics of residents, relationship between individual and family, and function of housing, the characteristics of everyday life have changed due to the transition in the social structure and the attributes of residential space have to change accordingly.

In Section 4, based on the contents of Section 3, we present the design strategies of housing planning covered in the lifestyle magazines. The main objects of analysis are the residents' interviews published in the lifestyle magazines, which contain references to lifestyle from the view of the design strategies of housing planning. Through this, it will be possible to identify the conditions of ideal housing in the present age from the views of the general public.

In Section 5, we discuss the design strategies from the views of architects and critics, who are experts in the field of architecture, by analyzing the architectural magazines. The perspective of housing planning has been analyzed by considering the positions and architectural solutions of the architects, and the criticism of the critics. We hope to achieve a meaningful interpretation of the current housing culture by comparing the views of the architectural experts with those of the general public in Section 4.

Interviews of the residents and cases of residential space from 2015 to 2017 (i.e., three years) were the main research subjects of the study. In Section 4, the lifestyle magazines, "House Full of Happiness", "Maison", and "Living Senses" were chosen for the study. Unlike women's magazines centered on celebrities and fashion pictorials, domestic lifestyle magazines with main contents such as lifestyles, interior designs, and residential spaces have begun to be published in earnest since 1990. Of these, there are currently four influential magazines that have been continuously published for more than 10 years. Among them, three magazines accessible in both online and offline versions were selected for research. We analyzed a total of 108 monthly issues published by three lifestyle magazines over three years. In Section 5, the architectural magazines, "Space," which is a representative and monthly architectural magazine in South Korea, was chosen for the study. The "Space Academia" section of this magazine was listed in the A&HCI. The "Space" magazine focuses on articles related to domestic projects including residential spaces. All the articles on residential spaces covered in architectural magazines from 2015 to 2017 were investigated.

Finally, in Section 6, through comparative analysis of lifestyle magazines and architectural magazines, the similarities or differences between the views of the general public and those of architectural experts are examined and the implications thereof are investigated. This helps to fundamentally explore the characteristics of contemporary lifestyles and residential spaces that existing apartmentoriented urban housing should contain.

In this study, the humanistic approach, which was somewhat neglected in previous studies, was attempted based on the interviews and discourses of magazines. Lifestyle is a factor that should be considered when discussing residential spaces in the field of architecture, but discussions on lifestyles have been poor. Therefore, this study aims to examine in depth the topic of residential spaces considering lifestyles, which has hardly been discussed in the existing architectural field. Analysis of magazines may have limitations in securing complete objectivity and systematization due to its nature. However, since the subject of qualitative content analysis of this study focused on interviews with residents and the personal opinions of various architects and critics, it can be seen that it serves as a meaningful means to grasp the viewpoints of various public and experts.

## 3 TRANSITION IN CAPITALIST SOCIAL STRUCTURE AND CHANGES IN THE CHARACTERISTICS OF EVERYDAY LIFE

3.1 Transition in Capitalist Social Structure in the Contemporary Society

Modifications in the meaning of housing and the residential spaces are primarily based on the social structure and everyday life. The industrialized culture of the beginning of the twentieth century and the consumer-driven society that followed in the middle of the century are similar to the current society, but the structure and perspective of daily life are fundamentally different. Nowadays, the force that drives innovation, influences society, and creates wealth is not industrial civilization's mechanical effectiveness, or the symbolic value of class and status in buyer society; it is human creativity that is a crucial element of the economy, and it affects systems and values in the society, which in turn leads to changes in everyday life. People's choices, values, and general trends and patterns of daily life are changing as a result of the modern society's shift from the industrial and service sectors to the creative sectors. In his work, Richard Florida offers a novel worldview brought about by innovation. The Rise of the Creative Class, released in 2002 [9]. He describes the difference in the structure and characteristics of everyday life found in the age of organization and the age of creativity. This is summarized in the Tab. 2 [2]. This phenomenon is spreading universally and is becoming a dominant trend in this era.

What is particularly interesting is that in this era, creativity, which is the means of production, is succeeded by workers, and not by the capitalist class. Traditionally, "land, labor, and capital" were regarded as the three factors of production, but Peter Drucker's Knowledge Economy regarded "information and knowledge" as more important factors of production. However, the factors of production in this new era centered on creativity, whose factors can be considered as "people, people, and people". Even in the industrial sector, knowledge-based companies are trying to secure innovative workspaces to attract talent of the millennials. To maximize the creativity of R&D developers. play, rest, and work spaces are combined together, and open, low-rise campuses are chosen in a green area. There is a growing belief that creating ideas in the comfort of nature or that of home, and working by chatting and playing with others in an open space produces high quality output [10].

The revolution in the working space, which appears as if the boundary between work and life blurs, extends not only to the office but also the residential space. Creativity can be nurtured and supported through a variety of physical and non-physical environments, and people seek an environment that encourages creativity. In line with this paradigm shift, the residential space needs a new direction, which has to play a role beyond providing shelter for rest and relaxation after returning home from work like in the past.

structure							
	William H. Whyte	<b>Richard Florida</b>					
	"The organization man"	"The creative class"					
	The age of organization	The age of humanism					
	(the mid-20 <sup>th</sup> century)	(the 21 <sup>st</sup> century)					
	enterprise	people					
	as a foundation for economic	as a foundation for economic					
	growth	growth					
	- steady, dependable, and	- unpredictably,					
	recurring	instinctively, and					
	- advancement according to the	subconsciously					
attailantaa	vertical hierarchy	- experience and choice as					
attributes	- top-down, transparent labor	opposed to advancement					
OI WOIK	allocation, and specializations	- horizontal, competent, and					
	<ul> <li>Protestant principles</li> </ul>	communicative					
		- personal requirements,					
		aspirations, and contentment					
	- the group identity inside an	- unique identity (engaged in					
	institution	independence and the					
human	<ul> <li>an individual's identity is</li> </ul>	significance of life)					
human identity	defined by their workplace,	- work and way of life as					
lucinity	church, and community.	opposed to business					
	- societal capital as opposed to	<ul> <li>local way of life as</li> </ul>					
	personal lifestyle	opposed to social capital					
	<ul> <li>organizational principles and</li> </ul>	- expression of oneself and					
	standards (individuals	uniqueness					
	institutionalized)	<ul> <li>embracing variety and</li> </ul>					
	<ul> <li>consistency, deference,</li> </ul>	individuality while honoring					
	flexibility, steadiness, and	the abilities of others					
	honesty	- advancing, realistic, and					
norme	<ul> <li>conventional and</li> </ul>	receptive to new ideas					
and	conservative	- self-established standards					
lifestyle	<ul> <li>command and oversight</li> </ul>	- effectively allocating their					
mestyle	(vertical command)	time					
	- set schedule (from nine to	<ul> <li>combining business and</li> </ul>					
	five)	leisure					
	- separation of recreation and	- wear whatever they want					
	job	and express themselves					
	- a uniform-like grey flannel	artistically.					
	suit						

## 3.2 Changes in the Characteristics of Everyday Life Due to Transition in Capitalist Social Structure

We analyzed the lifestyle magazines and architectural magazines from the perspective of "characteristics of residents", "relationship between individual and family", and "functions of housing" to examine the changed attributes of daily existence and the features of newly constructed homes to accommodate them. As creativity is a keyword in the new era, everyday life and lifestyles, which have been overlooked due to mass production in domestic urban housing, have been becoming important. The constraints of the current residential spaces and the need to surpass them were the realities that were discovered during the analysis of the altered lifestyles and residential spaces.

## 3.2.1 Changes in the Characteristics of Residents

In the lifestyle magazines, the current idea of a fourmember nuclear family with clear gender roles was no longer valid, and a brand-new idea of inhabitants with various, multi-layered characteristics surfaced. Particularly, most of them were engaged with creative occupations, and the jobs titles too varied dramatically. They were more concerned in aggressively disclosing the subjects and nature of their work rather than emphasizing their position in the organization. In addition, they tried to develop their individuality and identity by pursuing various professional hobbies. The characteristics of cultural capital they intend to possess are different from those of high-class culture that symbolize uniform attire or sense of social class. Since openness is the defining quality of creativity, they showed interest in experimenting and attempting a fusion of diverse and heterogeneous cultures. The household composition has also diversified beyond current universal nuclear family, and each member's traits and way of life have been enlarged to the extent that it is hard to assume there is uniformity.

On the other hand, there were very few detailed allusions to the inhabitants or their way of life in the architectural journals. In the case of detached houses, tries to reflect the differentiated features of residents were mostly dedicated on the aesthetic values of the architecture from the outside. Critics took a critical position on the formative nature of housing, saying it was a collaboration between the client's desire to show off and the architect's desire to achieve. Nevertheless, they favorably evaluated the cases of experimenting with the distinct of the spatial variation in every room as against the same arrangement of rooms in the apartment. Also, in the case of multi-family housing, it was discovered that attempts to reflect the characteristics of residents lead to aspirations for varied kinds of dwelling and specialized units which is beyond the scope of apartments [11].

## 3.2.2 Alterations in the Family-Individual Relationship

While the current urban housing obviously shares each space and pursues distinction in function for individuals, and has reduced social spaces, recent lifestyle magazines show that family members enjoy feeling each other's presence and a sense of family togetherness. And for this, the boundaries of space tended to be flexible. The aspiration for a sweet home, which held the nuclear family together with the rise of modernism, has recently been reinforcing the meaning of the community as a family as against individual privacy and independence as the hierarchy among family members is blurred. The relationships between family members become closer leading to true happiness. Unlike previous family communities, the recent ones show the characteristics of flexibility and seek to communicate together while respecting individual liberty and individuality. The spatial resolutions for this constitute an open plan, door sliding, visibility through the use of glass doors or windows, and communal areas for social places such stairwells and hallways.

Open plan, flexibility, and transparency were also planning elements that appeared consistently for communication in architectural magazines, similar to what was stated in lifestyle magazines. Furthermore, the architectural magazines consider the inside or outside void spaces as spaces with various possibilities from the point of view of communication. In addition to being assigned additional tasks beyond circulation, common areas with mixed void spaces were also seen as new interaction spaces. As a result, the living room's social role was diminished and its status was somewhat diminished, while the kitchen's significance in terms of communication increased. The most significant sensory component for family communication is "sight", and interest in various enthusiasm for the area of space above the apartment's standard floor height was sparked by the use of imagery [11].

## 3.2.3 Changes in the Functions of Housing

A most of the cases that featured in lifestyle magazines noted the trend of changing private spaces' purposes as workspaces. Residential spaces and workspaces had been completely separated since modern times. Residents, however, demand a new function, namely production, within the residential space. The Internet and other technology advancements made it easy to look for a residential room to use as a workstation. It also required openness and flexibility in residential space. There were several examples where spaces were visually linked, but had an option of audio or spatial disconnection if desired. In addition, functional distinction as opposed to, they chosen to use the spaces complexly, similar to the traditional Korean houses. Therefore, they wanted a residential space to be a multispace, for work, for spending time as a family and for recreation when needed. With this, residents were demanding changes in the stiff wall-style building typical of ordinary apartments which restrict the complex and flexible use of spaces.

The views of architectural experts from the Architectural periodicals are typically not the same. In fact, views and confidentiality, which have been taken into consideration as essential features of housing since the present, have continued to be acknowledged as the most significant in housing planning. However, there is hardly any mention of utilizing a residential area for business or the function of production which are newly required by residents in the residential space. Instead, they focused on physical and mental relaxation, which remained the most representative function of housing since modern times. Therefore, rather than experimenting with overly aesthetic, unfamiliar, and innovative aspects, they preferred the projects that were devoted to the initial goal of the house that include relaxation and constancy. A house that is accurate to its fundamentals, even if it is trivial, and which maintains its original worth as a "house," which was appealing.

The hunt for a residential space that could be used as an office was essentially a manifestation of the inclination that lifestyle magazines displayed to actively adapt the newly altered lifestyle to housing that corresponded with the developing social structure. In contrast, the architectural magazines were not quick to react to such changes, and considered a cozy haven with seclusion and a nice view as the most important function of the house [12].

## 4 CHARACTERISTICS OF IDEAL LIFESTYLES CORRESPONDING TO THE CONTEMPORARY SOCIAL STRUCTURE: LIFESTYLE MAGAZINES' POSITIONS WITH REGARDS TO DESIGN STRATEGIES OF HOUSING PLANNING

This section examines the design strategies of housing planning from the views of lifestyle magazines based on our previous studies. Unlike the opinions of architectural experts acquired through architectural magazines and analyzed in Section 5, this puts forth the aspects of an ideal lifestyle from the point of view of the general public.

## 4.1 Stimulating Creativity and Supporting Multidimensional Experiences

The number of laborers available for hiring as housekeepers reduced in the 1970s in South Korea just like in the early 20<sup>th</sup> century in the west. That is when the middleclass homemakers began to engage in kitchen work in South Korea, and kitchens that were equipped with convenient structures and facilities in apartments began to gain popularity. Even now, space arrangement that reduces domestic labor, and encourages efficient composition of functional spaces for convenience is still recognized as the biggest advantage of apartments.

While the average number of household members is decreasing every year and the residential area is becoming larger than before, the original functions of houses, including cleaning, can be moved to metropolitan services provided outside of homes, if desired. In this condition, the efficiency and function-oriented aspects of the modernist period also have to undergo a change; and the question that arises is "how to fill this spacious house? and what is the essential value of a new era's residential space?" [2].

In this regard, creativity, which forms the core of the newly reorganized social structure, provides a clue for a new direction. In other words, unlike mechanical efficiency of the previous era, human creativity is a talent that must be continuously cultivated through experience and environment rather than through simple efforts in a short time. Being conscious of this aspect, lifestyle magazines suggest an environment that stimulates creativity and multidimensional experiences.

Even in the kitchen space, for example, cooking is no longer as essential as it used to be. With the increase of 1–2 person households and dual-income couples, the everevolving fast food, instant food, meal kits, and innumerable restaurants offer a variety of dishes at reasonable prices. Dining out and food deliveries have become so common that a new word "*jibbab* (home-cooked meal)" has come up for this concept. Moreover, cooking has become a hobby or an interesting experience, and not an essential housework. Richard Florida also commented on this aspect, and said that cooking is a very creative field, so people now enjoy creative experiences through it [9].

Despite this generalization of eating out and food delivery, various spices and ingredients from all over the world are easily available in the grocery section of marts. Even though people rarely cook, the refrigerator in a regular household is full of ingredients that could be found only in a chef's kitchen previously. People no longer eat to just fill their stomachs, but rather to enjoy a special experience through the combination of various flavors and the cooking process. This is another reason for the increased interest in the kitchen and dining space, which is in line with the growing importance of the dining space in the house in the context of the bond between a family and a particular person [13].

In addition, previous studies indicate that residential spaces also need to function as workspaces. It means no more just a small, disconnected area for simple telecommuting, but requires an open workspace. This means that as the number of jobs in which creativity is the core increases, the home must become a creative place where new inspiration and ideas can arise through various experiences and stimulation for residents [12].

## 4.2 Pursuit of Individual Taste and Identity

Home interiors, a source of creative inspiration and ideas, show a distinctly different trend from the past. Above all, considering that the core of creativity is thoughts and ideas that are different from others, nowadays people want to pursue their own tastes and identities that are different from those of the others rather than settle for average or ordinary things.

In fact, in the past, most of the women were full-time homemakers and their community comprised just the neighbors; hence, the home interior designs were compared only with them in most cases. However, as women have become more social, and with the development of Internet, various sources of reference for the trend of home décor is growing.

Compared to the prior age, where even dining out was not common, people, who are now more affluent due to improved economic conditions, have patronized various commercial and cultural facilities such as cafes, hotels, and art galleries. Travel, business trips, and studying abroad have become more common than before, and various experiences gathered abroad take shape in the form of meaningful events for the individuality and taste of the residents [13]. This trend in society forms the basis for the pursuit of individual taste and identity.

Therefore, people try to begin their own individuality and taste that are relatively permitted from the trend, moving away from the previous pattern of simply imitating the house next door or copying the model house of brand apartments. This means a breakup with homogeneity, with which the South Korean society is obsessed; hence, it can be concluded that it is a change in era where diversity and autonomy must be pursued for creativity. Only one's own taste, individuality, and unique identity are now linked to potential economic value and are recognized as the most important assets.

In addition to the diverse references for home decoration, the range of product selections are also diverse to the point where it is possible to reveal differences in one's taste. While the diversity in the domestic market has grown, it has also become common to collect items through overseas travel or online direct purchases from overseas markets, away from the restrictions in the domestic market. Furthermore, it is in the same context that people pay more attention to "works (of art)" that are rare or are only of its kind in the world, and hence, are not swayed by fashion.

However, there are many cases where an individual's taste is not clearly recognized by himself or herself. That is

why one can discover, specify, and refine one's taste through various experiences, experiments, and opportunities. In this way, home decoration provides an opportunity to know and discover one's taste, and the taste thus formed can be developed anew through other stimuli and influences over time. The attempt to decorate the house itself is a creative work and a process of learning, experimenting with ideas and examining the results in one's own way. Therefore, some residents in the lifestyle magazines say, "I discovered my interests and found true satisfaction when I got involved in decorating my home" [14], or "I am maturing with my house" [15].

Therefore, people do not try to decorate the house completely at a given point, and fill it over a period of time with items that reflect their individuality and preferences which can change with time. Eventually, the items collected been a "collection" after such a long time and form the tastes of residents [13].

# 4.3 Searching for Residential Spaces beyond the Limitations of Housing

Reflecting this trend, lifestyle magazines in recent times do not find the references of ideal housing in the same building type category such as housing. In the past, the meaning of home as opposed to workplace was important, and there was a clear image of a home symbolized as a cozy place for relaxation. However, the house now wants to become something other than a house, especially in lifestyle magazines. This is in stark contrast to the opinion of architectural experts who essentially want the house to be a house. Architectural experts tend to have unfavorable attitude toward the house that does not look like a house.

As noted in Section 4.1, lifestyle magazines attempted to explore new characteristics of a house to stimulate creativity and support multidimensional experiences. Therefore, it is intended to promote a creative environment by infusing new characteristics that do not exist in the ordinary house. The residents want a house "like a little atelier of Parisian artists" [16], "like a wine bar or a cigar bar" [17], or a house that "looks like a gallery" [18]. And they hope "to have a living room with open space like a studio (...) café-like space" [19] and "to reduce the feeling of home" [19].

For house decoration, people have been drawing inspiration from various places, regardless of the social conventions that the original meaning of the house had. By introducing various cultural and artistic elements or commercial elements from places such as cafes, hotels, libraries, studios, or art galleries into the house, the residential space is intended to be reborn as a creative environment that supports multidimensional experiences and stimulates creativity.

As a result, people want a house "where they want to stay all day, combining the mood of residential and commercial spaces" [17], or "in this house, no matter where they look at, it feels always different. They don't need to go on vacation" because they live everyday feeling like they are traveling [20].

## 5 CHARACTERISTICS OF IDEAL RESIDENTIAL SPACES CORRESPONDING TO THE CONTEMPORARY SOCIAL STRUCTURE: ARCHITECTURAL MAGAZINES' POSITIONS WITH REGARDS TO DESIGN STRATEGIES OF HOUSING PLANNING

In Section 4, to investigate the qualities of perfect lives shown in contemporary society, the lifestyle magazines were analyzed from the view of the design strategies of housing planning. Beyond the efficiency and function-oriented planning and the resulting convenience, the residential space is transforming into an environment that supports multidimensional experiences and stimulates creativity. The concept of housing, which supports various experiences and becomes a source of creative inspiration, is emerging. To this end, the house did not look for a reference of ideal housing in the category of the same building type, but something more than just a house. Regardless of the conventional wisdom in the original meaning of the house, inspiration for home decoration comes from various aspects of different building types.

This section also covers the point of view of the design strategies of housing planning, but we try to examine the characteristics of dwelling areas that facilitate altered lifestyles that appear in architectural magazines. In Section 4, conferences with the residents, i.e., the general public, was the basis for the main analysis. However, in this section, the analysis of architecture magazines, and the opinions from professionals in the field of architecture, which includes architects and critics, are the main subject of analysis.

## 5.1 Richness and Extraordinariness of Everyday Life

The design strategies of housing planning, which is covered remarkably in the architectural magazines, is that of an abundant and prosperous life, that is, a life that has not lost its diversity and creativity. However, it is different from the trends in lifestyle magazines. Rather, it is a more fundamental context where the residents realize the essential nature of everyday life and enrich it further.

The housing projects of architectural magazines tend to enliven everyday moments that are neither grand nor special, thereby helping the residents recognize their value, and enjoy the ease and abundance, as described in the following instances: "The *Toit Maru* (traditional Korean narrow wooden porch running along the outside of a room) facing the living room and kitchen is a beautiful space with sunshine and sounds of the surrounding area" [21]; "After coming back home from work, one may leisurely have a beer on the wooden veranda" [22] (Figure 1, left); and "This place allows the users to enjoy the sun on the floor, take a nap, and also have a drink with friends (...)" [23]. It's "simple and small (...) enough to just shed light on the scent of the roasted coffee" [24] but it's by no means insignificant.

Therefore, to support practical uses in everyday life, "the yard is intended to be more of a living space than an empty space designed for mere aesthetic purposes" [25], and a house should have a nature of a house as in the case of "the architect intends to create a comfortable place (...) it has the

measurement which can be sensed with our body, familiar materials, and the privacy that secures the territory of the individual life from the public" [25] (Fig. 1, center).



Figure 1 Examples of residential spaces for richness and extraordinariness of everyday life (Source: "Space" magazine).

However, the everyday life should never be rigid, monotonous, and banal, and should essentially be one in which extraordinariness is hidden. The familiar things must be recombined into the novelty of each moment, and there should be a vivid and lively everyday life that can never always be the same, as reflected in the following instances: "The layers of stairs that sometimes open up and close towards the adjacent buildings, the cityscape, and the natural scenery transform the somewhat ordinary daily scenes of the neighborhood into an uncommon momentary experience" [26] (Fig. 1, right); and "The staircase will not only mean vertical movement, but will also embrace its surroundings by containing the function of the view, of rest, and of memory. It will become an old-new. (...) These coincidental images will slice the image of the city into fragments. The fragmented image of the surrounding context will be reserved and unified, according to the individual experiences. In the reserved images, new stories will be made with the addition of sky, ground, village, roads, and the city. Coincidental and unexpected new will become familiar, which will speak with the existing context by transforming itself into the old-new" [27]. These moments will come together to create a unique placeness and meaning, and life will eventually be completed through these small and new everyday moments.

Therefore, they take a critical stance on residential spaces that miss the meaning of everyday life and cannot enjoy its richness. This is supported by the following instances: "the morphology of the indoor space (...) does not seem much different from the four bay apartment plan which is very popular of late. (...) Should there have been a difference in the height of the layers, and the fan lights squeezing in between that allow for the change of light to be part of one's daily life; more colorful, rich experiences, rather than simple spatial change coming from partial difference in application of the finishing materials, could have been delivered" [28]; "The abundant lives and memories of the occupants don't seem to be embraced by the privacy-focused wall and window designs." [29]; and "The extremely carefully designed details of the interior make it difficult to have a relaxed feeling that you would expect in a garden. I think this is due to the architect's intention to create a modern space within a space of composure. However, I have concerns that this modern feeling will lead the people living here to the uniform and busy life of the city" [21].

Unlike that described in the lifestyle magazines, a life filled with gratitude and joy for life following the laws of nature is believed to be the core and essential point of housing planning pursued by the architecture magazines, as described by "the space will become a place of peace in which we can all feel thankful for our everyday lives. We can then feel the joy of living in tune with the sun's rise and fall" [24].

## 5.2 Connection with Nature and Senses of the Body

The source of this richness of everyday life in architectural magazines is, above all, "nature". The desire to escape the introverted apartment space and the desire to view the nature as mentioned in Section 3.2.3 serve as the stepping stones for the beginning of true communication with nature. "There is no escape in the modern life, and pacification is something that cannot be expected. However, the value of beauty and the leisure of life provided by nature still remains" [30], and nature is also an object that has been missed throughout one's life, as in the case of "this is the dream of the client, who, for 20 years coped with intensive work, only taking two days off a year. (...) This house is bound to surprise its residents with the joy of unwrapping a gift. Removing all the gift-wrap, the ever-changing ocean that the client yearned for becomes visible" [31]. Hence, the architects hope that "the design for each floor takes into account sunlight, wind flows, and the views to make it a space coexisting with nature, (...) a place to enjoy nature even in downtown areas" [32].

Such a place is not just a view or a wonderful landscape, it is praiseworthy for its delicate and wonderful characteristics of nature that change subtly from moment to moment. Between life and architecture, nature brings relaxation and abundance to human emotions, enhances the quality of life, and becomes a source of inspiration, as described in the following instances: "As part of the built environment, architecture must necessarily inspire people, to prevent an otherwise fateful dearth of our sensibilities, and to enhance our quality of life. This house becomes sculptural canvas molded by the architect, abundantly embracing mankind's original source of inspiration: light from nature" [29]; and "Nature brings in inspiration and expiration, color and seasons, warmth and fragrance, forest and sea. (...) There are overlapped flowers and trees in several layers and many kinds of winds embracing inside and outside of space. There is a rainy corridor and garden, and plenty of evening glow, stars, sky, mountains, and sea through the various gaps of the building" [33]. Furthermore, it is necessary to plan a space that values humans who interact with nature, because: "human spirit can be healed by communication with nature, which can also vitalize the communication between humans" [34].

Therefore, it is important to "observe the greenery, and feel the change of seasons" [34]. However, for this purpose, there is a premise that one must overcome the situation where one's basic senses are dulled and absent by being accustomed to the existing homogeneous artificial environment. That is because "In an environment rampant with apartments, we have lost our human instincts of wanting the sunlight" [24], and "The cramped space in the small-scale houses makes humans lose their mind and spirit, making them become like animals in cages. The environment takes away all qualities of humanity, such as sensitivity to sounds, clear color sensations, the observation of surroundings, sensitivity towards others, and passionate emotions" [34]. This blunting of the senses and sensibility of the body means "the alienation from one's ego, which is the loss of one's spirit" [34].

Therefore, the experts, whose opinions were cited in the architectural magazines were yearning for a space that awakened and sharpened one's senses and sensibility, so that one could feel the richness of everyday life and the delicacy of nature with the senses and spirit of the whole body. For this purpose, the following may be required: "It creates an experience in which light and shade intersects, landscape changes through gaps between boxes, and plants planted by the residents harmonize, providing a variety of senses such as touch and smell, as well as sight." [35] (Fig. 2, left); and "People will climb architecture as they would climb up mountains. They will gaze the sky between spaces as one would look up the sky above the ocean. They will sense the flow of time through the shadow on the ground" [27].

The space that maintains a constant relationship with the residents through the senses of the body has "depth", as in the case of "special depth has a close relationship with our experience, and it is therefore certain that depth itself is not something that space creates, but something that is created by the intervention of our body. The architect's 'view' or 'scenery' is not a 'picture' that we passively view with our eyes, but is something that we, with our entire being, feel. (...) Scenery in a picture, which is a completely different object from ourselves, is recognized in distance and height, but the architect's scenery is created by the walls, ceiling, and floor, and because of the potential directivity; the scenery never disconnects from ourselves and is ceaselessly connected to us" [36]. Eventually, it creates a "new feeling of human being" [24] that enjoys nature lost in an apartment space without depth and disconnected from nature. In other words, communication with nature leads to the restoration of humanity that has been lost since modern times.

The space that sensitizes the sense of nature further leads to sensitivity to others and to the joy of life. Therefore, architecture places importance on these senses of the body, and although it is sometimes a matter of functional scale and dimensions, it eventually moves to human emotions. In the end, what they are trying to reach is: "this space is both a meditative and affectionate one" [22] and the creation of "poetic emotion" [37], as described in the case of if there was anything missed, it might have been the sense of the body. These essential senses-walking, sitting, lying down, and touching-were lacking in a few locations around the house. Yet, because the floor had been elevated excessively high, it was challenging to sit. One was concerned that any senseenticing depth, such quiet or reflective times, might be disturbed since the inner partition doors were too quick to react to movement and lacked a complex sensation when opening and closing [38]. The emotions that the house should contain are not eye-catching splendor or sophistication, but rather that of contemplating life with thoughts and meditation and realizing the true meaning of life. With contemplative emotions and acute sensitivity, self-realization is the real purpose. In this aspect, the fact that a house is similar to the prayer space of the cathedral is considered the best compliment for the residential space in architectural magazines [24].

Therefore, beyond economic or physical efficiency, emotions are becoming more important, and it is critical that the space is capable of communicating with nature; as in the case of "no matter how small the land or a high-rise apartment is, if it has a beautiful courtyard or a safe balcony where you can breathe in the fresh air, it means that there is an architectural medium to receive the blessings of nature" [39].

And this primarily leads to an active search for external or semi-external spaces such as yards and terraces. This yard is lost after converting a *hanok* (traditional Korean house) to apartments. And the balcony that is reduced to a depth of 1.5 m in apartments and had been existed as a semi-external space, but incorporated into area of exclusive use space; now most of them are completely internalized. According to the description, "the desire for more indoor space is causing the terrace and balcony, which are regarded the best spaces in the entire structure in the western world, to disappear in Korea". [27]. However, these external spaces, which have been overlooked so far, and the various semi-external spaces or transition spaces located at the interface between the interior and exterior, are connected with the interior space in their own way, making the lives of residents colorful and rich.

A house that breathes with nature is also the result of "actively linking indoor and outdoor spaces with terraces (...), and rooftops" [32]. "Compared to the terrace or balcony of general multi-family houses, this one is quite large. Thus, the owners wanted to install a sash around its outer edge and expand the interior. I totally understand them. Yet, the architect wanted to give them a true terrace that can draw nature inside and enable users to walk into nature (...) the architect persuasively stated, 'terrace is an emotional space where users can communicate with nature' made the owners choose 'nature' over 'size'" [39]. The terrace and courtyard, which are external spaces where one can feel both nature and others. Some experts stated as follows: "sometimes, you can enjoy the wind and sun lights on a terrace with which the master bedroom and children's rooms are connected" [40]; and "the courtyard, pouring across the courtyard area, will be permitted spaces which connect nature, humans, and the city" [27]. It also says: "the yard (...) is a residence where one experiences nature and self-fulfillment, and is also a space of possibility which facilitates dialogue with the neighborhood" [34].



Figure 2 Examples of residential spaces for connection with nature and senses of the body (Source: "Space" magazine)

Therefore, it becomes important that the residents actively engage with nature, as in the case of "one final disturbing note is that the relationship between the interior and exterior, which is currently formed in a different manner from what was originally intended by the architect, does not seem active enough. The main residential area, except for the large window in the living room, is an inner-facing space, and thus it is doubtful whether it pushed the residents to the exterior in a natural manner. (...) Thinking about the various possibilities of recognizing the forest as tangible instead of a more abstract idea of nature, it is regrettable that the house does not take a more active approach towards nature" [41]. Therefore, beyond the terrace, the affection to the traditional Toit Maru space, which is located under the eaves at the boundary between the internal and external spaces, and designed to sit on the floor by taking advantage of the level difference between the interior and exterior, is also shown as in the case of "the highlight of this house is the newly interpreted Toit Maru" [23] (Fig. 2, center and right). Sometimes there are designs that force people to go through the outdoors or nature when going between buildings in a house or rooms; such as in the case of "from Ando Tadao's Sumiyoshi House to Seung H-sang's Sujoldang and Toechon House, there has been a series of modern adaptations made on the northeast Asian tradition of houses composed of detached units; but this example certainly pushes the boundary of such efforts to the extreme" [42].

## 5.3 Searching for Residential Spaces open to the Possibilities of Life

In Section 5.2, it could be seen that the architectural experts are aiming for a house where the residents can enjoy the richness of everyday life along with nature, rejoice in the moment they are living, and contemplate their lives. In order to advance into a space that sharpens the senses, improves the sensibility of the body and leads to a new relationship with nature and others, it is necessary to overcome the situation of the general apartments that "it is a perfect example of spatial regression, addressing only basic residential needs of sleeping and eating" [36].

To this end, new residential spaces, rather than simple arrangement of existing rooms with clear and limited functions, are required. It is not necessary to have a typical space composition as in the existing apartment units, but it is necessary to have places, where one can find hidden fun, as described in the following instances: "a loft under the slope of the roof expands to the stair hall between children's rooms and the top of bathroom, so it creates a wider space for every room. The entrance has storage space, but it is a secret space that can only be found by opening the doors of shoe closet. (...) You can have a barbecue party in a small garden on the courtyard, and the garden becomes an outdoor theatre when you pull down a hidden screen at the top of the storage" [40]; "A little round skylight in the child's chamber lets light in from the night sky, and a hole in the ground leads to a lower play area not covered by the building or the entire floor area" [43]; "Lifted by half floor, this unit has an advantage in height in terms of spatial quality as the ceiling height of its living room is 1.5 times higher than the usual standards. Above the kitchen, which doesn't need to have such a high ceiling, there is a small useful attic. It is a good place for storing all sorts of things or for the children to play hide and seek" [39] (Fig. 3, left); and "There was a possible field for the creation of fragmented space across the inside and a polygonal envelop. This can occasionally be utilized as an attic or a service area like a storage closet" [44].

A space beyond the existing organization leads to unexpected events, which bring novelty and pleasure, as in the following cases: "the color white and the spacing becomes the central idea that creates windows, holes, rooftops, stairs, and gaps, which create coincidental images" [36]; and "a space that gives us joy by creating an unexpected relationship between the scenery and the sky using various angles of the rooftop" [26]. And it could "draw imagination and creative inspiration by implementing the strategy of unpredictable surprise and defamiliarization" [45]. These concerns eventually lead to loose organization and concerns about non-deterministic spaces.

The architects hope to be open to the various possibilities of life without arranging everything, as indicated in the following instances: "Maybe an architect is not a profession that allows spontaneity. An architect always calculates ahead, and has to anticipate and imagine. However, since the future is something that we cannot know, when the lives of the people that use the place created based on the imagined life of the architect, it is then that a new building is born." [21]; and "As I was carelessly moving in time with the fictitious construction line, I also established the order of randomness apart from my inclination to use lines to connect seemingly irrelevant things,'; this become the basis for designing external appearance of buildings. (...) The main reason I let chance and random events handle unpredictable situations in my work as a designer—rather than becoming apathetic-is that they frequently offer better answers than I can" [46]. In the end, the space is given a real meaning as the residents intervene, as in the case of "Patio has several possible meanings. This space-the patio-can serve as a destination or an assignment in addition to being a location where we unwind. It can serve as a garden, an entrance yard, an outdoor living room, or even a home area. The terrace will still be maintained by users. By means of this kind of activity, the area and its users merge, and the area will be finished by adding more features and activities" [27].

In a way, it is the most fundamental intervention of architecture to simply list areas defined by the functional lifestyle patterns and circulation system; but criticism may arise on the spatial organization that does not allow more possibilities. Housing that leaves no room for residents is monotonous and does not allow for novelty and pleasure. This is sustained by the following cases: "Why not fill the 'scenery of the livelihood' as territory of variables for another habitability, with undefined territories, such as Toit Maru or the yard, which can contain variable stories in life and reach beyond the boards to develop relationship with the peripheral regions as the 'domain of the gap'?" [23]; "This project incorporates a refined architectural style to complete an aesthetically advanced project. However, for a residential project, the indoors would benefit from more interesting spaces" [29]; and "It can feel a bit suffocating because of its excessive completeness. There is no room to intervene." [47]



Figure 3 Examples of residential spaces open to the possibilities of life (Source: "Space" magazine)

Unexpected use and fun are considered truly interesting, as presented in the following cases: "The architect instead resolves this condition in the interiors with triangular forms that resolutely intrude into the living spaces as a kind of interiorized landscape. Humans and pets invent their own functions over time as the ledges act as benches, shelves, catnap areas, or something else altogether" [48]; and "a single guiding logic applied to the façade characterizes the whole space, presenting both intimate and open interior and exterior used for sleeping, eating, and playing. The Lilac Roof House was the playground of harmony, conflict, and of unexpected fun between the exterior and interior of the house" [49] (Fig. 3, center).

Sometimes, to capture more possibilities of life, more elaborate imaginations, and respect and detailed. consideration for small actions of everyday life are needed. It is described as follows: "Not all the courtyards are the same. Architects have to provide a careful design attentive to the life around the courtyard in order to make residents experience in the space as they intend. Based on this, architects have to make careful plan design and detail drawings and consider space dimensions, and even bear in mind the change of atmosphere created by light and shadow." [22]; "By placing a tiny box in the corner window, I attempted to introduce a micro-space-a smaller-than-room category-into daily existence. A room inside a room is an ambiguous environment. I wanted to create a focused look, like sipping tea while admiring the scenery or reading a book on the study windowsill" [44]; and "Space introduces kinds of behavior. The presence or absence of a chair, the question of how one is supposed to sit, all greatly affects the behavior of its user" [50].

Through loose organization and non-deterministic space, what the architectural experts are trying to reach is a space that is open to the possibility of a colorful and rich life that can create new meanings, as in the case of "the 'Through Garden House' is a rare masterpiece, with formal/spatial reasoning and completion incorporated by design and site management with great confidence from the client. So we ask. Can this house contain the full spectrum of life beyond the quantitative level of a small domestic house and a big house? What status does the house present as its own in that sense?" [51]. "Architecture is built to contain 'being'. A spatial form without 'being' is close to a pure sculpture art. 'To be', of course, is a verb. (...) There are too many nouns being used in architecture that should approach 'being' as a verb. Living room, bedroom, dining room, kitchen, bathroom are all nouns. But in a 'living room', the word 'living' is more important than the 'room'. The family activities such as resting, conversing, telephoning, doing homework, reading the newspaper, watching television, arguing, and amending relationships are the essence of a living room. Actions that are expressed via verbs are experiences (...) If there are children in the house, the house will be a 'pandemonium' of behaviors, and to reduce this space into a mere noun results in limiting the variety and the creativity of ways 'to be'" [50] (Fig. 3, right).

Therefore, as in the case of "the architect might have to turn his attention once again to the possibility of forming 'a free life (...)'" [41], housing should bring in diversity and creativity in life and allow people to experience "the freedom" [52] of life and existence through architecture.

The final point of design strategies for housing planning is that "It is same as providing a frame of possibility, which can transform a passive principal agent to an active family that can exchange the new potential of the occupation of the place" [37].

## 6 CONCLUSIONS

The issues of lifestyles and everyday life have regarded as the abstract and conventional functions, despite being sensitive to changes in the times and social structures from a macroscopic point of view. Changes in macroscopic social structure can be discussed through various academic discourses. However, research on people's microscopic real life and lifestyles is almost difficult to find, and data collection is also limited. For this reason, existing studies have in common that they do not adopt a microscopic attitude in their research methods. In this study, magazines were selected as materials for this micro-historical approach, and this study was intended to interpret them in relation to macroscopic social structures. In particular, through the analysis of lifestyle and architectural magazines, the comparison of the perspectives of the general public and architectural experts is an original part of this study that cannot be seen in other studies.

As human creativity emerges as a means of production in capitalism, the fundamental essence of everyday life and its values are changing. A paradigm shift, such as blurring the boundaries between work and life, is required, respecting human values and emphasizing an environment where creativity can be cultivated. In response to the change in the function of housing, the general public focused on the residential space as a workspace, and preferred the complex use of space rather than its functional differentiation. However, architectural experts consider privacy and view as the most essential features of housing layout. They focused on physical and mental relaxation, and from a relatively conservative point of view, it was desirable to have a house that preserves its original value as a "house".

After analyzing the lifestyle magazines from the view of the design strategies of housing planning, we concluded that the general public viewed house as a creative place for gaining inspiration and ideas as an extended position on the function of housing. In addition, as they wanted to break away from the idea of an average nuclear family, engage in various creative occupations, and pursue their individuality and identity continuously through various professional hobbies in the characteristics of residents, they also wanted to establish and express their taste and identity through their house. Unlike architectural experts who want a house "to be a house" above all else, the general public wants a house "not to be just a house" more than anything else. The general public wanted the house to be a creative environment by introducing various cultural, artistic or commercial elements from places, including coffee shops, lodgings, businesses, studios, libraries, and art galleries within the building.

The architectural experts were also intent on life by pursuing a rich and abundant life that does not lose diversity and creativity. However, they were interested in realizing the essence of everyday life and to enrich it further, rather than aim for a life that stimulates creative experiences that follow trends similar to those published in lifestyle magazines. In other words, they aim to live a life where they can feel the specialness and joy of every moment with gratitude and experience the freedom of existence.

The source of abundance in everyday life is "nature" rather than culture or art. They prefer to admire the delicate, wonderful, and abundant nature that changes subtly from moment to moment and be inspired by it. And the senses of the body and emotional depth such as contemplation and reflection were considered important. The architectural experts consider it ideal to contemplate life with thoughts and meditation, to realize the true meaning of life, and to attain self-realization. As a result, there is a tendency to pay particular attention to spaces such as yards, terraces, and various transition spaces between inside and outside, where one can breathe with nature delicately and enjoy leisure of everyday life. Therefore, in architectural magazines, rather than wanting a house to become something other than a house, there is a strong desire that a house does not lose its essence. While art gallery-like houses favored by the general public are subject to criticism, the only building type that is used as an ideal reference other than housing is the cathedral's space for prayer. It emphasizes on the contemplative emotions that enable people to realize the meaning of life and existence.

In addition, architectural experts seek a house that is open to the possibilities of life rather than a house where everything is perfectly defined by the architects and does not allow the intervention of its residents. They wanted to create a new meaning by adding a new story of residents to the house every moment, because small but different and unpredictable everyday pleasures and novelties should be hidden in every corner of the house. In other words, they considered the most desirable residential space as an infrastructure of possibilities, a flexible structure that is open to diverse and affluent everyday life. It eventually becomes a unique and authentic place that cannot be compared with any other houses.

In terms of the design strategies of housing planning, the opinions of the general public and specialists in architecture are slightly different. In the case of the general public, they focus more on the new paradigm of the changing social structure, while the architectural experts place more importance on the fundamental dimension of life and existence that does not change. When compared to the broader population, the conservative viewpoints of architectural specialists may be seen as being slow to adopt new trends. Yet, it can also be regarded as a mindset that places more importance on core principles than on fads. This difference in views may be the fundamental reason for revealing different directions of housing planning. However, considering a sense of life that cannot be captured in the existing rigid apartments can be seen as a common goal that must be reached in contemporary domestic housing to gain sustainability. In addition, it highlights the importance of preliminary analysis for public and private market of development initiatives by exploring the improved needs. It is expected that this research will be a useful reference bycapturing fundamental indications for future development for the sustainable housing.

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## The Assessment Model of Robotic Process Automation (RPA) Project Using Benefit Study and Balanced Scorecard (BSC) Approach

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Abstract: Assessing Robotic Process Automation (RPA) projects is challenging, especially for small and medium-sized enterprises (SMEs) with limited resources. The most common approach, cost-benefit analysis, measures the financial success of a project, but it does not capture all RPA benefits, which can lead to erroneous decisions about starting, continuing, delaying, or stopping an RPA project. This research presents a novel RPA project assessment model that combines a benefits approach with the balanced scorecard (BSC) framework. The model identifies RPA benefits from the scientific literature and classifies them into four BSC indicators: financial, business process improvement, customer satisfaction, and learning and development. SMEs can easily use the model by comparing expected and actual benefits to make quick and holistic decisions. The model's simplicity, ease of use, and ability to reveal both monetary and non-monetary RPA benefits make it a valuable tool for SMEs.

Keywords: assessment; Balanced Scorecard (BSC); benefit; project; Robotic Process Automation (RPA);

## 1 INTRODUCTION

Technological advancements have enabled many companies to automate well-structured business processes with high volumes, error rates, and repetitive routines [1, 2]. Automation has been applied in various fields, from factory manufacturing processes to office accounting. Extending automation to all departments makes companies more efficient and agile [3]. However, automation in the office is not easy to implement. The biggest challenge does not only come from technology but also from decision-makers in the company who are not fully convinced about technology and its benefit to the organization [4-6].

One form of office automation technology is Robotic Process Automation. It is a software robot that performs repetitive back-office tasks by mimicking the behavior of people in interaction with computers [2], such as: opening the application, searching data in the database, extracting data from PDF files, sending emails, and so on [2, 7]. RPA offers a non-invasive and flexible technology that is easy to implement in various business processes, such as the on boarding process in the human resources department, the invoice processing in the purchasing department, the inventory management in the production & logistics department, the order processing in the sales department, and others [7].

RPA has been proven to provide benefits to companies. However, some companies, especially SMEs failed because they considered that the implementation of RPA does not provide benefits that are worth the sacrifices made [8, 9].The companies that have implemented RPA sometimes feel stuck, and choosing not to continue the RPA project [10]. This is partly because these companies do not know how to assess the performance and success of their RPA Projects.

To avoid mistakes and hasty decision-making, the authors devised a model that can be used to assess RPA Projects with several indicators of benefits. With this model, RPA assessments can be more objective, and decisions to continue or stop RPA are more accountable. This model is inspired by the strategic decision assessment and monitoring model in business management known as the balanced scorecard [11, 12]. This study will depart with the research questions:

- RQ1: What are the benefits of RPA?
- RQ2: How to build and use an assessment model of RPA Projects using the benefits study and balanced scorecard (BSC) approach?

The research began by collecting information and data on the benefits of RPA from scientific contributions. The identified benefits were then grouped into four clusters of BSC perspectives, and used as parameters in the assessment model. The assessment model that has been built is then tested directly on one SME (Small&Medium Enterprise). The authors report on the feedback received, regarding the obstacles encountered by SME while using the model.

## 2 STATE OF KNOWLEDGE 2.1 An Overview of RPA Benefits

According to Axmann and Harmoko (2020), RPA is one step closer to making a business lean with the benefits acquired in the short-term and long-term, for management, employees, and customers [7]. RPA provides the highest efficiency in personnel cost, and it requires the lowest investment cost [9, 13, 14]. As RPA is easy to integrate with processes when compared to other automation technologies [15]. And its development is faster, because it uses the existing infrastructures such as networks, desktop, and server [2, 15]. It can improve data quality and accelerate digitalization in the whole company [7].

RPA brings benefits for customers in the form of excellent service, from ordering items to after-sales service. With RPA, the company can interact more with customers, such as serving their orders, answering their questions, and knowing their preferences for the new product [7]. RPA helps employees as assistants (attended mode) to perform mundane tasks [16]. The technology assists them in completing tasks faster. While indirectly, RPA can increase creativity, selfconfidence, and satisfaction of the employee, because when employees are free from repetitive tasks, they will have the opportunity to increase skill and knowledge [7], which makes them confident to execute high value-added tasks [13].

Research on the benefits of RPA has been conducted by several researchers before. Koljonen (2023) describes the benefits of RPA and combines them with risks, to illustrate that RPA implementation has two different sides (advantages and risks) that must be considered. Furthermore, Meironke and Kuehnel (2022) designed metrics that can help measure the benefits of RPA with 62 indicator metrics [17, 18]. In addition, to assess the overall RPA project, RPA providers have equipped their products with cost-benefit analysis features such as UiPath Automation Hub, and Automation Anywhere Business Analyst.

In contrast to all, authors conducted a benefits study to support the development of an RPA project assessment model in SMEs. Based on the experience and interview with RPA consulting company and SMEs [19, 20], authors found that not all indicators described in Meironke and Kuehnel's research can be understood by SMEs, besides that the costbenefit analysis method provided by RPA providers is not sufficient to reveal non-monetary benefits of RPA. Starting from this, the authors designed an RPA project assessment model with a balanced scorecard approach as a business management method that is familiar to SMEs, so that it can be used immediately and helps in a fast and accountable decision-making process.

## 2.2 The Balanced Scorecard (BSC) Theory

The Balanced Scorecard is a monitoring tool for strategic decisions taken by a company on the basis of pre-defined indicators that should address four dimensions: financial, customer satisfaction, internal business processes, and learning and growth [12, 21]. Organizations use BSC (1) to communicate what they are trying to accomplish, (2) to align the day-to-day business to the company's strategy, (3) to optimize projects, products, and services, and (4) to monitor the achievement of strategic targets [11].

The BSC was created as a measurement system and as an answer to various criticisms of unilateral measurement of a company's performance capability [12, 22]. Nevertheless, the concept of BSC has evolved beyond a simple perspective that focuses on financial, into a holistic system that manages, measures, and tracks the success of organizations in achieving their strategic goals [11]. In addition, the BSC has been used to measure the various benefits of information technology projects such as E-business Projects by Grembergen and Amelinckx (2002) [23], Enterprise Identity Management Project EIdM by Royer and Wolfgang (2008) [22], and Information Communication Technology ICT Project in Southern Africa by Ogembo-Kachieng et al (2013) [24].

The balanced scorecard model consists of four tables. Each table represents four perspectives on a company's vision and strategy (see Fig. 1). A table consists of four columns; (1) objectives, (2) goals, (3) indicators, and (4) initiatives. The first column, objectives describes what the company wants to achieve (objectives) from the company's strategy or vision. The second column goal is the magnitude or quantification of the objective that has been described in the first column. The third column is indicator or places where goals and objectives can be evaluated and tracked when the company's vision and strategy have been implemented. Meanwhile, the fourth column, or initiative describes what strategic steps are being and will be taken to meet the goals.



Figure 1 The Origin Balanced Scorecard Model [12]

To better understand the balanced scorecard model the four section are generally described and an example of a balanced scorecard in a company (Jewellery store) is shown in Fig. 2).

**Financial perspective:** This perspective is possible if the development, implementation, and execution of new strategies generate profit [12, 22]. The Profit is a positive amount of total income after deducting costs in a certain period [25]. If the company can reduce costs through efficient business processes, profits will automatically increase [25, 26]. This shows that the financial perspective is closely related to efficiency, therefore the benefits of RPA will classify into efficiency clusters that represent the financial perspective in the BSC. **Customer perspective:** The old argument holds that it is essential for companies to develop the best products to achieve the best financial performance, but in reality, the customers and their behaviour bring strong influence to the market [11, 12, 27]. Customers can easily buy products from unknown brands, but on the other hand, they can also refuse products from well-known brands for various justifications. Understanding customer needs and how to satisfy them is not only to keep loyal customers but also to attract new customers [27]. In the context of our study, we perceive that the implementation of RPA must satisfy customers, which are not only real customers but the owners and employees of the company, who gain benefit from RPA implementation.

	Objectives	Goals	Indicators	Initiatives
Financial Perspective	To increase profitability	Increase the profitability of the company by 15%	Financial statements	Negotiate installment partnerships with credit card companies
Customer Perspective	To have a more attractive store for customers	Increase the average number of daily visits of customers by 20%	Count of Customers	Improve window jewelry display and invest in social media
Internal Process Perspective	To be a benchmark in Customer Service	Increase the number of compliments in Customer Service by 15% and reduce complaints by 80%	Statistical analysis of Customer Service reports	Redesign the Customer Service process
Learning and Growth Perspective	To have a sales force of experienced professionals	Replace 30% of the salespeople	Number of new contracts vs staff terminations	Start the process of recruitment and selection

Figure 2 Balanced Scorecard example: Strategic map for a Jewellery store [28]

**Business processes perspective:** To satisfy stakeholders, business processes must be value oriented. Processes that have a significant impact on value creation must be more effective. The effectiveness of the process can be seen from the increase in productivity and accuracy [11, 12, 22]. In this study RPA should provide direct benefits to business processes. Therefore, the business process perspective will include in identifying the RPA benefits.

Learning & Development perspective: This perspective complements the other perspectives. However, its role is not less important than the others, because it ensures sustainability [12]. From a learning and development perspective, the company knows that a new strategy, such as the RPA implementation will continue to improve the capacity and capability of human resources, infrastructure, and management. Therefore, this perspective is included, to ensure that the benefits of RPA must support sustainability.

The concept of the BSC lies in the fact that strategic objectives are listed by indicators, target values, and action plans. Those make sure the realization of the new strategy must be clear [11]. If the success of implementing RPA is indicated by obtaining comprehensive benefits as much as possible, then incorporating the BSC perspective into this study becomes relevant.

## 3 RESEARCH METHODOLOGY

Our study employs three research methods: (1) a structured literature review identifying the benefits of RPA, (2) a meta-analysis that presents statistical data on the benefits of RPA in the scientific contributions, and (3) an a first interview for problem identification, model testing, and feedback collection. It is planned to execute more interviews in future research.

## 3.1 Procedure of Structured Literature Review

The structured literature review refers to the guidelines of Webster & Watson (2002) and vom Brocke et al. (2015) [29, 30], where future academic research is based on the review of previous literature. Effective review creates a solid foundation for advancing knowledge. This facilitates theory development, covers areas with a lot of research, and uncovers areas that need further research [30].



Figure 3 The Literature Survey Process

To guarantee scientific rigor, relevant data have been collect following Brocke et al. (2015) study on Structured Literature Review (SLR) [29]. Academic contributions related to the topic of RPA using the search query: "RPA OR robotic process automation" have been surveyed. Search queries have been kept deliberately generic to avoid excluding contributions that indirectly address the various benefits of RPA. In this way, 1,522 academic contributions

have been found, however only 149 of them addressed RPA. With abstract, title, and keyword analysis, full-text analysis, and forward and backward searches, 119 academic contributions have been found that mention the benefits of RPA (see Fig. 3).

## 3.2 Meta-Analysis

Meta-analysis is a statistical technique that combines two or more similar studies to obtain a quantitative mix of data. It is a retrospective observational study, where the researcher makes recapitulation of the data without conducting experimental procedures. Meta-analysis does not emphasize the findings of various studies, but the data [31]. This method has been used in several scientific papers, including by Axmann et al. (2021) to identify RPA cost drivers [6]. Using a similar method information/data on RPA benefits have been collect and classified into four BSC perspectives. Fig. 4 shows its distribution in RPA papers published in the last 5 years (2018-2022).

## 3.3 Interview

The main purpose of the case study in this research is to test and get feedback on the established assessment model. Case study data collection used the one-on-one interview method by Ryan et al. (2009) and Bullock (2016) [32, 33], where the experience of the interviewee (company owners) in evaluating RPA pilot projects (1 month) is explored in depth. Furthermore, the interviewer presents an assessment list as in Tab. 2 (see Section. 6) to be filled in by the company owner as an assessment model for his project. During this process, there was an interaction between both (the interviewer and the interviewee) about some terminology on the list which is not understood by the interviewee. Once completed, the interviewer asked for feedback on this kind of assessment model from the interviewee.

In the future the model needs to be tested by more experts.

## 4 THE BENEFITS OF RPA

From 149 scientific contributions, at least 27 benefits have been found, which can be classified into four BSC perspectives such as Tab. 1. **Efficiency & Financial**: RPA implementation provides financial benefits for the company through cost and time efficiency [7, 34]. The time saving here includes operational time, programming, and testing when the RPA is initiated [35]. In the context of investment, RPA is feasible and profitable because the return on investment of RPA is relatively faster than the other automation technology [36]. In addition, RPA can support company growth [37] by improving economic performance [38] such as increasing revenue and saving full time employee [39].

**Business Process Improvement:** To improve business processes, RPA robots offer 24-hour non-stop service without getting tired [40, 41]. This reliability is followed by the ability to execute fast, effectively, and accurately [13, 42], thereby accelerating the decision-making process [13,

35]. RPA implementation is also easy and not complex [14, 15], it can be used in every unit in the company [7], and is easy to integrate with existing systems [2, 16]. In addition, RPA can also increase employee utilization through refocusing on value-added tasks [41, 43].

Table 1 The Benefits of RPA					
Benefits	Mentioned on				
Efficiency & Financial					
Improve Productivity	33 Papers				
Improve Accuracy	41 Papers				
Efficiency in Implementation Process	28 Papers				
Availability Service 24/7	23 Papers				
FTE (Full time employee) Saving	27 Papers				
Improvement Worker Utilisation	10 Papers				
Cost Saving	48 Papers				
Cycle Time Reduction	6 Papers				
Testing Time Reduction	4 Papers				
Accelerate ROI	2 Papers				
Business Process Improvement					
Provide Reliability & Agility	14 Papers				
Provide Compliance	11 Papers				
Support Scalability of Process	14 Papers				
Provide Transparency Process	12 Papers				
Reduce Complexity of Process	26 Papers				
Speed-up Decision-Making Process	17 Papers				
Versatility to Any Business Process	4 Papers				
Flexible to Any Existing System	20 Papers				
Error Reduction	31 Papers				
Stakeholder Satisfaction					
Increased Motivation Satisfaction Employee	18 Papers				
Reduce Employee Workload (manual task)	11 Papers				
Increase Employee Skill & Creativity	19 Papers				
Customer Satisfaction	8 Papers				
Learning & Development					
Promote Innovation & Development	20 Papers				
Provide Data Security	15 Papers				
Support Business Growth	25 Papers				
Support Risk Management	8 Papers				

**Stakeholder Satisfaction**: The implementation of RPA provides satisfaction not only to the customers and owners but also to employees. With the automated process, employees will be liberated from tedious and mundane tasks. They will be stimulated to upgrade their skills and creativity to become more valuable. In terms of customer satisfaction, RPA can help customer service staff in speeding up the order process or complaints made by customers [7, 42].

Learning & Development: The implementation of RPA will accelerate the digitization process and other aspects that accompany it, such as transparency, data security, machine learning, and so on [22, 37, 42]. This is because RPA encourages all processes or documents to be automated to be digital, transparent, and secure from cyberattacks [7, 13, 44].

In Fig. 4, the meta-analysis explains how the benefits of RPA are calculated among scientific contributions over time. The graph shows that scientific contributions in the past 5 years mostly looked at the benefits of RPA from the perspective of business process improvement (50.1%) compared to learning and development (21.6%), efficiency (17.7%), and stakeholder satisfaction (10.6%). The graph also shows from 2018 to 2022, the benefits of RPA have been

or not ok.

revealed through scientific contributions, which are different from costs.



## 5 THE ASSESSMENT MODEL OF RPA PROJECTS

This assessment model is inspired by the balanced scorecard, in which the decision of whether to continue the RPA project is based on an assessment of the expected benefits (target) and actual benefits (actual) of the RPA. When the benefits obtained are by company expectations, the decision maker can continue the project, but if not met expectations, the decision maker can postpone or stop the project. In section 2, an example of a balanced scorecard was explained, along with the accompanying table.

This assessment model adopts part of the concept, especially in the classification of benefits that follow the balanced scorecard perspective. BSC itself is not a rigid method, it is applied flexibly in each company or business unit. Fig. 1, section 2 shows an ideal figure of BSC which includes objective, measure, target, and initiative columns, but in its application at the Jewelry store, the name or definition of the assessment columns differ (see Fig. 2).

The assessment model consists of four lists of benefits, namely: efficiency and finance, stakeholder satisfaction, business process improvement, and learning & growth. Each list consists of four columns; (1) benefit description, (2) target, (3) actual, and (4) measure (see Fig. 5). In the benefit column, the company describes the benefits it wants to get from RPA. To provide insight into the benefits of RPA, and help the company/organization to fill the first column benefits, the authors have conducted a literature study on the benefits of RPA. Identified benefits are classified and entered into four different lists of benefits in the assessment model. The second column is target, where the company can enter how much (magnitude) the obtained benefits from the RPA project. Column three is the actual amount of the respective benefit, regarding the existing project. And the fourth column, measure, contains two things: (1) the differences or



gaps between the target and the actual, and (2) comments ok

Figure 5 The Assessment Model of RPA Project

## 6 MODEL TESTING

To clarify the assessment model, the authors tested the model on a small and medium-sized company in Germany. The company had implemented a 1- month trial of RPA in its inventory management. Although the RPA project is still a pilot project, the company owner does not mind applying the author assessment model to evaluate the project. Currently, the owner sees the existing assessment tools as too complicated and partial [20]. The business analytics features in Automation Anywhere and UiPath can assess the RPA project, but it needs a lot of effort and is time-consuming to apply them. On the other hand, it is not enough for companies to assess the benefits of RPA only from financial benefits, because there are many non-monetary benefits obtained from the implementation of RPA. However, measuring nonmonetary benefits is not easy and requires in-depth observation of each individual in the company. For this reason, the owner of Flamm GmbH thinks that the assessment model offered is simple and logical because it only compares expectations and reality [20]. This is also in line with the Expectation-Reality Gap study in SMEs, where the failure of a new method is when it fails to meet predetermined expectations [45].

Table 2 Example of Using the	Assessment Model in SMEs

Benefits	Target	Actual	Measure
Efficiency			
Improve Productivity	yes	yes	OK
Improve Accuracy	100%	97%	Improve
Efficiency in Implementation Process	yes	yes	OK
Availability Service 24/7	yes	yes	OK
FTE (Full time employee) Saving	2  FTE	3 FTE	(+)1 FTE
Improvement Worker Utilisation	yes	yes	OK
Cost Saving	€1000	€500	(-) €500
Cycle Time Reduction	35 min	27 min	(-) 8 min
Testing Time Reduction	55 min	$45 \min$	(-) 10 min
Accelerate ROI	yes	no	not OK
Business Process Improvement			
Provide Reliability & Agility	yes	yes	OK
Provide Compliance	yes	yes	OK
Support Scalability of Process	yes	yes	OK
Provide Transparency Process	yes	yes	OK
Reduce Complexity of Process	yes	no	not OK
Speed-up Decision-Making Process	yes	yes	OK
Versatility to Any Business Process	yes	no	not OK
Flexible to Any Existing System	yes	yes	OK
Error Reduction	yes	yes	OK
Stakeholder Satisfaction			
Increased Motivation Satisfaction Employee	yes	N/A	N/A
Reduce Employee Workload (manual task)	yes	yes	OK
Increase Employee Skill & Creativity	yes	N/A	N/A
Customer Satisfaction	yes	yes	OK
Learning & Development			
Promote Innovation & Development	yes	N/A	N/A
Provide Data Security	yes	N/A	N/A
Support Business Growth	yes	yes	OK
Support Risk Management	yes	N/A	N/A

Although the object of our research is not a large company and only SMEs, the need for reliable and real-time inventory management is essential. The limited number of staff makes the company owner interested in using robotic process automation (RPA) solutions to solve problems in inventory management. Automated inventory management allows companies to plan to meet variable demands for components or materials. The Bot of RPA will notify managers when stock is below the level specified in inventory management. For example, when the current stock (CS) touches the reorder point (ROP) or extra safety stock (EES), it creates an alert and automatically places a new order, which is ready to be approved by the manager. With the above use case, a benefits list was created for the RPA project, which was then filled out by the company owner (see Table 2). From the assessment, there is a negative gap between expectations and reality, which is marked in red. This is what the company needs to pay serious attention to. They must find the cause and initiative steps to mitigate this potential failure (see Tab. 2).

The feedback from this test was that the company owners found the model uncomplicated and easy to understand. The model is suitable and sufficient for pilot projects and periodic project assessments. However, for final project assessments or feasibility studies, it should be combined with a detailed cost benefit analysis. From this model testing, the first proof of concept/model was achieved. More test have to be done to further verify the model but the first evaluation shows positive results and the model can be applied at companies to periodically monitor or assess their RPA projects so that the potential for failure (the gap between expectation and reality) can be detected and mitigated immediately.

## 7 CONCLUSIONS

The development of the RPA project assessment model is motivated by the need for a decision-making process to start, delay, continue or stop RPA projects quickly and accountable. The parameters in the assessment and model are the benefits identified in the literature study. According to model testing on an SME (section 6), the model is considered suitable for assessing pilot projects of RPA and periodic RPA project assessments because the model considers all important criteria and has the advantage of being quick and easy to use. For the final assessment of RPA projects or RPA feasibility studies, it is better if the model is combined with a cost-benefit analysis.

Future research is directed at testing the model more widely, on many SMEs to better understand its challenges and limitations. This will be done with more interview partners and also in comparing the model with other models.

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## Requirements for the Transformation towards Returnable Transport Item-Enabled Circular Economies in the Austrian Parcel Industry

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Abstract: The European Green Deal sets the ambitious targets of establishing the first climate neutral continent by 2050 and reducing emissions by a minimum of 55% by 2030. In order to move the involved stakeholders to action, the European Commission has formulated proposals for regulations. One such proposal defines a legal framework to force industries to reduce the environmental burden caused by packaging waste. A major waste producer is the parcel service industry (CEP; courier, express, and parcel) and the industries it serves. Once put into place by the EU member states, the new laws will force all players in these sectors to increase business innovations in circular economies, which are based on the principles of recycling and reuse. Circular economies can be achieved by the implementation of returnable transport items (RTI) integrated with Industry 4.0 technologies. The ongoing research project ReKEP, which is largely funded by the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, investigates potential impacts of RTI-based circular economies in the Austrian parcel service industry. The project's particular interest is to identify the requirements of the most relevant stakeholder groups in the CEP industry for the successful transformation towards RTI-enabled circular economic Chamber. This paper summarizes the interview results, which indicate that, despite recognizing the high potential of RTIs for reaching ecological sustainability goals, the contemporary awareness of the EU Green Deal and the concomitant responsibility to take action seems too low for successful implementation. The study outcome suggests that research and development in RTI should focus on operational requirements of workers and line managers from CEP industries for successful transformations to circular economies.

Keywords: Circular Economy; Ecological Sustainability; Packaging Waste; Parcel Industry; Returnable Transport Item

## **1** INTRODUCTION

## 1.1 Returnable Transport Items for the Elimination of Packaging Waste

The European Green Deal aims at the ambitious target of turning Europe into the first climate neutral continent. As part of this initiative, proposals for policy frameworks were formulated with the intention to ignite business innovations that prioritize the reduction or elimination of the environmental burden of packaging waste. In order to remain compliant with EU regulations in the upcoming years, European courier express parcel (CEP) industries will need to increase recycling, refilling and reusing of packaging material to reverse the trend towards processes that rely on one-time use and disposal of packaging materials [1].

Currently, the most widely used transport items are paper-based boxes, which are a major reason for an everincreasing environmental burden. Such solutions generally come without refilling or reuse features and thus are usually turned directly into paper waste. While fibers are partly recyclable, the underlying cycles are limited, before ending up in incineration plants that generate carbon emissions (Fig. 1A) [2].

One frequently proposed solution to effectively turn around the trend of mounting paper waste production is putting returnable transport items (RTIs) in circulation, which are defined as "any product for the purposes of transport, handling and/or distribution of one or more products or product packages that are returned for further usage [including] pallets [...] as well as all forms of reusable crates, trays, boxes, roll pallets, barrels, and trolleys" [3]. The RTI concept would theoretically allow hundreds to thousands of reuse cycles before recycling becomes necessary. In addition, a single reuse cycle is shorter compared to the recycling process of its paper counterpart. Therefore, RTIs would conceivably create less environmental burden in terms of waste and carbon emissions (Fig. 1B) [2, 4].

Although the advantages of RTIs in contributing to global ecological sustainability goals seem obvious, and were even demonstrated in specific industries [5], implementation on a broader scale is sluggish [4, 6]. One of the challenges for a transformation towards RTI systems is the establishment of a functioning RTI system that meets the needs of several stakeholders. If there is no added value from the stakeholders' perspective, the potentials of RTIs cannot contribute to reaching global sustainable development goals.

With a focus on these notions of stakeholders, this paper investigates the main challenges associated with the implementation of RTIs in the CEP industry and defines the specific needs of the most important stakeholder groups in the Austrian context by addressing the following research questions:

- 1) Are RTI systems viable alternatives to cardboard-based or other one-way packages?
- 2) What are the challenges associated with the implementation of RTI solutions?
- 3) What are the prerequisites for turning RTI solutions into successful enablers of circular economies?

## 1.2 State of Current Research

The theoretical advantages of RTIs over linear transport solutions and the interest in reaching the global sustainable development goals recently resulted in multiple development projects and research initiatives [7, 8]. Depending on the underlying lifecycle management approach [9], the transportation strategies [10], the design of the logistics system [11], the integrated technical features of the transport solution [12], or the use case scenario [5], the potential advantages of RTIs seem to be indeed detectable. However, some studies show contradictory results [2], which suggest knowledge gaps concerning the technical and strategic requirements. Shifting research from development of economic and ecological indicators to defining more usercentric success factors (operational requirements for RTIbased circular economies) might increase the rate of adoption.



Figure 1 Reuse cycles of returnable transport items are shorter than recycling cycles of fibers. (A) The cycle of fibers from paper-based transport items. The box starts its journey at the box factory, from where it is delivered to another factory of a manufacturing company or a parcel delivery service provider. Once filled with a product, it is used as a transport item for the delivery of a product. After the receiver has unboxed the product, the box is disposed of as paper waste, which is ideally returned to a paper-box factory producing new boxes with recycled fibers. (B) The tightened delivery and reuse cycle of returnable transport items. After manufacturing, RTIs start their cycle at the sender of a product. Once the product is delivered, the RTI is backhauled to the sender for reuse. Figures kindly provided by BOOXit.

Considering these research gaps, currently the most reliable source of information are the stakeholders groups involved in existing supply chain [13]. In comparison to linear supply chains, closed-loop supply chain networks have an increasingly complex stakeholder structure, due to the additional reverse logistics processes [4]. Therefore, a prioritization of the most relevant stakeholder groups might be necessary, before inquiring about their requirements for the implementation of RTI systems in circular economies [7].

The stakeholder view could also apply to either of the recently derived frameworks to develop and implement RTIenabled circular economies in specific use case scenarios [14–17]. Under this assumption, this paper focuses on the perspectives of the most influential stakeholder groups with the objective of detecting and evaluating the stakeholder requirements, which are to be defined as success factors for RTI systems [18, 19].

## 1.3 The Research Project ReKEP

This paper is an outcome of the research project ReKEP, a consortium research project funded by the Austrian government to investigate the stakeholder requirements for successful transformation from cardboard-based transport items usage to RTI-based circular economies. The Institute for Digital Transformation and Strategy at the University of Applied Sciences for Management and Communication in Vienna, and the University of Applied Sciences Upper Austria as well as the consortium leader, the Austrian Institute of Technology, conduct the research activities together with start-up and logistics company partners providing consulting services and process resources for onsite investigations [18, 19].

The paradigm technology of ReKEP is the BOOXit RTI solution, which had been advanced by the project DigiPharmaLogNet [20]. BOOXit RTIs have a range of features that are advantageous over cardboard-based boxes in circulation [21]:

- Stackability of boxes with different sizes (Fig. 2A)
- A drawer mechanism for storage in a proprietary rack (Fig. 2B) allowing "one-shot" loading and unloading of multiple boxes (Fig. 2C)
- Detachability of the lid (Fig. 2D)
- Mechanism for combining multiple box frames for upscaling box volumes (Fig. 2E)
- Integrability of Industry 4.0 sensors for the purposes of tracking and tracing of transported products
- Compatibility with a patented robot arm for full automation of warehouse management processes (Fig. 2F)
- A proprietary inventory control system and a mobile application for optimal box management (Fig. 2G).

The establishment of a functioning Industry 4.0enhanced RTI ecosystem using a solution such as BOOXit requires that the needs of several stakeholders are met. To derive stakeholder needs, a stakeholder identification framework has been established in ReKEP, which allows prioritization of stakeholders according to either a claimsbased view (e.g., interested in either financial returns or maximizing sustainability impact) or a resource-based view (e.g., direct vs. indirect providers of supply chain resources).

From a resource-based perspective, courier express parcel (CEP) service providers and their business customers, i.e., retailers, can be seen as the two most important stakeholder groups, since they provide direct input to the transactions [7]; in other words, they perform the delivery and theoretically the reverse logistics.



Figure 2 The BOOXit RTI solution. (A) A proprietary mechanism allows stacking and fixation of boxes with different sizes. (B) Proprietary racks enable the drawer mechanism of BOOXit boxes. (C) Racks enable the "one-shot" loading and unloading of multiple BOOXit boxes. (D) Box lids are detachable. (E) Box volumes can be upscaled through the combination of multiple box frames. (F) A patented robot arm for full automation of warehouses. (G) A proprietary mobile app for using an inventory control system. Figures kindly provided by BOOXit.

In order to define the specific needs of these stakeholder groups in the Austrian context, semi-structured interviews of CEP service providers and retailers partaking in the Austrian parcel industry were conducted. The interviews focused on the challenges faced when adopting RTIs in their delivery processes. We deliberately included German companies that have connections to the Austrian market to increase the volume of the database, because the Austrian CEP market is rather small. The Austrian and German markets are also closely connected, since many German companies serve the Austrian market. The analysis of the interviews resulted in the categorization of the responses into themes that highlight the industry's readiness, the barriers of RTI implementation, and the innovative practices applied to achieve a circular economy. The outcome of this study provides a comprehensive understanding of the current state of RTI adoption in Austria and the key influencing factors.

## 1.4 Organization of the Article

The rest of this article is structured as follows: Section 2 describes the qualitative research approach to data collection and analysis; Section 3 presents the research findings in several subsections; while Section 4 discusses the findings and draws conclusions from the study.

## 2 METHODS

## 2.1 Semi-structured Interviews

The research questions were addressed using a qualitative research approach based on semi-structured interviews with executives or senior managers responsible for sustainability issues [22, 23]. The target companies were parcel service providers (PSPs) and retailers either headquartered or operating in Austria or Germany.

The interviews were recorded, and the transcripts or interview protocols were analyzed in-depth for coding of relevant sentences or paragraphs using the ATLAS.ti software program from ATLAS.ti Scientific Software Development or the MAXQDA software program from VERBI. The codes relevant to addressing the research questions were grouped. The coded transcripts were exported as QDPX files for subsequent merging into a single project for the determination of code frequencies or code cooccurrences using ATLAS.ti.

#### 2.2 Interview Partners

A total of 15 invited companies, involving small, middle, and large enterprises operating either as CEP service providers or retailers with their headquarter or subsidiaries established in Austria agreed to an interview. Sustainability representatives of CEP and retailer companies were interviewed (Tab. 1).

Table 1 Interview partners					
Interviewee #	Firm	Job role	Country		
1	Parcel service provider	Innovation manager	AT, DE		
2	Drugstore retailer	Head of Human Resources & Internal Communication	AT		
3	Fashion retailer	Head of sustainability	DE		
4	Natural cosmetics retailer	Head of Global Relations	DE		
5	Office supplies retailer	Head of Sustainability and Quality Management	DE		
6	Sporting goods retailer	Head of HR und SCM	AT		
7	Coffee and consumer goods retailer	Project Manager Logistics & Sustainability	DE		
8	Spare parts retailer	Head of Logistics	AT		
9	Installation and fixing material retailer	Executive Board Member and Head of Logistics	AT		
10	Apparel retailer	Senior Operations Manager supply chain logistics	AT		
11	Installation and fixing service provider	Innovation Manager	DE		
12	Parcel service provider	Senior Key Account Manager	AT		
13	Parcel service provider	Managing Director	AT		
14	Parcel service provider	Sustainability Manager	AT		
15	Parcel service provider	Co-founder & CEO	AT		

## 3 RESULTS AND DISCUSSION

## 3.1 Readiness to Adopt Returnable Transport Items

Given that RTIs have the potential to support companies in contributing to the global sustainability goals, it is expected that logistics providers would design and implement business initiatives for putting RTIs in circulation. Therefore, the interview partners were first asked about current corporate sustainability measures in general, and then specifically surveyed about ecological sustainability goals in place. As expected from logistics companies, sustainability measures were in place to improve ecological factors; especially, for the purpose of achieving carbon neutrality.

Despite their potential positive impact on ecological factors, RTI solutions seemed to play a rather minor role in the implemented sustainability measures. As shown in Fig. 3, only three statements on sustainability measures involved RTI solutions (retailer #10 and #9). Eleven responses about RTI usage were mentioned in conjunction with the ecological sustainability topics, which were addressed by sustainability measures, e.g., reaching carbon neutrality, improving energy efficiency, reduction of waste production or increasing sustainability in the areas packaging, procurement, or supply chain.



This observation indicates that despite CEP companies recognizing the potential of RTIs in reaching sustainability goals, there is a general hesitancy in their exploitation. Instead, interviewees implied that measures with lower associated risk for failure are given priority. For example, in the context of improving energy efficiency and achieving carbon neutrality, PSP #14 mentioned measures that demand less drastic changes in the companies' processes like the use of electric vehicles or installing photovoltaic systems.

## 3.2 Experiences and Assessments of RTI-Systems

Independent of planned sustainability measures, we continued asking the interviewees about their knowledge of RTI implementation to gain insight on their current perspective of the RTI concept. Some CEP companies already have experience in RTI implementation. For example, retailer #9 reported that they have been working

with reusable packaging for 15 years and managed to close the gap internally. Similarly, retailer #5 noted that they had positive experiences with their reusable shipping system and that they were able to reduce the disposable packaging and the resulting waste, and that they even received the Blue Angel award for environmentally friendly practices.

We further questioned them about their opinions on the RTI concept, which indicated apparent advantages and disadvantages of RTI implementation (Fig. 4). The decision on the packaging material (returnable and/or recyclable) appeared to be highly dependent on customer (receiver) needs because the implementation of return processes must allow a win-win situation. This underscores the importance of customer involvement in the design of reuse processes. When retailer #7 spoke of the challenges of transforming to a circular system based on RTIs, they highlighted the following: "The results of the pilot project reinforce our focus on customer needs and our commitment to improve the sustainability of online retail. However, the journey is not without obstacles; the technical integration of incentives, the continuous optimization of packaging and the need for economically viable processes for the return of empty packaging remain key areas of focus."

When asked about the customer (receiver) view of RTIs, the attitude towards RTI solutions seemed positive according to retailer #9, who mentioned that they have a lot of requests from customers who want to be supplied with reusable solutions. Comparable customer feedback was also reported by interview partners without experience in RTI systems.

The only advantage of RTIs seen by both retailers and PSPs is the improved handling (box management) associated with package delivery when the RTI system is enhanced with smart technologies. Retailer #15 commented: "[...] if the [BOOXit] returnable box system works, then collecting the empties is just significantly faster than [...] looking at cardboard boxes [...]". This statement referring to semiautomation of delivery and return processes was also underlined by PSP #14: "[...] If we could switch many of our customers to such a reusable system, like a [BOOXit] box or maybe other options, we would be able to [...] know the size of the package by scanning [...] and [...] plan our volume. That would be a big advantage for us [...]".

Unlike the prevailing perceptions of advantages on the customer side, contradictions remain about the (customer) acceptability of RTIs among PSPs and retailers. While interest in sustainable packaging is growing and some customers are willing to share the additional costs, potential risk factors need to be considered.

On one hand, customers of online retailers were mentioned to prioritize product protection over sustainable packaging and seem unwilling to pay for reusable systems, especially if they involve significant additional costs. As retailer #8 pointed out that if customers had to pay a deposit for the boxes and were required to take them back to a special place, this will not be widely accepted.

On the other hand, online retailers, who already offer sustainable products, reported high acceptance, and underlined the need for a deposit on returnable packaging as stated by retailer #3: "We have received positive feedback from customers using our returnable packaging [...]. Incentives such as a deposit system or bonus points could be part of the strategy to encourage the return and reuse of returnable packaging".



in implementing RTIs or comparable systems

The advantages and disadvantages, which were partly pictured based on experiences with RTI usage, insinuated that receivers have a substantial impact on the decision whether to implement RTIs. Therefore, involvement of these stakeholder groups in the design of RTI strategies would probably result in a more directed approach and ultimately elevate the success of putting RTIs in circulation. This view is also supported by previous findings that indicate the need of a multi-stakeholder approach for the sustainable establishment of RTI-based circular economies [7].

## 3.3 Challenges Associated with the RTI Concept

Considering the advantages and disadvantages of RTI systems, the interviewees were then explicitly asked about challenges they would expect from executing RTI initiatives (Fig. 5). Of these, reverse logistics emerged as the most crucial problem. For example, retailer #10 depicted the issue of reverse logistics, and the development of robust systems for managing the return of empty packaging as critical for its success. It also highlights the importance of collaborations and business relationships with PSPs in both directions of the logistics chain.

The challenge of reaching the necessary customer acceptance was another particularly critical issue with comparable relevance as reverse logistics. Retailer #9 exemplarily illustrated this barrier as follows: "[...] the focus is primarily on acceptance by the customer and even by the PSP. If the PSP must wait for the container to be emptied [...] too much time is lost [...]". This brief statement again underscores the importance of functional return processes that are efficient and accepted by all stakeholders involved.





The establishment of reverse logistics processes presents several additional challenges, beyond others, matching backhaul rates with delivery rates, as was mentioned by the apparel retailer #10: "[A] circulatory system obviously needs a sophisticated balance system. With a reusable system, [one] must always have the reusable containers in the right place [...], [otherwise] it [remark: the system of forward and reverse deliveries] quickly leads to [...] imbalance [...], [i.e.,] there is more going in one direction than the other and [one] always [must] balance it out". In case of unmatched reverse logistics rates, compensating backup systems must be in place according to the interviewee #10: "[W]e solved these challenges through mass measures [i.e.] we have a relatively large pool of reusable containers that we use". Such solutions certainly entail additional obstacles in RTI implementation. In fact, the interviewees mentioned challenges, which are relevant to change management: "initial problems", "process deviation", "resistance to change", "feasibility constraints", "implementation of new systems", and "shrinkage".

Interestingly, the role of automation and policy regulation was mentioned less often than expected in these discussions, even though these factors were previously considered as enablers [24] or main drivers [17], respectively, in realizing circular economies. This observation suggests that the focus of current efforts is more on overcoming logistical, financial, and behavioral barriers than on considering technological or legislative aspects, despite the incumbent European Green Deal and the formulation of EU directives on packaging [1].

Taken together, these are notable barriers, which drive the reluctance of PSPs and retailers to change established business models by switching to RTI systems. This opinion is also reflected by recent findings suggesting a common resistance within the logistic industries to move away from traditional, linear models of consumption and waste [25].

## 3.4 Requirements for the Adoption of RTI-Systems

Given the multitude of challenges discussed, the interviewees were also asked about their expectations concerning the requirements for successfully putting RTIs in circulation. Surprisingly, the suggestions by the retailers and the PSPs to overcome those challenges turned out to be less multifaceted than expected. Next to "matching backhaul rates with delivery rates", only four additional requirements factors were listed in comparable frequencies (Fig. 6).

Similar to retailer #10, who stated that to "match backhaul rates with delivery rates", retailer #9 drew on inhouse experience and suggested putting RTIs in high numbers in circulation. The issue of aligning forward and return rates is also discussed in literature. Since successful matching depends on flexible reverse logistics, the establishment of robust return processes is a must [26].

In connection with the backhaul procedure, some specific requirements for the box material were mentioned; in particular, high robustness for box handling seems to be an issue. The choice of material (and the RTI construction determining nestability) is a disputed topic because it affects the RTI's life cycle, including its recyclability. PSP #12 insinuated that boxes with lids have insufficient durability: "[O]ver time [...] boxes become broken because of the [daily] manipulation of these containers [...]. We sometimes have boxes with lids. [...] And the hinges tend to be a bit vulnerable." Accordingly, hinge parts as shown in Fig. 2D are particularly fragile, which is a problem if stackability is a required feature for backhauling of non-foldable empties since stacking and dismantling may cause attrition.

Recognizing that the transformation towards circular economies, especially if enabled by RTI solutions, is a multistakeholder endeavor [7], CEP players do not seem to see responsibility in-house, but at external administrative institutions. For example, PSP #15 indicated that legal frameworks are needed to give the required impetus to RTI implementation: "I think, even if many entrepreneurs don't like to hear it, [...] without legal regulations or guidelines or any pressure from outside, not much will change".

Such governmental guidelines could also stipulate the establishment of standards concerning recyclable materials. The EU directive on packaging and packaging waste already addresses this issue and promotes "standard sizes", which were proposed as a requirement by some interviewees. Standardization of RTI systems is seen as a prerequisite because all stakeholders directly participating in the circular process need to agree on a single solution [7,27]. If a CEP player is a part of different circular logistic systems, the management of different RTI solutions is expected to raise the effort unproportionally, as is sketched by the PSP #14 as follows: "[I]f we now assume, for example, that we have a

customer with a lot of small packages [...]. And then we have a customer who [...] has packages [that] are just a little bigger [...], so [...] the size is a little different. But if, for example, we were to switch many customers to a [single] reusable system, such as a box or perhaps other alternatives [...] we could of course [better] plan our volumes afterwards. That would of course be much more to our advantage."



Figure 6 Requirements mentioned to successfully bring RTIs in circulation

The observation that a range of challenges were mentioned, whereas requirements to be met in order to overcome those hurdles were comparably sparse, might indicate a knowledge gap in designing suitable initiatives. A couple of agendas on the integration of Industry 4.0 with circular economies solutions have already been published previously [14-17]. However, those roadmaps primarily focus on strategic issues rather than on operational problems referred to by the CEP players (Fig. 5 and Fig. 6). To guide RTI development and implementation on an operational level, user requirements should be considered as well, including requirements of workers and line managers from CEP industries.

## 4 CONCLUSION

Our research findings reveal a multi-layered picture of the Austrian parcel industry's journey towards circular economy practices from the perspective of the industry's major stakeholder groups, i.e., the PSPs and the retailers. The specific focus of the study was the adoption of RTI solutions. While the statements of the interviewees indicated a positive attitude towards implementing circular economy practices in the CEP industry, the interviews pointed at a common sense of underlying economic and logistical challenges associated with putting RTIs into circulation. This insight highlights the need for the establishment of a consistent regulatory framework to support an industry-wide transition to circular economy systems. Therefore, collaborative efforts within industries and in cooperation with government institutions could be the starting point in creating the necessary synergies to overcome the existing challenges.

However, it must be mentioned that the number of available interview partners was limited and geographically confined to Austrian and German companies (Table 1). Accordingly, complementing this study by expanding of investigations to additional countries and industries would provide even more insights on requirements for RTI systems.

Nevertheless, the findings further indicated that the transformation of the parcel industry towards RTI-enabled economies requires a profound strategic circular reorientation within the CEP industry. This includes not only the adoption of new technologies and practices, but also a cultural shift to the focus on sustainability and environmental protection. The success of this transformation will depend on the industry's willingness to invest in innovative RTI solutions and to build long-term partnerships that are a prerequisite in establishing circular economies. Strategic roadmaps, which have been recently published [14-17], thus should also consider requirements on the operational level, since they build the basis of informed decisions for investments in research on RTI solutions and the development of process-oriented circular economies.

In conclusion, this paper provides insights into the dynamics of adopting circular economy practices in the parcel industry and highlights the urgency of a concerted effort to improve environmental sustainability. It calls for an increased commitment from all stakeholders to build a future where economic activity and environmental protection demand equal consideration.

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## Development of a Model to Support the Management of the Resistance Welding Process

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Abstract: The work was carried out as part of a project to improve the corrosion resistance of welded joints. The optimal selection of input parameters reduces the consumption of welded material as well as the negative impact on the environment. The samples were welded by electrical resistance welding, more precisely by cross-wire welding. Electric resistance welding is a process for welding with electricity in which of high electrical resistance is used to generate heat at the contact point of the welded parts. Steel wire S235 with a diameter of 4 and 3 mm was used. The article shows the creation of the model to predict the percentage of setdown and weld strength as a function of the input parameters, welding current and welding time. The first task was to create a Design of experiments in which the process parameters or the range of input parameters are determined. The Design of the experiments was created for both wire diameters. This covers the range of parameters with which a welded joint of wires can be realised. A statistical analysis of the process follows, where it was found that for 4 and 3 mm diameter wires the percentage setdown increases with increasing welding current and time. An increase in strength as a function of welding current and welding time is also observed, but the results overlap in most cases and the range of their values is greater than that of setdown. The appearance of the weld was analysed for each sample. The visual inspection revealed seven categories of welds, which were divided into two groups, i.e. good and poor welds. All results were listed in a table with the percentage of expectation for a particular category of weld appearance. Based on the analysis, a model for determining the welding result parameters welding result parameters were determined to the electric resistance welding process.

Keywords: cross-wire welding; design of experiments; management; model; weld classification; welding process

## 1 INTRODUCTION

This research was carried out on the basis of work on the European Regional Development Fund project. Causal relationships were identified and empirical modelling of the process was carried out to predict the output parameters of the resistance welding process.

Resistance welding is one of the most important processes used in the automotive, electrical, construction, and aerospace industries as well as in the manufacture of household appliances. In resistance welding, the metals to be welded are brought into contact with each other, Fig. 1. The electrodes are connected to the secondary terminals of the welding transformer and a strong welding current flows through them, which heats the contact surface. The resistance at the contact surface generates heat and increases the temperature in its immediate vicinity, which increases the electrical resistance of the metal. The heat generated in the metal itself rises rapidly and quickly reaches the welding temperature, causing a weld nugget to form. The welding current is switched off and the weld nugget is scrubbed off, creating a solid metal bond between the two parts [1-4].



The principle is the same for different types of resistant welding, such as butt, spot, seam or even impact welding.

The advantage of this method is that it can be used to join a variety of metal materials and is also suitable for welding the most commonly used metal-coated steel sheets [1-4].

The most important parameters in resistance welding are the welding current, the welding time and the pressure force of the electrode. The amount of energy introduced into the weld seam depends on the welding current and the welding time. A slight increase in the welding current quickly increases the diameter of the weld seam and thus its strength. The welding time has less influence on the size of the weld seam than the welding current. In resistance welding, short cycle times are generally preferred, which means a higher welding current and a shorter welding time. In this case, less heat is transferred to the areas immediately around the weld, so the thermal expansion remains at a lower level and the weld solidifies and cools down more quickly. The electrodes transfer the welding force and current to the desired location. One of the tasks of the electrodes is to cool the weld seam during the welding process. The contact between the electrodes and the workpiece is influenced by the force of the electrode. If the electrode force is too low, insufficient contact is made between the workpiece and the electrodes. This can lead to sparking, spattering, and faster wear of the electrode. If the electrode force is optimal, there is no spatter outside the area supported by the contact surfaces. In this case, the weld has a very good thermal balance. If the electrode force is too high, the electrodes press too hard on the workpiece, which can lead to indentation. In this study, the influence of the absolute value of the welding current and time at a constant electrode pressure force on the output parameters of the welding process, namely the setdown and the weld strength, was determined [3].

Cross-wire welding is a form of projection welding and a subtype of resistance welding. Cross-wire welding is mainly used in the electronics industry and in the manufacture of wire mesh. In his work, Knowlson [13] has given examples of cross-wire welding of various components such as diodes, resistors, capacitors, transistors, etc. In practice, a series of parallel wires are usually welded at right angles to one or more other wires or rods. In cross-wire welding, the electrodes exert pressure on the parts to be welded during and after the welding time in which a very strong electric current flows through them. The greatest resistance occurs at the contact surface of the two parts, which is why the greatest heat is generated there. This causes the two parts to join in the contact area. When the welding current is interrupted, the material in the heat-affected zone cools rapidly due to the cooler surrounding base metal, resulting in a solid weld [5].

The aim of this paper is to present a model that predicts the percentage of setdown and strength as a function of the input parameters of welding current and time, which was created for the purpose of the project. The welding process used in this work is cross-wire welding, and S235 steel wires with diameters of 4 and 3 mm are welded. Various studies can be found in the literature in which welding processes and process parameters are analysed. In their work, Kim et al. [6] determine the parameters of pipeline welding. They presented an intelligent system for determining the welding parameters for pipeline welding. In their work, Karadeniz et al. [7] investigated the effects of welding parameters on the setdown depth of Erdemir 6842 steel with a thickness of 2.5 mm, which was welded using robotic gas metal arc welding. Kim et al. [8] investigated the effect and contribution of welding current, electrode force, and welding time on joint strength during resistance spot welding of 316 LVM stainless steel cross wires with a diameter of 0.38 mm. Scotchmer [9] described the process of cross-wire welding in his work and presented the numerical modelling of cross-wire welding with SORPAS® with a very good comparison with the experiments carried out. Mikno [10] and Iatcheva et al [11] applied 3D simulation to the study of welded joints, and Nielsen et al [12] presented the development of a threedimensional finite element computer programme for electrothermo-mechanical industrial modelling of resistance welding, and the programme was applied to the simulation of projection welding of square nuts on sheet metal.

## 2 EXPERIMENTAL DETAILS 2.1 Material Details

For the purposes of the project and this study, S235 steel wire with diameters of 4h9 and 3h9 mm was used. The material S235 is part of the steel grade "S". This grade is mainly used for structural purposes in construction and mechanical engineering. In the designation S235, S means that it is structural steel, and 235 means that the minimum tensile strength of the steel is 235 MPa with a steel thickness of less than 16 mm [16].

## 2.2 Welding Process and Sample Preparation

The welding process was carried out in an industrial facility on a machine for electro-resistance welding. The wires cut to the same length are placed at right angles in the machine's fixture. The number of wires used for one mesh is 18 and two electrodes are used for welding. The electrodes are designed in such a way that when they come into contact with the surface, they weld in three positions simultaneously. In cross-wire welding, the electrodes exert pressure on the wires to be welded, through which a very strong electric current flow. The greatest resistance occurs at the contact surface of the wires to be welded, which is why the greatest heat is generated at this point. This causes the wires to join in the contact area. If the welding current is interrupted, the material in the heat-affected zone cools quickly due to the cooler surrounding base metal, resulting in a solid weld [5, 14-16].

Once the welding process is complete, the grids can be cut to obtain smaller samples that are then used for analysis. There are 81 samples or 81 measurement points in each grid [14-17]. Each sample goes through three test phases:

- 1) Adjustment measurement
- 2) Visual classification of welds with regard to their appearance
- 3) Measurement of weld strength.

Measurements and welding tests were carried out in laboratory conditions.

## 2.3 Equipment Used for Sample Analysis

The equipment selected for setdown and strength measurement and visual inspection of welds consists of hardware and software components. A Mahr 40 EVR digital micrometre is used to measure setdown [14]. Two Basler industrial cameras with associated lenses and Pylon software and a Dino Lite digital microscope with tripod and integrated lighting are used for visual classification. A tensile testing machine and a Burster 8524 sensor are used to measure strength. The Burster is a sensor used to measure compressive and tensile loads in various application. It is supplied with the DigiVision software package, which is used to display, set and read the measurement results [15].

## 3 EXPERIMENTAL PROCEDURE

## 3.1 Design of Experiments (DOE)

DOE is a statistical tool consisting of a series of statistical techniques for process improvement and planning. DOE can be used to adjust the optimal parameters to achieve the best output levels and a robust process, i.e. a process with minimal variability [19]. Astakhov [20] describes in his paper the use of DOE in experimental studies on metal cutting, and Khanna [21] describes its use in research on metal cutting of titanium.

The most important input parameters for this type of welding are welding current, welding time and electrode pressure. In the preliminary results, it was found that the electrode pressure and the position of the electrode do not have as significant an influence as the welding current and welding time. Therefore, welding current and welding time at constant electrode pressure are used as input parameters for this study [14, 16]. Considering that the aim was to develop a more accurate model for predicting the output parameters of the welding process, it was, therefore, necessary to extend the range of input parameters. This include several parameters with which a welded joint of wires can be realised. In the Tab. 1 and Tab. 2 it can be seen the area marked with "x", which indicates that a weld was achieved with these parameters. The area marked with "-" indicates that the use of lower values for welding current and time does not result in welded joint in the contact points and the use of higher values of welding current and time results in excessive deformation of the mesh. Joints where no weld was achieved or the deformation of the mesh was too large for further processing were not included in the analysis.

A Design of experiments was drawn up, which was divided into two series: Series 1 for a wire diameter of 4 mm, Tab. 1, and Series 2 for a wire diameter of 3 mm, Tab. 2. A total of 972 experiments were conducted and the results obtained are analysed by the DOE using Minitab statistical software [22].

In Series 1, the wire diameter of 4 mm, the pressure of 3,5 kN, and the position of the electrode are constant. Two factors are observed: welding current and welding time. The welding current consists of 9 and the welding time of 7 levels, there are 9 repetitions for each mesh, which means that a total of 567 experiments were carried out.

Table 1 The range of input parameters used for a wire diameter of 4 mm

	Series 1								
Wire diameter: 4 mm			Time, ms						
Pressur	e: 3.5 kN	20	50	100	200	300	400	500	
	8	-	×	×	×	×	×	×	
	10	×	×	×	×	×	×	×	
<	12	×	×	×	×	×	-	-	
, k	14	×	×	×	×	-	-	-	
ent	16	×	×	×	×	-	-	-	
nı	18	×	×	×	×	-	-	-	
0	20	×	×	×	-	-	-	-	
	22	×	×	×	-	-	-	-	
	24	×	×	×	-	-	-	-	

Fig. 2 below shows a diagram of the main effect of the percentage of setdown as a solution for the Design of experiments.



The diagram shows that as the welding current increases, the percentage of setdown also increases up to a value of 49% and then decreases slightly. With increasing time, however, the percentage of setdown increases without decreasing.

Fig. 3 below shows a diagram with the main influences on the weld strength.



The diagram shows that the strength of the weld increases as the welding current and welding time are increased. The welding current increases slightly, while the welding time shows an almost linear increase in weld strength as a function of time.

In Series 2, the wire diameter of 3 mm, the pressure of 3.0 kN, and the position of the electrode are constant. Two factors are observed: welding current and welding time. The welding current consists of 9 and the welding time of 5 levels, there are 9 repetitions for each mesh, which means that a total of 405 experiments were carried out.

Series 2										
Wire diameter: 3 mm		Time, ms								
Pressure: 3 kN		20	50	100	200	300	400	500		
	6	-	-	×	×	-	-	-		
Current, kA	8	-	×	×	×	-	-	-		
	10	×	×	×	×	-	-	-		
	12	×	×	×	-	×	-	-		
	14	×	×	×	-	-	-	-		
	16	×	×	-	-	-	-	-		
	18	×	-	-	-	-	-	-		
	20	×	-	-	-	-	-	-		
	22	×	-	-	-	-	-	-		

Table 2 The range of input parameters used for a wire diameter of 3 mm

Fig. 4 shows the influence of the main influences on the percentage of setdown when the wire diameter is 3 mm.

The diagram shows a similar situation to a wire with a diameter of 4 mm. Increasing the welding current also increases the percentage of setdown up to a value of 74%, after which it decreases slightly. Increasing the welding time leads to a sharp increase in the percentage of setdown.

Fig. 5 below shows a diagram of the parameters than influence the weld strength when the wire diameter is 3 mm.

The diagram shows a clear difference in the situation with a wire diameter of 4 mm. Increasing the welding current from 6 kA to 8 kA leads to an increase in weld strength.

Increasing the welding current from 8 kA to 10 kA leads to a slight decrease in weld strength. The same situation occurs when the welding current is increased from 12 kA to 14 kA and from 18 kA to 20 kA. Increasing the welding time also leads to an increase in weld strength up to a value of 200 ms. However, if the welding time increases from 200 ms to 300 ms, there is a sudden drop in weld strength.





It can be concluded from these diagrams that welding current and welding time have a major influence on the output parameters of the process, setdown and weld strength.

## 3.2 The Visual Classification of Weld Appearance

The welds were classified visually after each weld was inspected and photographed from all positions using a camera and digital microscope. After inspecting each weld, the weld is categorised into one of two basic categories: good or poor. A good weld is one whose surface is smooth or, in extreme cases, has a line, with no protrusions, splashes, spatter or needles, Fig. 6. A poor weld is one with needle-like protrusions, foam and larger, sharper irregularities, Fig. 7.

In the comprehensive analysis of visual weld quality, a total of 17,292 images of the appearance of the welds were taken, which were used to determine the classification of the welds, i.e. whether the weld is good or poor. In this study, there were 9 samples in each mesh, which means that there

were 544 samples in total. Each sample was photographed 6 times to cover all sides of the weld. This is because in some cases a weld can be classified as good on one side and as poor on the other. The total number of images of welds in this study is 3,264 images.



Figure 6 Good weld

Figure 7 Poor weld

# 4 RESULTS4.1 Regression Equations

Based on the previous solutions, the following equations were obtained, which are the basis for creating the model to support the management of the welding process:

A. Regression equations for a wire with a diameter of 4 mm:

Percent of Setdown =  $-0.1831 + 0.03201 \cdot current - -0.000790 \cdot time - 0.000897 \cdot current^2 + (1) + 0.000156 \cdot current time,$ 

With  $R_{sq}$  of 97.25 %, which mean that 97.25 % of the variation is explained by this regression equations.

Weld Strength = 
$$-2.689 + 0.5789 \cdot current - -0.0205 \cdot time - 0.01560 \cdot current^{2} + (2) + 0.001221 \cdot current time,$$

With  $R_{sq}$  of 69.04 %, which mean that 69.04 % of the variation is explained by this regression equations.

B. Regression equations for a wire with a diameter of 3 mm:

Percent of Setdown =  $-0.2298 + 0.03957 \cdot current -$ 

 $-0.000633 \cdot time - 0.001051 \cdot current^2 -$  (3)

 $-0.000002 \cdot time^2 + 0.000375 \cdot current time$ ,

With  $R_{sq}$  of 96.49 %, which mean that 96.49 % of the variation is explained by this regression equations.

Weld Strength = 
$$-0.275 + 0.2546 \cdot current -$$

$$-0.00447 \cdot time - 0.00780 \cdot current^2 +$$
 (4)

+0.001023 · current time,

With  $R_{sq}$  of 58.38 %, which mean that 58.38 % of the variation is explained by this regression equations.

C. Regression formula to determine the probability of occurrence of the good weld:

$$P(0) = \frac{exp(Y')}{(1 + exp(Y'))},$$
(5)

a) For a wire with a diameter of 4 mm:

 $Y' = 51.0 - 4.17 \cdot current - 0.01740 \cdot time, \tag{6}$ 

b) For a wire with a diameter of 3 mm:

 $Y' = 282 - 23.3 \cdot current - 0.205 \cdot time.$ (7)

## 4.2 The Model

Based on the previously determined regression equations, a model was created to support the management of the welding process. To create the model, it was necessary to write code. The result is shown in Fig. 8.

WELDING COMPONENTS										
	Vire V Tape	Wire Tape								
Dimension	4		Dimension	4						
INPUT DATA										
Current	11	_								
Time	120									
Pressure	3,5	_								
		RUN								
EXPECTED RESULTS										
	Setdown	17,16	%							
	Strength		kN							
	Expected weld quality		good weld	s						
MINIMUM REQUIREMENT										
	Setdown	20	%	not achieved						
	Strength		kN	accomplished						

Figure 8 Model to support the management of the welding process

The model is divided into 4 categories:

- 1) Welding components represent the shape and diameter of the material used for the welding process. It is possible to choose whether the input material is a wire or a strip and what dimensions it has.
- 2) Input data are input parameters of the process. Various welding current, time and pressure parameters can be selected from the extended range resulting from the previous equations. After all input parameters have been selected, the model is started by pressing the "Run" button.
- 3) Expected results are obtained when the model is run. Based on the input parameters and the regression equations, the output parameters of the process are predicted as a solution, namely setdown and the weld

strength. In addition, the probability that the weld will be good is shown.

4) The minimum requirement is the last category in which the user of the model enters the minimum requirements for the output parameters. If these requirements are met, the result is displayed as "accomplished", otherwise "not achieved".

## 5 CONCLUSIONS

A new Design of experiments was drawn up covering the range in which a welded joint can be produced from S235 steel wires with a diameter of 4 and 3 mm. The graph shows that the welding current and welding time have a major influence on the output parameters of the process, setdown, and the strength of the weld. The welds were also visually classified into two basic categories, namely good and poor welds. A good weld has no visible irregularities, while a poor weld has various dents, spatter, sharp spots, etc.

Based on the previous solutions, regression equations for setdown and weld strength for 4 and 3 mm wire and regression equations to determine the probability of the desired result were created. Based on the accumulated knowledge of the process and the research and analyses carried out, a model was created to support the management of the welding process. The aim of this model is to predict the output parameters of the welding process. In this way, the user can quickly and easily determine which form of input material and which input parameters should be used when welding with the specified minimum requirements.

The limiting factors of this model are that it was created for one material, for two dimensions of wires and the limited data set presented in this paper. These limitations provide room for further research and improvement of the model presented.

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# Failure Prediction of Automated Guided Vehicle Systems in Production Environments through Artificial Intelligence

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Abstract: Modern industrial systems demand intricate connectivity and automation, especially in the realm of shop floor processes and intralogistics. Automated Guided Vehicle (AGV) systems are characterized by their potential for seamlessly networking value creation areas. However, failures and disruptions in AGV systems and adjacent facilities can lead to production halts, adversely affecting delivery reliability and quality. A substantial portion of the downtime stems from manual troubleshooting, underscoring the pivotal importance of the response time from maintenance staff. This paper introduces an approach employing a neural network with long short-term memory for forecasting and predictive maintenance to enhance AGV system reliability and availability in production environments. By analysing historical data, identifying patterns, and predicting potential failures or maintenance needs in AGV components and neighbouring facilities, the proposed AI-based forecasting ensures timely preventive measures. A case study shows the effectiveness of this approach in significantly improving AGV system performance, minimizing disruptions, and enhancing operational availability. This research contributes to smart manufacturing by providing a practical solution for optimizing availability of the concerned AGV system through advanced AI-based forecasting strategies.

Keywords: Artificial Intelligence; Automated Guided Vehicle; Long Short-Term Memory; TensorFlow; Time-Series Analysis and Forecasting

### **1** INTRODUCTION

Since decades the advantages and challenges of implementing automated guided vehicle (AGV) systems as well as worldwide growing importance of such systems for optimizing logistics and production processes have been highly concerned [1]. As key components of smart factories, automated guided vehicle systems play a critical role in optimizing material handling, logistics and transportation. Their autonomous navigation capabilities facilitate the smooth movement of goods and increase operational efficiency and productivity in industrial environments. Additionally, an AGV system should be seamlessly integrated with surrounding smart devices and systems to enable real-time data sharing and automated intelligent system control.

Despite numerous advantages of AGV systems, they may encounter numerous challenges during their operations, particularly the challenges of unexpected disruptions and stops due to failures. In many cases, it is required to fix errors and failures through manual intervention. However, the availability of technicians is not always guaranteed in a timely manner, which results in lower availability of AGV systems, more production interruptions and loss of productivity of the entire production system. To address this challenge, a proactive approach, particularly the use of predictive analytics models based on deep learning techniques, could be promising. By predicting potential disruptions in AGV operations, these models can preemptively mitigate problems, reduce the need for manual intervention, and increase overall productivity in Industry 4.0 environments.

The main aim of the paper is to analyse failure patterns in AGV operations and develop strategies to mitigate manual interference, enhance availability of AGV systems and hence increase productivity of highly automated production systems in Industry 4.0 environment. By understanding these patterns, it is expected to improve failure identification and rectification, minimizing operational disruptions of the systems. Given the significance of AGV systems in modern manufacturing and logistics, this research is crucial for optimizing their performance and reducing downtime through predictive failure prediction.

The rest of the paper is organized as follows. In the second section, a literature review of methods for ensuring and increasing availability of production and logistics systems is given. The focus of the review is placed especially on time-series analysis and forecasting by using artificial intelligence. The third section presents mainly the considered automated guided vehicle system of a food manufacturer and the historical data of the system especially failures recorded in the AGV controlling software as well as the pre-processing of data for the deep learning models used in the paper. In the fourth section, the first deep learning model, i.e. a long short-term memory (LSTM) model and the results obtained by this model are presented. Conclusion and outlook are given in the last fifth section.

### 2 LITERATURE REVIEW

In this section a brief review of models and methods especially based on deep learning for time series forecasting is given, including the applications of time series in the field of AGV failure prediction.

As a subdomain of time series analysis, time series forecasting involves developing a model that describes the underlying characteristics of historical data and extrapolating the model into the future [2]. Over the last decade, many machine learning and deep learning models have been developed to analyze time series. Multivariate Time Series (MTS) has received much attention. Deep learning models based on recurrent neural network (RNN) and convolutional neural network (CNN) haven been developed for MTS forecasting.

Athanasopoulos et al. demonstrate the utility of multivariate statistical models and machine learning

techniques for predicting air quality parameters in the realm of environmental science with high accuracy [3]. The study introduced by Bai et al. explores the effectiveness of Graph Neural Networks (GNNs) in capturing temporal dependencies and relationships between variables in MTS data and shows promising results in various areas, including finance and healthcare [4].

Borovykh et al. explore the application of CNNs for time series forecastingby treating the time series as a onedimentional signal [6]. According to their research and observations, CNNs are proficient in capturing local patterns and could be applied in fields such as sensor data analysis and medical signal processing. Bai et al. have specifically designed Temporal Convolutional Networks for sequential data modeling and applied CNNs to various time series forecasting tasks, including electricity load forecasting and traffic flow prediction due to the ability of CNNs to capture long-range dependencies [7].

Shubyn et al. explores how federated learning techniques can be utilized to train predictive models using data distributed across multiple AGVs [8]. As signal for prediction energy consumption has been selected. The results of their experiments based on federated learning let to better signal priction results than the results of just using single LSTM model. Zahng et al. [9] introduce a novel approach that combines the Transformer model a type of neural network architecture commonly used for sequence modeling, with the K-means clustering algorithm for power consumption prediction and anomaly detection. According to Benecki et al., RNN-based forecasting, together with a proper selected telemetry features used in prediction, can be effectively utilized on AGV telemetry data as a first step in anomaly detection schemes [10].

Long Short-Term Memory networks have emerged as powerful tools for time series forecasting, providing the ability to capture long-term dependencies and complex patterns in sequential data [9]. To improve prediction performance of LSTM, recent studies have explored various improvements to it architectures. For instance, Zhang et al. propose a hybrid LSTM model integrated with attention mechanisms to selectively focus on relevant temporal features, resulting in superior forecast accuracy in financial time series data [12].

Based on the study of Prakash et al., of all the state-ofthe-art famous time series algorithms and combinations, including LSTM, Bi-Directional and Stacked LSTM, Prophet, GRU-LSTM, CNN-LSTM and LSTM with Attention, the simple algorithms have given the better result than hybrid and complex algorithms [13]. Song et al. employ Particle Swarm Optimization to optimize the essential configuration of the LSTM model and exhibit the outperformance of the proposed approach in comparing to traditional methods such as ANN, RNN and decline curve for predicting daily oil rate [14]. Livieris et al. propose a forecasting model of CNN-LSTM for the prediction of gold price and movement, which utilizes both LSTM layers and additional convolutional layers and exhibits a significant boost in increasing forecasting performance [15]. Besides theory and model development in using LSTM for time series analysis, open-source tool kits and libraries in the field of deep learning have also received much attention. For example, TensorFlow, an open-source library created by Google Brain, has gained popularity in recent years due to advances in machine learning. It is especially useful when combined with Long Short-Term Memory (LSTM) networks for time series analysis, because they can capture temporal dependencies and long-term memory [16].

Because of easy installation, relatively high speed, and easy customization, TensorFlow is used for different research aims based on LSTM by different researchers. Numerous domains, including finance, meteorology, air quality monitoring, and energy forecasting, have demonstrated encouraging outcomes with these models. Sang and Di Pierro emphasize the use of LSTM in modeling stock performance and forecasting market trends by utilizing TensorFlow's features [17]. Yazdan et al. investigate the use of LSTM to analyze the dynamics of energy consumption using renewable energy sources and emphasize TensorFlow's applicability as a neural network training and deployment framework for energy forecasting [18]. The use of LSTM models in TensorFlow for single-step and multi-step time series prediction of urban temperature is examined by Zhang et al. [19]. According to their research, longer-term dependencies and nonlinear correlations in temperature data can be captured by LSTM using TensorFlow and produce more accurate predictions.

Due to successful experience of TensorFlow for deep learning and especially for LSTM in the literature, it is also selected in this paper for the purpose.

### 3 PROBLEM STATEMENT OF THE CONCERNED AGV SYSTEM AND DATA PREPARATION

After introducing the concerned AGV system briefly, the data preparation for the LSTM model is explained, including the basic data set with irregular time intervals and the preprocessed data set with regular time intervals.

### 3.1 The Concerned AGV System and Research Aims

The automated guided vehicle system concerned in this paper is composed of five vehicles, which are responsible for moving semi-finished products between different processing stages of the whole highly automated production system. During operations of the AGV system, many different kinds of messages are recorded in a manner of irregular time intervals. Some of the messages are just records of events, which may not influence the AGV operation at all. Some of the messages are failures, which can be corrected by the system automatically. The rest of the 34 messages correspond to failures, which can only be corrected by the technician manually. The current situation in the company is firstly, these failures cannot be easily avoided and secondly, technician cannot prepare his/herself immediately for correcting the failures. If these failures cannot be corrected on time, the availability of the vehicles is then reduced. As a consequence, the semi-finished products cannot either be collected from some stages or be delivered to some stages of the production system. The productivity of the whole system is of course influenced.

A measurement could be to avoid or reduce failures, which are manually corrected. However, this is not the aim of the paper. The paper focuses mainly on developing predictive analytics based on LSTM model for failure forecasting. If the technician could be informed much earlier than the time when a failure happens, there could be more time for the technician to prepare the required materials and tools for correcting the failure and downtime of the AGV system could be reduced. If at the beginning of the shift, the technician receives predicted failure information for the next several hours, the technician can plan activities and schedules much better. For example, during periods of time, when An AGV does not run, the technician does not need to plan activities for other machines or systems. If the prediction results are relatively quite accurate, if an AGV failure occurs later, technicians can fix the problem almost immediately. The downtime of the AGV system can be reduced and the availability of the AGV system is of course higher. The main aim of the paper is to predict if there are failures or not in the next certain period by using a LSTM Model.

### 3.2 Preparation of Data Set as a Basis

To achieve the aim, a basic data set must be at first prepared. The first step is to collect event-based records in two months from the AGV controlling software. After analysing the original data set, which consists of approximately 50 columns, the data set is simplified to just seven columns as a basis for further analysis. Tab. 1 shows several rows of simplified data as examples.

ID	Module	Message	Location	Vehicle	Time	Failure
0	32	1	502	4	23-10-12 02:23:40	23
1	32	1	502	4	23-10-12 02:25:41	26
2	2	10	2601	4	23-10-12 02:26:39	34
3	15	12	2601	0	23-10-12 02:27:37	34
4	15	6	2601	0	23-10-12 02:27:39	23
9548	14	18	2617	0	23-12-12 08:50:38	20
9549	14	32	3407	0	23-12-12 08:56:41	20
9550	14	26	5	4	23-12-12 09:22:15	27
9551	15	13	5	0	23-12-12 09:22:41	16
9552	14	13	5	4	23-12-12 09:26:00	20

Table 1 Prepared data of the AGV system

The first column "ID" serves just as the primary key for unique identification. The second column "Module" tells the number of the module in the system, which has a relationship to the failure. The third column "Message" tells the event number. A combination of both Module and Message results in a specific failure in the last column. The forth column "Location" corresponds to the block numbers in the layout, where the vehicles drive. That means, the locations where the failures happen can be obtained based on this column. The fifth column "Vehicle" is just the number of the five vehicles from 0 to 4. In the sixth column "Time" the exact time of the event to second is recorded. The last column "Failure" presents the number of the 34 manually corrected failures.

It is obvious to notice, that the time intervals are irregular, because the controlling software makes event-based records. In this table, only manually corrected failures as event are prepared. The rest events, which do not need manual interference, are just deleted from the original records dataset.

### 3.3 Pre-processed Data with Regular Time Intervals

Based on the basic dataset, several datasets with different regular time intervals for the LSTM model are created. These time intervals are 60 minutes or 1 hour, 30 minutes or half hour and 10 minutes.

The partial dataset with 10 minutes as time intervals is shown in Tab. 2. To create this dataset, irregular time intervals are firstly changed to regular time intervals of 10 minutes. Then a column of "Failure Label" is inserted. The values of this column are binary only. A value of 0 means there are no failures occurred in the next 10 minutes after the corresponding time in the same row and a value 1 means there is at least one failure occurred in the next 10 minutes after the corresponding time in the same row. For example, there are several failures after the time 12-10-23 02:20:00 in Tab. 1, hence the value of the column Failure Label corresponding to this timestamp is 1. Other datasets are similar to this dataset, but with other time intervals.

Table 2 Data samples with regular time intervals of 10 minutes

ID	Time	Failure Label
0	2023-10-12 02:20:00	1
1	2023-10-12 02:30:00	1
2	2023-10-12 02:40:00	0
3	2023-10-12 02:50:00	0
4	2023-10-12 03:00:00	1
8825	2023-12-12 08:50:00	1
8826	2023-12-12 09:00:00	0
8827	2023-12-12 09:10:00	0
8828	2023-12-12 09:20:00	1
8829	2023-12-12 09:30:00	0

The reasons of creating different data sets with different time intervals are as follows. First, A 60-minute time interval is used, because it is a more appropriate length of time for planning and analysis. A time interval of two hours is also good. However, it is not proper for the case in this paper, because the occurring possibilities of failures in every 2 hours are almost guaranteed based on the preliminary analysis. In other words, there is almost always at least one failure in every 2 hours. Hence, it is not necessary to do forecasting.

The second time interval is set to be of 30 minutes. The shorter the time interval is, the greater the flexibility in planning and scheduling can be obtained. However, if the time interval is too short, the accuracy of the prediction will also decrease. This time interval must be practically tested to find out if the accuracy is high enough or at least acceptable.

The third time interval is set to be 10 minutes, which are in fact a little bit too short for planning. This time interval aims mainly at training the model and forecasting failure occurring in every 10 minutes. The obtained results are then used for generating prediction for every 60 minutes. If at least one 10-minute time interval in one hour has a failure, then there is at least one failure in this hour. That means the value of "Failure Label" corresponding to the timestamp of this hour is 1. Otherwise, if no 10-minute time interval in one hour has a failure, then this hour has a failure, then this hour has the value of 0 for Failure Label. Of course, the data can also be used for predictions every 30 minutes.

### 4 LSTM MODEL AND RESULT ANALYSIS

As mentioned at the end of the second section, the tool kit of Keras in TensorFlow is used for building LSTM model. All data analysis and programming tasks are conducted within the environment of Jupyter Notebook. The LSTM model is composed of three layers. Each of first two layers has 50 neurons and the fully connected layer has one neuron. For the fitness function, a batch size of 32 is defined. The whole dataset is divided into a training set comprising 80% of the data and a test set comprising 20% of the data. As a suitable metric for evaluating models predicting values that are either 0 or 1, Mean Absolute Error (MAE) is selected for evaluating the accuracy of the train and test sets of our LSTM model.

Many experiments have been conducted and a selection of representative results is shown in Tab. 3. From the results, it is to notice, that the higher the epochs are, the lower the MAE values are and the more accurate the prediction can be achieved. This trend is adaptable to any time intervals. However, the difference between 300 epochs and 350 epochs is not very evident. The improvement of the prediction quality is limited after setting higher values for epochs than 350. Hence, only the results until 350 epochs are presented.

The best results for different time intervals are obtained when the value of epochs is set to 350. Hence, the following analysis focuses only on these results. The lower the time intervals for training the model are and the longer the time intervals for prediction are, the better results with lower MAE values can be achieved. Hence, the best result for predicting failure occurrences every hours among the experiments is obtained by using time intervals of 10 minutes for training the LSTM model. The MAE value of 0.030 is quite low, which means the prediction results are relatively reliable and promising.

Table 3 MAE values across different sce	narios
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Time intervals for model training: 10 Minutes							
Epochs	50	150	300	350			
10 Minutes	0.312	0.184	0.086	0.085			
30 Minutes	0.206	0.145	0.062	0.064			
60 Minutes	0.164	0.088	0.036	0.030			
Time intervals for model training: 30 Minutes							
Epochs 50 150 300 350							
30 Minutes	0.180	0.155	0.060	0.064			
60 Minutes	0.069	0.063	0.038	0.040			
Time intervals for model training: 60 Minutes							
I me intervals for model tra	aining: 60 M	linutes					
Epochs	aining: 60 M 50	inutes 150	300	350			

Corresponding to the best value of MAE, some samples of the actual and predicted values of "Failure Label", which shows the occurring possibilities, i.e. occurrences of AGV failures, are presented in Fig. 1. Three time periods of 500 hours are randomly selected. The red points correspond to predicted values of failure occurrences and the blue points correspond to actual values of failure occurrences. It is to notice, except for very less blue points, most blue points are covered by red points. This also fully demonstrates the prediction accuracy.



# Predicted occurrences of AGV failures Figure 1 Data samples of actual predicted occurrences of failures

### 5 CONCLUSION AND OUTLOOK

Based on the evaluation of our LSTM Model, the key insight that the developed LSTM Model in TensorFlow demonstrates promising results in predicting failure events in terms of predictive performance, can be drawn. It exhibited low MAE values on the dataset, indicating a close fit between actual and predicted values showing failure occurrences. This method can be used for any AGV systems, if the required data can be available. However, the method is still very limited in its capability, which can only help the staff of doing his or her planning in a time interval of one hour.

Future research could focus on refining model architectures, exploring alternative algorithms, and incorporating domain-specific knowledge to enhance predictive accuracy for shorter time intervals. Additionally, the model performance and robustness could be improved by conducting further experiments with different datasets. Furthermore; multivariate LSTM model should be developed for predicting more information of AGV failures, including predictions of which failure, by which vehicle, at which location and at what time. If this aim is achieved, the technician can even better plan the activities, tools and materials for fixing failures.

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## Climate Friendly Transport: A Study on Sustainable Trade Logistics in Multi-Channel Retail based on a Survey of Floristry Retailers in Germany

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Abstract: Retail is currently in a state of upheaval due to digitalization and the associated booming online trade. Sales figures in stationary retail are stagnating. Online trading offers advantages through convenience and quick availability that customers no longer do not want to miss. Due to climate change, retailers and customers have changed their mind set towards more sustainability. Consumers are increasingly demanding sustainable products, so retailers must act appropriately to be both digital and climate-friendly in the future. The aim of this exploratory study is to use the example of floristry retailers to analyze whether they are growing with digitalization and whether they are taking sustainable initiatives to act as climate-friendly as possible. In addition, the florists' whole value chain is examined for climate friendliness. The results of the exploratory online survey of 68 floristry businesses in Germany show that both digitalization as well as climate and sustainability awareness play a significant role in floristry retail.

Keywords: Climate Friendly Transport; Commercial Business Administration; Floristry Retail; Multi-Channel Retail; Sustainability Management; Sustainable Trade Logistics

### **1** INTRODUCTION

Retail is currently in a state of upheaval due to digitalization and the associated booming online trade. Sales figures in stationary retail are stagnating. Online retail offers advantages of convenience and fast availability that customers no longer want to do without. Due to climate change, retailers and customers have changed their mindset towards more sustainability. Consumers are increasingly demanding sustainable products, so retailers must act appropriately to be both digital and climate-friendly in the future.

The aim of this exploratory study is to use the example of floristry retailers to analyze whether they are growing with digitalization and whether they are taking sustainable initiatives to act as climate friendly as possible. In addition, the florists' whole value chain is examined for climate friendliness. Chapter 2 shows the literature review and is followed by the methodology in chapter 3. The results are presented in chapter 4 and the conclusion in chapter 5.

### 2 LITERATURE REVIEW

### 2.1 Commercial Business Administration

The Internet has changed the role of bricks-and-mortar retail in recent years. The momentum generated by the internet has affected the retail sector more than almost any other industry. In addition, many sectors in bricks-andmortar retail experience low growth or even stagnate [1]. The shift from shopping in city centers to online retail platforms is causing a decline in retail sales. However, online shoppers are not automatically turning their backs on the city center; instead, they are increasingly combining both shopping options [2].

With the rapidly growing importance and power of ecommerce, it follows that conventional retailers must create new channel systems to satisfy customers across multiple channels. Management is considered a retail management technique for controlling various multi-channel channels. It occurs when two or more channels are used. Retailers who want to optimize performance for each individual channel pursue the multi-channel strategy. The boundary between online and offline shopping tends to disappear as efforts to integrate channels spread [3]. The concept of multi-channel retail can offer numerous advantages for a company. These include access to new markets, improved customer satisfaction and loyalty and the creation of strategic advantages [4]. Buyer analyses have shown that multichannel customers generate higher sales than customers who only use one sales channel. Multi-channel creates the opportunity for retailers to reach existing customers even better and increase growth potential in the existing customer portfolio [5].

Retailers who offer more than just online or bricks-andmortar stores will therefore be able to survive in the market. Retailers can use digital marketplaces such as Amazon to reach larger markets. Increasing network size also increases the benefits for the participants involved, for both retailers and customers [6].

Accompanied by the widespread use of e-commerce and the advance of innovative information technologies, retailers have begun to use new approaches. Information technologies such as virtual screens, virtual mirror fitting rooms, selfservice kiosks, service robots, QR codes and smartphone apps are available in addition to mobile devices. Companies are actively integrating these new technologies into their business [7]. E-commerce is opening up new markets and customer groups for brick-and-mortar retailers. With the help of the internet, retailers are no longer limited to a regional market, but can tap into large markets at an acceptable cost. As a result, bricks-and-mortar retailers cannot afford to ignore online business [8].

In 2020, the Covid-19 pandemic hit Germany with full force. It is estimated that almost 200,000 retail businesses went into lockdown in March 2020. Brick-and-mortar retail is still suffering from the resulting low customer footfall. In many sectors, sales are not reaching the level of previous years. The trend towards online shopping because of the lockdown is exacerbating the crisis, especially for retailers who are not using digital sales channels. Low sales and ongoing fixed costs such as rent payments are leading to insolvencies [9]. Due to the pandemic, flower shops in Germany had to close completely over several months during two lockdowns. As a result, floristry businesses suffered financial losses and had to fear for their existence and the jobs of their employees. Due to hygiene requirements and capacity restrictions, the work processes for providing services became increasingly complex during the pandemic. According to a survey by the Fachverband Deutscher Floristen (FdF) (Association of German Florists), 73 percent of the association's members who participated in the survey said they experienced declining sales in their flower shops since the be-ginning of 2021, especially in federal states with lockdowns [10]. Small and medium-sized floristry businesses experienced lower sales due to fewer walk-in customers and the loss of event decorations, e.g. for weddings, etc. [11].

In Germany, the profession of florists is assigned to the retail sector [12, 13]. In 201912,310 retail companies selling flowers, plants, seeds and fertilizers existed in Germany. In this context, a floristry company employed an average of 1.9 employees in 2019 [14, 15]. Accordingly, floristry businesses in Germany can be classified as small and medium-sized enterprises (SMEs) in the enterprise typology [16].

### 2.2 Climate Change and Sustainability Management

Individual economies are affected differently by climate change. On the one hand, climatic changes cause direct damage to nature, while on the other hand; economic adaptation burdens arise, such as physical damage to production facilities [17]. Climate change also influences the distribution of agricultural production and thus global markets [18]. On the one hand, all these developments have an impact on goods and companies. On the other hand, economic growth is a factor in environmental pollution [19]. Holistic sustainability management is required so that companies can master the extensive challenges in the future. The target dimensions to be considered include Environment, economy, social issues, and technology [20].

Retailers are looking for sustainability in their strategic management. They are increasingly inclined to think sustainably in their regular decision-making processes. There are varieties of ways to contribute to sustainable development. One aspect of a sustainable product is sustainable or no packaging. This encourages the customer to avoid waste. Customers need support to focus on new opportunities for zero waste when shopping. Zero is symbolic, producing no waste is impossible. The basic idea here is to bring waste as close as possible to zero [21].

Companies can benefit from implementing sustainable initiatives. In addition to financial benefits, an improved brand image and stronger customer loyalty are realized. In a survey of companies, operational cost savings, increased competitive advantages and improved supplier relationships were identified as the most important benefits [22, 23].

### 2.3 Sustainable Trade Logistics

Since 2012, there has been a continuous increase in the transport of goods by road. Total road transport, which includes international road transport, reached a total transport

performance of almost 317 billion ton kilometers in 2018 [24]. In an economy based on the division of labor and globalization, the transport sector is more important than ever. As its importance increases, so does the environmental impact of transport-related emissions.

The decarbonization of the transport sector is one of the biggest challenges in the coming years [25]. The reduction of motorized private transport and the strengthening of intelligent and integrated mobility solutions must be a central element of a climate-friendly and sustainable transport system. Shifting traffic to rail can reduce greenhouse gas emissions and energy consumption. Freight transport can also take place using electric mobility. Electro mobility is considered a central component of a sustainable transport transition [26].

Between 2000 and 2017, the number of shipments in Germany doubled from just under 1.7 billion to 3.4 billion. As a result, the number of recipients has also increased, as in online retail a pallet is divided into many individual parts and distributed directly to the customer. This contrasts with conventional retail, where the goods are delivered in large pallets to a few addresses and purchased by the customer. This creates an inefficient situation for city logistics and increases cost pressure for retailers [27]. As the products ordered online do not always meet expectations, e-commerce often results in returns. One in five purchases is returned to the retailer. This means that Germany alone accounts for almost 286 million returns per year [28]. With 280 million returned parcels in Germany, a calculated value of just under 850 g  $CO_2$  per return leads to a burden of 238,000 tons of CO2 [29].

E-commerce is rapidly changing the way companies manage logistics along the entire value chain, making it one of the mega-trends. While the frequency of shipments is increasing, the size of shipments is shrinking. The ubiquity of the internet creates both new challenges and opportunities for companies to serve geographically dispersed customers [30]. Logistics 4.0 characterizes the effects of the digital revolution on the transport and supply sectors. As consumer habits change, supply chains must become more dynamic and adapt to new requirements. Established logistics companies are competing with new competitors across the entire transportation spectrum. Logistics 4.0 is creating a multitude of new opportunities and solutions through digitalization and networking [31, 32].

The ever-growing acceptance and increased demand in society for green products and services is also causing a rethink in the logistics industry. Failure to act and insufficient anchoring of sustainability efforts in the strategic orientation of logistics companies can lead to permanent cost and competitive disadvantages [33]. Many logistics companies, such as DHL, Schenker AG, UPS, Kühne & Nagel, etc., are now applying the principles of green technologies in the implementation of their activities. By green logistics, they mean an effective approach to managing technological processes and the flow of resources in order to reduce environmental and economic damage. Solutions for this are reflected in green programs, strategies, and projects [34]. Green practices that support green goals through organizational methods or techniques include, for example, eco-driving, the reduction of empty runs, the full loading of vehicles and routing techniques to minimize driving distances [35].

In the following, five major parcel service providers in Germany (DPD, DHL, GLS, Hermes and UPS) are compared in terms of green logistics. According to its own information, DPD fully offsets unavoidable transport emissions by investing in renewable energy projects. In this way, almost one billion tons of  $CO_2$  were offset in 2018. However, only one percent of DPD's fleet consists of alternative vehicles, i.e. those without combustion engines. DHL, on the other hand, sends its mail within Germany in a climate-neutral way as standard. The company is also attracting positive attention, particularly with the development of the electrically powered street scooter. Almost 10,000 of these environmentally friendly vans are already in use. Like DHL, GLS delivers all parcels within Germany in a climate-neutral manner.

However, only around 460 of the 23,000 delivery vehicles have alternative drive systems. UPS, on the other hand, shows only below-average environmental commitment; in 2018, CO<sub>2</sub> emissions increased by six percent compared to the previous year. At Hermes, absolute  $CO_2$  emissions have remained consistently high in recent years, and there is no mention of climate-neutral shipping for private customers. The fleet conversion to alternative drive systems is only progressing slowly at Hermes [36].

DHL's GoGreen Logistics Solutions program is one of the company's innovative strengths in sustainability. Diversified innovation techniques that contribute enormously to improving fuel efficiency and reducing air and noise pollution are part of this program. In 2007, DHL set itself the target of reducing its carbon emissions by 30% by 2020. The target was achieved long before the deadline, in 2016. The interim target is to achieve a 50% reduction by 2025 with the aim of approaching, zero net carbon emissions for all transport-related activities by 2050 [37].

### 3 METHODOLOGY

The study design is an interplay of the above presented literature review and a quantitative survey of flower shops in Germany.

The literature analysis is based primarily on articles from peer reviewed journals that were not older than three years. Literature was searched for in the scientific areas "Commercial Business Administration", "Climate Change and Sustainability Management" and "Sustainable Trade Logistics" as well as under the keywords Climate Friendly Transport, Commercial Business Administration, Floristry Retail, Multi-Channel Retail, Sustainability Management and Sustainable Trade Logistics.

Based on the literature review the survey is used to explore new insights. Descriptive statistical procedures are used for data analysis and interpretation.

The literature research includes the indexing and processing of the documented results in the scientific fields relevant to the study commercial business administration, climate change and sustainability management as well as sustainable trade logistics. The literature review has integrated the study into the state of research. Findings documented in literature on the scientific fields of commercial business administration, climate change and sustainability management as well as sustainable trade logistics developed the three research questions (RQ1, RQ2 and RQ3) [38]. Hereby the focus was on the operationalization of relevant variables for the empirical investigation as well as on the development of explanatory approaches.

The quantitative survey of 450 randomly picked flower shops in Germany was conducted between 2th of August 2021 and 16th of August 2021. The florists were sent an email with a link to the "umfrageonline" platform, which invited them to take part in the survey. A total of n=68 businesses took part in the survey (response rate of 15.1%). Both highly standardized and structured questions were presented in the survey. This study contributes to the field of research in sustainable transport by analyzing flower shops.

The following research-guiding questions were the basis for the design of the quantitative survey and data analysis:

RQ1: To what extent are brick-and-mortar retailers already active online?

RQ2: Do multi-channel retailers source their products sustainably?

RQ3: Do multi-channel retailers sell their products sustainably?

RQ4: To what extent do multi-channel retailers see climate change as an opportunity for their company/industry?

### 4 RESULTS

### 4.1 Results Commercial Business Administration

In the first step, the florists were asked about their presence on the retail channels. None of the businesses surveyed had an exclusively online presence. 70% have a purely stationary, local presence, while 30% pursue the multi-channel approach both stationary and online.



Figure 1 Online and offline presence of retailers

Contrary to the findings of the literature review, according to which stationary retail is dying out, there is a clear trend towards stationary retail in the floristry industry. However, almost a third of those surveyed are also pursuing a multi-channel approach by relying on more than one sales channel. This enables them to achieve a greater reach. Of the companies that pursue a multi-channel approach, three quarters sell their products via their own online store; while a quarter choose to do so via marketplaces. None of the companies surveyed use both distribution channels at the same time.



Figure 2 Distribution channels of online retailers

The results show that florists are increasingly opting for the channel that they can best influence themselves: the online store. What is striking here is that none of the retailers chooses both the online store and the marketplace as a dual distribution channel, which could generate even more reach and influence.

In the following, the biggest difficulties for florists in online retail were surveyed. The retailers were given the opportunity to rank the challenges in order from one (greatest challenge) to four (least challenge). Half of the participants identified online marketing as the biggest challenge. Competitive pressure is seen as a minor challenge in online retail. Retailers see legal certainty and environmentally friendly transportation as the least challenging aspects.



Figure 3 Challenges in online retail

The findings from the literature review that online marketing is considered important were confirmed by this result. With retailers stating that they see online marketing as the biggest challenge, it can be deduced that they want to focus on it and grow with digitalization.

In the next question, the florists were asked about their strategic planning for the next five years. The focus was on which retail channel they would like to pay more attention to in the future. As there are no purely online retailers, no one stated that they only wanted to focus on online retail. At 63%, hybrid retail will become more important in the floristry sector in the coming years. Just over a third will continue to focus on bricks-and-mortar retail.



A frequent response from florists was that both channels are important to them and that they therefore want to strengthen both. Others only see online retail as a supplement to their traditional business model. It was also increasingly argued that it is impossible to escape the trend towards digitalization. Some of the retailers who want to concentrate on their brick-and-mortar business in the long term do not see the size of their business as suitable for online retail. Personal contact was repeatedly mentioned, which, according to the retailers, makes the difference in the industry.

The florists were then asked about their online affinity. At around 70%, and thus the clear majority, the majority of retailers make an effort to maintain their social media presence. Almost 30% have neither a social media presence nor a smartphone app. Other retailers are increasingly offering click and collect.



It has become clear that the majority of florists are integrating social media marketing into their business. This offers retailers even greater reach to reach customers. Retailers can quickly and easily listen to customers' opinions via comments on social media and respond accordingly. Furthermore, a smartphone app does not yet play a role for florists. Costs and the time required to develop the app could be possible obstacles. The click and collect tool is the classic combination of online and stationary retail, which has already found favor in the floristry industry.

The retailers were then asked which tools they use in stationary retail. At just under 70%, customer events or events are the most popular among florists. The card service entry is only used by just under 10%, while 33% stated that they do not use either tool.



Events are very popular in the stationary floristry trade. as they provide an opportunity to promote products on site. A measure that is also possible online, but products are traded in the floristry sector that can be presented more vividly on site. In addition, events create direct customer contact and a personal exchange, which can be a further factor in customer acquisition. It should not go unmentioned that customer events and functions have only been possible to a limited extent, if at all, over the past year and a half due to the coronavirus pandemic. However, the card service entry, which can be used to gain additional reach via Google, is hardly popular in the floristry industry.

Sustainable or no packaging when selling their products is very important to 33% of florists with a score of ten. Followed by just under 15% at nine and 30% at eight, florists show an environmentally friendly attitude here. Only 5% see no real relevance in sustainable packaging.



With an arithmetic mean of 7.7, the florists show a high level of environmental awareness when selling their goods. The value shows that retailers try to sell their products in the most climate-friendly way possible by using sustainable or no packaging. This also avoids waste.

### 4.2 Results Climate Change and Sustainability Management

In the first question, the floristry businesses were asked to what extent they see their company affected by climate change. At just under 90%, almost all businesses see themselves affected by natural-physical events, such as extreme weather events. This is followed by 69% who see themselves affected by market events, such as changes in demand, and just behind them 61% who see themselves affected by regulatory events, such as laws and regulations.



The results show that businesses see themselves affected by climate change through a wide range of measures and events. Extreme weather events are assigned a high level of importance in the floristry sector - due to the agricultural industry. Furthermore, the discussion of climate change is reflected in the realization that none of the companies does not see themselves affected by the specified criteria.

The second question analyses the extent to which floriculture companies are trying to counteract climate change. Almost all the companies surveyed promote domestic, local production. Almost 75% of businesses use alternative raw materials, while 50% use climate-friendly technologies and 39% reduce their CO<sub>2</sub> emissions.



Figure 9 Sustainable measures

The results clearly show that the companies are making efforts to tackle climate change. None of the companies stated that they were doing nothing to combat climate change. The companies avoid long supply chains and transportation routes by promoting local production. By using alternative raw materials, plastic and waste can be avoided and energy consumption is reduced through climatefriendly technologies.

The floristry businesses were then asked about opportunities arising from climate change. Half of the respondents see opportunities both in cultivation from regions that are more southern and in creating a green image. Just under a third each see incentive, pro-grams for products or the creation of new business sectors as opportunities.



### 4.3 Results Sustainable Trade Logistics

The retail model used by florists is analyzed here. The majority of retailers use their own warehouse. Retailers who do not use any of the trading models mentioned follow this. A small proportion of 13% use drop shipping, while 5% of retailers rely on the just-in-time model or fulfillment.



This result confirms the theoretical finding that the majority of retailers rely on their own warehouse, despite the potentially considerable costs involved. By having their own warehouse, florists are able to manage order processing themselves at all times. This is the most significant advantage of having your own warehouse. Fast order processing always ensures customer satisfaction. Drop shipping, the JIT model and fulfillment have not yet found favor in the floristry industry, which may be due to the product traded in this sector.

The florists were then asked which parcel service providers they integrate into their logistics processes. The majority of retailers (60%) stated that they do not use any of the service providers mentioned. This is followed by 40% who use the services of DHL, followed by DPD with 20%.

10% of retailers each use GLS and Hermes and 5% use UPS or others.



The result shows that florists do not rely on the big names in the parcel service sector for the most part. The first major parcel service provider that is used the most is DHL. As the Literature Revie shows, DHL has emerged as the parcel service provider that is considered the most climate friendly. By using this parcel service provider, florists can make an environmentally friendly contribution.

In the following figure, the florists were asked what reasons motivate them to choose a parcel service provider. Almost 90 % stated that none of the reasons mentioned were decisive for their choice of service provider. In each case, 11% of retailers choose the service provider because it promotes electro mobility, because it promotes renewable energies or for other reasons, such as parcel size or performance. None of the retailers uses the service providers because they deliver parcels by bicycle.



The result clearly shows that florists do not attach much importance to sustainable initiatives by logistics service providers in this area.

The retailers were then asked to what extent returns play a role in their business. The result concludes that all retailers surveyed have to arrange returns less than three times a month.

The literature review has shown that returns can play a significant role in greenhouse gas emissions. In the floristry sector, this does not apply - probably due to the freshness aspect of the goods. The clear result shows that retailers do not, or hardly ever, have to deal with returns.



Figure 14 Returns per month

The following question analyzed how florists get their products transported. The majority of retailers, 93%, receive their products by road. Air and sea freight each account for 43%. Rail transport falls slightly behind with a value of 18%.



The result illustrates that road transport is the main mode of transportation in the floristry industry for the delivery of goods; almost every floristry business relies on this mode of transportation. Just under half of the companies use air transport in addition to sea freight, while a small proportion of retailers only uses rail transport, which is considered particularly environmentally friendly, (18%).

In the last question, the florists were asked about the radius within which they procure their products. A third of the retailers procure their goods within a radius of 51 to 100 km, closely followed by the local radius of up to 50 km (29%). Just under a quarter of retailers, procure their goods within between 101 and 500 km. The greatest distance, between 501 and more than 1000 km, is claimed by 15% of retailers.



The last result of the online survey shows that retailers mainly source their products locally or regionally. This shows that the majority of florists avoid long transportation routes. However, 38% of retailers also procure their products from a radius of 101 to more than 1000 km, which means long and costly transportation routes. It can be concluded that the majority of florists contribute to sustainable procurement by preferring short transport routes of up to 100 km.

### 5 CONCLUSION

### 5.1 Summary

To gain a precise insight into the challenges and opportunities of climate-friendly multi-channel retail, the study presented here conducted a survey of florists in Germany in the form of an online survey based on the literature review. The literature review shows that less and less attention is being paid to bricks-and-mortar retail and that online retail is benefiting as a result. Retailers cannot escape the trend towards digitalization and must act accordingly to avoid being squeezed out of the market. The aspect of corporate sustainability is also becoming increasingly important. Companies can combine economic success with sustainability.

The survey results showed that more than two thirds of florists are increasingly opting for the stationary approach, while only one third of retailers are pursuing the multichannel approach. However, over the next five years, more than two thirds of retailers want to focus more on a hybrid sales channel. Of the smaller proportion of floristry businesses that are active online, 75% rely on their own online store, while 25% rely on retail platforms (RQ1).

Just over half of florists procure the products they need locally and regionally (RQ2). This is mainly done via road transportation. Just under half of the retailers procure their products by air and sea freight. Florists only rarely use rail transport. By looking at the end of the value chain, it becomes obvious that climate friendly distribution of their products is important to florists (RQ3). Both the green image and sustainable packaging were given very high importance by the retailers.

In addition, more than half of the retailers integrate sustainable products into their range. It can therefore be concluded that both digitization and sustainability awareness play a significant role for florists. As many negative aspects as climate change entails, the clear majority of florists can also see opportunities in it. Due to the rising climate, they can imagine growing products that are otherwise only native to southern climes. The companies also see the profiling opportunities associated with an incentive program for green products as a perspective (RQ4).

### 5.2 Discussion and Limitations

As the study shows, the floristry industry has not yet assigned online retail the importance that has been identified in the literature. Only just under a third of retailers are represented in online retail - combined with bricks-andmortar retail (RQ1). An exclusively online business model was not found among the florists surveyed, which may be due to the products traded. In terms of long-term strategic orientation, however, the majority of retailers see themselves on the hybrid path. This may also be linked to the fear that future crises such as the coronavirus pandemic will occur more frequently and that bricks-and-mortar retail may not take place at all or only to a limited extent as a result. Both the relevance of a green image and the importance of sustainable packaging and the integration of sustainable products were considered significant in literature and empirical studies. Retailers can contribute to environmental sustainability through these measures. The predominantly local and regional procurement of florists can be done for both sustainable and economic reasons (RQ2). This could not be fully clarified by the empirical data.

Regardless of this, the conclusion is that local and regional procurement means that fewer tons-kilometers are covered, resulting in lower CO<sub>2</sub> emissions. Retailers mainly transport their products by road, which is particularly harmful to the environment. Slightly less than half of the florists receive their goods by airfreight, which has the highest CO<sub>2</sub> emissions. Just under 40% of retailers receive their goods by sea freight, which generates very low CO<sub>2</sub> emissions when using an inland waterway vessel. In the area of product transportation, it can be deduced that retailers can act in an even more climate-friendly manner. When choosing a parcel service provider, almost half of the florists stated that they use the services of DHL. DHL is currently considered the service provider that is working most effectively on its green, sustainable programs. By choosing DHL as their parcel service provider, retailers can make a climate-friendly contribution. (RO3).

The aim of this study was to find out to what extent retailers in the floristry industry are positioned for the future regarding digital and ecological issues. The results in sustainability show that florists are taking climate change seriously. None of the retailers stated that they were not affected by climate change. The importance of corporate responsibility from the literature review was partially confirmed. (RQ4).

### 5.3 Implications

The Literature Review shows that digitalization is an ongoing process that will play an increasingly important role in retail in the future. Retailers need to think about the extent to which they want to equip themselves for the future and which digital topics are relevant to them in the floristry industry. The increased environmental awareness of consumers, who are prepared to accept a price premium for environmentally friendly products, offers retailers new possibilities and opportunities to build a sustainable green image.

The results of the survey have shown that floristry businesses will generally focus on both digital and ecological topics in the future. Nevertheless, the results presented raise further questions. One aspect that requires further empirical investigation is the retailers' stated long-term digital orientation. The reasons why retailers would like to become digital in the future, in the form of online retail, need to be explored here. In the area of green retail, retailers also stated that they attach great importance to a green image.

In this context, it would be interesting to investigate which measures retailers would like to use to create this image. In addition, further research into environmentally friendly transportation is required to obtain a clear and meaningful result. For example, when delivering products by sea, a distinction must be made between simple inland vessels and large freighters, and in road transport between combustion and electric vehicles, in order to be able to derive a climate-friendly trend. It would also be important to investigate the extent to which floriculture companies can influence the choice of electric cars by their logistics service providers.

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### Digital Twin and Simulation Analyses for Process Optimization of an Automated Guided Vehicle System

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Abstract: Development in industrial companies aims to digitize processes, ensure traceability and advance automation. Systems with automated guided vehicles (AGVs) can help meet these objectives. A core element of these systems is the higher-level system controller. When an AGV system is operated, some dynamic aspects appear. It is then to identify, that the previous specified rules for scheduling and routing of vehicles are not always proper and practical, which may result in waiting time of AGVs. That means the static performance requirements and the specifications based on them often lead to suboptimal results. A methodical problem-solving approach is to develop a digital twin as a reflection of reality and to carry out strategy analyses using simulation. For this purpose, a digital twin of the concerned AGV system with five vehicles and its technological environment is created using software of plant simulation. Various simulation scenarios are developed to simulate material flows by using different routing and scheduling rules and strategies. Drawing from the insights gained through the digital twin and simulation analyses, this study identifies novel scheduling and routing rules for the AGV system. These rules improve the overall efficiency and effectiveness of the system operations by easing traffic congestion, reducing transit time, and minimizing production downtime.

Keywords: Automated Guided Vehicle (AGV); digital twin; material flow optimization; routing and scheduling; simulation analysis

### **1** INTRODUCTION

European manufacturing industry is currently facing a number of challenges. These include global competition, pressure, comprehensive sustainability high cost holistic digitalization requirements, and adaptable production processes. The latter are particularly important because the number of product variants is increasing and the product life cycle is becoming ever shorter. In this context, the performance requirements for networked logistics are also increasing.

Against this background, Automated Guided Vehicles (AGVs) and their systems are of great importance. AGVs operate without a driver, are battery-operated, follow a specified driving course and receive their vehicle orders from a higher-level control system [1]. The control system transforms the transport orders into vehicle orders according to specified strategies.

Navigation systems are used to record the driving course and follow it. They are guideline-bound or guideline-free. A guideline-free variant is laser navigation, which enables the driving course to be changed using software. Inductively active and passive as well as optical navigation require physical guidelines that are fixed in or on the ground. Changes to the driving course, for example to generate new route elements, involve mechanical work. The case-specific selection of navigation technology is essentially determined by the conditions of the operation field.

AGV technology and its key components have developed rapidly with the high-tech Industry 4.0 strategy [2]. The result is a robust technology with high performance and availability of the vehicles and the system. In the planning phase, the driving course layout and the strategies must be developed. On this basis, the required number of vehicles must be determined, which is unchangeably interdependent with the driving course and the strategies.

If the developed and defined strategies turn out to be suboptimal, the consequences may be a too high or too low number of vehicles. In the worst-case scenario, this can lead to an impairment of the supply and disposal of production machines and production performance. The strategies of the AGV system concern in detail as follows:

- the right of way rules,
- the prioritization of transport orders,
- the exclusion of deadlocks,
- awarding transport orders to the most suitable vehicle,
- the concept for intermediate charging of the batteries,
- the implementation of transport orders into vehicle orders,
- minimizing the frequency and times of blocking and
- routing specifications.

Since the costs of the vehicles usually represent a significant proportion of the offer price, an excessive number of vehicles affects the competitive situation of the provider on the one hand and the results of the requester's profitability calculations on the other hand. The latter can lead to profoundly bad business decisions.

Conversely, if the number of vehicles is too low, the responsible company, i.e. the planner or the AGV manufacturer, can be blamed for it and must pay for the misjudgments.

An essential prerequisite for correct planning results is a complete and clearly formulated specifications that document the requester's requirements. A relevant part of this is the complete and detailed service description. In the case of AGV systems, the service description must include, among other things, information on sources, sinks, their positioning in the layout, routes and transport orders with reference to the peak hour and the shift model.

Due to unforeseeable production changes, it may well be necessary for an AGV system that complies with the specifications to require additional vehicles after acceptance and a longer period of operation and that the strategies must be adapted or expanded in accordance with the new production requirements. The relevance of the aforementioned topic areas has been shown above in the context of the objectives of companies. Since AGV systems are mostly planned and implemented in a tailor-made manner, simple and generally valid findings are not sufficient in many cases. In addition, this is particularly because AGV systems exhibit dynamic behavior. The dynamics and networking complexity increase as the number of vehicles increases.

For simple systems with low complexity, algorithmic determination of vehicle number using material flow matrices can be sufficient. This method of determining the number of vehicles will not be discussed further here. Improving the technological properties of AGVs, for example, increasing acceleration or driving speed, is also not a topic of this paper.

Rather, the focus is on the well-founded selection of strategies for AGVs as a control variable within the overall system. Findings are highlighted that are relevant for strategy selection. Since each AGV system represents an individual, these can be classified as guidelines for strategy selection.

### 2 CHALLENGES OF THE AGV SYSTEM CONTROL

In production, networking transport is a secondary function and its costs must be minimized. Nevertheless, its performance and quality influence the efficiency of production. In this context, it is crucial to which AGV the transport order executed before a certain arrival time is assigned and in which order the pending transport orders are carried out. In order for the scheduling task to be solvable, the transport capacity of all vehicles must be greater than the transport requirements to be handled.

The travel time from the starting point of the ordered AGV to the source station and the time required to carry out the vehicle order depend largely on the routing, i.e. on the specified route elements to be used, and the blocking situation on these routes.

Both the scheduling and routing tasks are taken over by the higher-level control system. In order to be able to fulfill these tasks, it is necessary that the master control receives all the necessary process data from the operational level in real time. This includes data about vehicle malfunctions or vehicle stops that have occurred, blockages on the route and malfunctions at the source or sink stations.

Discrete data transfer points that lead to "dark phases" for the control system and also for the vehicles must be avoided. Communication between the control system, the vehicles and the stations must be implemented permanently and without interruption in real time in order to ensure that the transport processes run in an optimized manner.

Algorithms are almost exclusively used to solve scheduling and routing tasks, which in turn access the data from the specifications in the planning phase and access the process data in the operational phase. The results determined are established rules that are transferred to the control system and are used in real plant operation.

A number of scientific papers deal with the planning and operational optimization of AGV systems based on heuristics and algorithms. Specifically, these are the following approaches:

- Multi-objective path planning for Automated Guided Vehicles (AGVs) using the improved Cuckoo algorithm [3],
- Algorithms for scheduling and route finding of AGVs [4],
- Use of the Invasive Weed Optimization algorithm to solve the problem of scheduling multi-AGVs in a matrix manufacturing workshop [5],
- Development of a novel multi-task chain scheduling algorithm based on capacity prediction [6],
- Algorithms for the problems of AGV scheduling in a matrix manufacturing environment [7],
- Path planning in dynamic environments with a combination of a Multi-Objective Particle Swarm Optimization (PSO) algorithm and the Dynamic Window approach [8],
- energy-efficient path planning with individual loading in a manufacturing workshop [9],
- Decision support for scheduling through a digital twin, which is a virtual representation of the real manufacturing system [10],
- Route planning based on quick response code technology (QR codes) [11] and
- Algorithms for conflict-free handling of route planning and control of AGVs [12].

The quality of the established rules is identified in real operation under real conditions using key figures. Frequently used key figures are the cumulative route, adherence to deadlines, waiting times at intersections, blocking times, the number of empty journeys, the cumulative empty journey time, the frequency of production stoppages due to delayed supply or disposal transport, etc.

In order to fully meet these challenges, this paper chooses a problem-solving approach in which the planning result or the physical system and its internal logic are depicted as a model in order to then carry out strategy analyzes using simulation. The basis is a real AGV system with five vehicles and a complex technological environment with paternosters.

### 3 LITERATURE REVIEW

This paper focuses on the planning and operational optimization of AGV Systems using simulation. Basic works are selected during the literature search.

### 3.1 AGV Systems

As early as 2007, Schulze and Zhao [13] discussed both advantages and challenges of implementing AGV systems as well as predicted the worldwide growing importance of AGVs for optimizing logistics and production processes were discussed. Our AGV statistics "Worldwide commissioning of AGV systems from European AGV manufacturers" up to 2023 also shows this trend.

An analysis of the implementation of AGVs and their effects on the efficiency and flexibility of logistical processes uses case studies to show how AGVs can contribute to optimizing material transport and warehousing in practical use [14]. In this context, the research results on an intelligent maintenance architecture for AGVs should be mentioned [15]. Implementing predictive maintenance and condition monitoring aim to minimize AGV failures and maximize uptime. A concept for integrating sensors and data analysis is being developed.

The study of strategies for efficient route planning and control of AGVs in a square topology is the focus of a paper by Matopolski [16]. By using algorithms, optimal solutions for AGV control are developed. The relevance of targeted planning and control of AGVs for sustainable and efficient operations in industrial environments is highlighted.

A study by Fragapane et al. [17] examines the potential for increasing flexibility and productivity in production networks that can be achieved through the use of AGVs and intelligent intralogistics. It has been proven that the use of technologies such as artificial intelligence and machine learning can optimize workflows.

The requirements of small and medium-sized enterprises (SMC) for AGV systems are specific and take into account their scarcity of resources [18]. It becomes clear that the implementation of AGVs poses particular challenges for SMEs. The focus is on aspects such as costs, flexibility and user-friendliness. The authors consider the importance of a tailor-made and robust solution as well as upstream system planning for the successful use of AGVs to be fundamental.

Schulze et al. [19] present the basics and principles of AGVs as well as their use in various application areas. Aspects such as navigation, control and integration into existing factories are examined in detail. The article provides an overview of the state of the art of AGV systems and emphasizes their potential for optimizing logistics and operational processes.

The current advances in the control, navigation, route planning and coordination of AGVs are discussed in the article by De Ryck et al. with the focus on new approaches for control algorithms [20].

Fragapane et al. [21] have compiled a comprehensive literature review for the planning and control of autonomous mobile robots in intralogistics and identified existing gaps and challenges. These results inform a research agenda that focuses on navigation, route planning, task assignment and coordination of AGVs.

The development of a simulation platform for the application of mobile robotics is carried out by Hegedić et al. [22]. This platform makes it possible to test different scenarios and evaluate the performance of mobile robots in a virtual environment. The work represents a contribution to supporting the development and implementation of AGVs and identifying potential problems at an early stage, i.e. before implementation.

### 3.2 Simulation and Digital Twins

Agalianos et al. [23] examine the areas of application of discrete event simulations and digital twins in logistics in their work. They outline the possible uses of these technologies and identify the challenges that can arise from the integration of simulation modules and digital twins.

The application of simulation technologies in logistics and the associated challenges of modeling logistics processes are certainly challenging. This is also underlined by the results of a survey on automatic model creation for material flow simulations in discrete manufacturing. Reinhardt et al. [24] present in their work various approaches and technologies for the automatic generation of simulation models and discuss their advantages and disadvantages. It is shown, which measures can be used to reduce the modeling effort and improve the efficiency of material flow simulations.

Chen, J. C. et al. [25] present a method based on metamodels to optimize the performance of AGV systems depending on the charging concept of the vehicle batteries. The authors analyze and develop a simulation model that shows the performance of the AGVs under different charging conditions and thus also influences the vehicle demand. The time for model creation is significantly shortened by the developed meta-models.

The simulation of the supply of workplaces in a digital factory environment by AGVs is the focus of a study by Neradilova and Fedorko [26]. By simulating various scenarios, potential bottlenecks and deadlocks could be identified in a planned system and optimization measures could be implemented.

The work of López et al. [27] presents a developed framework to enable efficient simulation and control of AGV-based transport systems in different environments. The results help to make the planning and implementation of AGV Systems more efficient.

The analysis of performance indicators for automated driverless vehicles is the focus of research that investigates different scenarios using Design of Experiment methods [28]. The aim is to identify factors that are significant for the performance of the AGV system under consideration. Using simulation, these factors are tested under different conditions.

In a study, Fu et al. [29] with the approach of combining discrete event simulation and the response surface methodology, i.e. a statistical method. The aim is to identify the complex dependencies on various variables and understand how these affect the performance of the AGV system or the number of AGVs required.

Vavrik et al. [30] present the application of computer simulation as a tool to optimize logistics using automated driverless vehicles. Their approach focuses on improving the performance and efficiency of logistics processes through the use of AGVs. The authors demonstrate how computer simulations can be used to analyze different scenarios and determine the optimal configuration of AGVs in logistical environments.

The development of digital twins for automated vehicles and their fleet management is of great importance. In the work of van der Valk et al. [31] and Matei et al. [32] the benefits and challenges associated with the implementation of digital twins are discussed. It shows how this technology can help improve the efficiency and transparency of managing fleets of automated vehicles. The results are based on a case study on the implementation of a digital twin for fleet management. Korth et al. [33].present the development of a simulation-ready digital twin for the real-time management of logistics systems. The approach integrates

advanced data modeling techniques and real-time data processing to create a digital twin that reflects the actual operating conditions of a logistics system. By using real-time data, the digital twin is continually updated and its performance is improved. Gartner [34] classifies the development of Digital Twins as hype, the goals of which will probably only be achieved in five to ten years.

#### THE CONCERNED AGV SYSTEM 4

The concerned AGV System in this paper is a system being operated in a metal processing company. There are four production lines, each of which has a supply requirement for two loading units of products every hour. In dynamic buffers, the preliminary products on gondolas are treated as loading units. Before further processing, the preliminary products are subjected to pretreatment and then returned to a buffer. The pretreatment gives the material the properties required for successful further processing on the production lines. The buffers are equipped with paternosters and each paternoster can hold 15 gondolas as loading units.

The logistical networking between pre-production, the buffers, the pre-treatment and the production lines is realized by AGVs. Fig. 1 shows the layout of the networking, including buffers I to IV (green), the four production lines (framed in orange), the waiting station for empty vehicles (framed in yellow), the pretreatment (framed in blue) and the driving course of the vehicles (gray). In the system, the AGVs can communicate in real time with the higher-level control system. When the vehicles have completed their vehicle order and are not assigned another transport order, they always drive to the waiting station to receive another transport order.

Every production line needs 30 minutes to process a completely filled loading unit. Each line is equipped with a transfer station for handling the products. Either buffer I or buffer II has five sections and each section is equipped with four paternosters, i.e. in total each buffer has a capacity of 20 paternosters with a total of 300 places. The minimum time a loading unit stays in a buffer corresponds to the process time. For either buffer it is 24 hours. Buffer III includes three paternosters with a capacity of 45 loading units. The process time is 4 hours. Buffer IV contains twelve paternosters and therefore offers a buffer capacity of 180 parking spaces. The loading units stored here have already undergone pretreatment and are only transported to the production lines as required. The load is picked up and delivered by the AGVs directly in conjunction with the gondolas of the paternoster. The gondolas must be in the transfer position for load transfer, which requires higher-level coordination between the paternoster control and the higher-level master control of the AGVs.

There are five automated guided vehicles in the system, all of which are constructed the same and have identical attributes. The vehicle length is 1.8 m, the vehicle width is 0.9 m and the maximum driving speed is 1.0 m/s. The maximum driving speed applies to both load and empty travel as well as when cornering. A minimum distance of 1.0 m must be maintained between two vehicles driving one

behind the other. The capacity per vehicle is one loading unit. The load transfer time, i.e. the time for load acceptance and load transfer, is 40 seconds each.



Figure 1 Overview of the System

The vehicle's accumulators are charged by inductive, i.e. contactless, energy transfer when stationary and while driving. Failure profiles of the technological units of the system, return transport due to quality defects in the products and intentional decommissioning of vehicles, e.g. due to maintenance work, are not taken into account.

#### 5 SIMULATION AS A SOLUTION GENERATOR

In order to analyze the effectiveness of scheduling rules for the running AGV system, the best solution is to create a digital twin of the system in the form of a simulation model. The static and dynamic factors of the whole system including production lines, buffers, vehicles etc. should be considered in the model. That means, the interactions of between AGVs and all influencing neighboring units are modeled.

Based on the model, the following three different scheduling rules and their influences on the number of vehicles and the connected production lines and in particular on the upstream buffers can be analyzed.

- Rule 1: Shortest empty route for the AGVs The AGVs' empty journeys are minimized. After the final execution of a vehicle order, the transport order is selected for the vehicle in question that results in the shortest empty journey.
- Rule 2: Longest queue of transport orders

The location with the longest queue of transport orders is given priority when converted into vehicle orders. For the affected vehicles, this means that they are assigned a transport order regardless of the empty route. At the same time, the formed queue shows, to what extent the maximum performance of the AGV system is sufficient.

• Rule 3: Longest waiting time for transport orders for supply

The supply of the production lines is crucial for the efficiency of the system. If there are orders for supplying production, the transport order that has the longest waiting time is selected from this order pool. This is then assigned to the vehicle that was the first to complete its vehicle order and is therefore available for dispatch.

Since this is a dynamic system with events whose time of occurrence is not deterministic but stochastic, an eventoriented simulator is used. In general, the events and the time at which they occurred are recorded, as is the condition of the object in question. The simulation tool "Product Lifecycle Management Software Tecnomatix Plant Simulation" was used for the simulation experiments, which supports the modeling, simulation, visualization and analysis of operational processes. Plant Simulation is ideal for optimizing the resource utilization of production and the material flow of complex, not easy to analyze systems and production lines.

The digital modeling of the system under consideration is supported by predefined blocks that are stored in libraries in Plant Simulation. For example, Automated Guided Vehicles can be created in the "AGVPool". "Single Station" is used to simulate a production line. Each production line is assigned two load transfer stations. One only realizes the input and a second only the output. "Parallel Station" together and "Single Station" are used simultaneously to model carousel. Many sensors are integrated in the model for modelling the actions and events. The rules to be analyzed are programmed with the internal programming language.

### 6 RESULTS

The results of the simulation experiments concern the scheduling rules and a number of improvement approaches for system operation. The effects of rules 1 to 3 compare to the results achieved in real operations. In reality, the basic rule "The transport orders are transformed into vehicle orders in the chronological order in which they were created" is followed. With regard to transport orders, a "first in – first out" policy is practiced. The length of the route of the affected vehicle is not taken into account. The transport order

is assigned to the empty vehicle that has been waiting the longest without an order.

"Rule 1: Shortest empty journey for AGVs" does not contribute to reducing the number of vehicles, but rather tends to increase the need for vehicles. The cumulative travel distance is shortened, resulting in lower energy requirements. The efficiency of the production lines and the pre-treatment facilities drops slightly to 95.8 %.

Scheduling according to "Rule 2: Longest queue of transport orders" and "Rule 3: Longest waiting time for transport orders for supply" improves the efficiency of the production lines as well as that of the pre-treatment facility. At 119.6 %, the efficiency values of the production lines that were determined using Rule 3 are significantly higher than those achieved with Rule 2.

Setting up additional waiting stations significantly reduces empty journeys. In this case, one vehicle can be saved for the same production output. The paternosters represent a complex dynamic at the time when a transport order is issued to a vehicle. In reality, the transport order is assigned to a vehicle without taking the gondola position of the target paternoster into account. If the destination gondola is positioned only after the vehicle has arrived, waiting times will arise.

The simulation has shown that a ten-minute lead time for generating vehicle orders significantly shortens waiting times. Compared to the real situation in which transport orders are assigned directly to vehicles without lead time, the approach of earlier generation and allocation of vehicle orders reduces the waiting time of vehicles by more than half by 55.6 % and at the same time increases the security of supply on production lines.

In a simulation experiment, the vehicle order was only started when the travel time of the vehicle corresponded to the positioning time of the target gondola. The aim is that when loading units are delivered, the positioning of the destination gondola is completed when the delivering vehicle arrives. The same applies to the collection of loading units. This made it possible to marginalize waiting times to 18.3 %.

Taking all the measures mentioned, the simulation shows that four vehicles are sufficient for the same production output. This means that one vehicle at a time could be available as a reserve or be subjected to preventative maintenance. In all cases, the buffer capacity of the paternoster did not represent a bottleneck.

### 7 CONCLUSIONS

Systems with automated guided vehicles will play a central role in the modern production and logistics landscape of many companies in the future. The use of AGVs increases efficiency, optimizes material flow and reduces the need for human intervention. New technologies, including sensors and control systems, and vehicle innovations will shape the future. The autonomy of automatic vehicles has already arrived in companies.

In order to optimally plan and improve the use of AGVs, the "tool" simulation is indispensable. It allows different scenarios and configurations to be tested virtually before being implemented in the real world. Through simulation, factors such as layout, material flow and resource utilization can be optimized with the most suitable strategies. The aim is to maximize the performance and efficiency of the AGVs and to avoid over- and under-sizing.

An important part of these simulations is the integration of digital twins. This virtual representation of a physical system or product simplifies the development of simulation models. They make it easier to virtually map the behavior and performance of individual vehicles or entire fleet management. By linking real-time data with the digital twin, companies can monitor, analyze and optimize the operation of their AGVs.

In this context, artificial intelligence (AI) methods will play a crucial role in the future in connection with AGVs, simulations and digital twins. AI algorithms can help identify patterns and relationships in the data to perform predictive analysis and predict future developments. In addition, AIassisted decision systems can be used to realign simulation models and continuously optimize the operation of AGVs.

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## Analysis of the Impact of Geometry Modifications on the Fit of Splined Shaft Connections Manufactured Using Selected AM Methods

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Abstract: Broadly, understood additive manufacturing techniques expand the spectrum of production of machine parts that are used in various types of devices. However, the requirements to ensure dimensional and shape accuracy require the determination of appropriate material allowances or clearances to enable correct assembly. For the above reasons, the study presents an analysis of the impact of the assumed geometry modifications on the possibility of assembling a splined connection manufactured using selected AM techniques. The work focused on the analysis of changes in geometry resulting from the technology used. Using the Atos II Triple Scan optical measurement system and Gom Inspect software, the possibility of installation was determined for four variants of the splined shaft connection geometry, resulting from the technologies used.

Keywords: 3D Printing; CAx systems; coordinate measurements method; coordinate optical measurements; quality control

### **1** INTRODUCTION

Geometric accuracy is one of the fundamental qualifiers for the correctness of manufacturing processes for machine and device parts. It is the result of many components constituting the overall effect of the production process. In order to provide it, it is necessary to integrate CAD / CAM / RP / CMM (Computer Aided Design / Computer Aided Manufacturing / Rapid Prototyping / Coordinate Measuring Machine) systems, which create a holistic environment for the production of products, regardless of the field of application [1].

Determining the accuracy of manufacturing parts with complex geometry, produced in the RP process, can be carried out using coordinate measuring techniques. The integration of computer-aided design (CAD), manufacturing (CAM / RP) systems and coordinate measuring methods (CMM) allows for a significant acceleration of the production process of high-quality machine parts. This is especially important in the case of manufacturing assembly elements, for which the dimensions responsible for their correct assembly are extremely important [2, 3].

The topic covered in this study aims to illustrate problems and phenomena affecting the accuracy of splined connections manufactured using selected additive techniques. The task undertaken in the research work resulted from the lack of reliable information regarding the size of geometry deviations resulting from the manufacturing techniques and materials used [4, 5]. The information provided by manufacturers of materials as well as 3D printers, does not offer a complete picture of geometry deformations resulting from the manufacturing method used. Moreover, there is a lack of studies containing guidelines for predicting appropriate assembly clearances when designing splined connections. This is an important issue because these connections are indirectly responsible for the correct operation of, for example, gear transmissions [6]. The research performed concerned the analysis of spline connections manufactured using Fused Filament Fabrication (FFF) and PolyJet technologies [7-9]. PLA and RGD720 photopolymer resin materials were used for the

manufacturing processes. Research models were developed for a gear mounted on a shaft.

In the conducted research, considerations regarding the analysis of the accuracy of the gear ring geometry were omitted. The interpretation of the measurement results focuses on the impact of the size of the designed clearances of the splined connection on its correctness or the possibility of its assembly. The presented results were based on measurements of a series of 5 samples with the same geometry for each defined clearance size and manufacturing method. Due to the scope of the study, selected representative analyzes are presented.

### 2 RESEARCH ISSUES

The objective of this study was to assess the impact of the size of assembly clearances, predetermined at the stage of modeling the geometry of a spline connection dedicated to manufacturing using selected incremental manufacturing techniques. Due to the geometry deformations inherent during production, it was imperative to investigate the influence of base geometry shape on subsequent correct assembly of the splined connection.

The scope of the study encompasses:

- Conducting the process of modeling the geometry of splines with nominal geometry and with assumed assembly clearances (Fig. 1).
- Production of 5 series of prototypes for each designed geometry and manufacturing method (Fig. 2) [10, 11].
- Carrying out post-processing to properly prepare research samples.
- Carrying out measurement processes and analyzing model accuracy using the GOM Inspect software (Fig. 3, 4).
- Comparative analysis of the results obtained in relation to real research models, considering nominal geometry without geometric correction.

The design work carried out included the development of the geometry of a splined connection, the geometry of which is the same for the hole and the shaft. Then, manufacturing clearances were assumed at the level of 0.1 mm, 0.15 mm and 0.2 mm, respectively, which were taken into account on the designed shaft (Fig. 1). The gear wheel was treated according to the principles of a constant hole, and thus the hole parameters were constant.



Figure 1 STL models of test bodies

Using FFF and PolyJet additive manufacturing methods, a series of 5 test models of gears and shafts for each designed geometry were manufactured using the Prusa MK3 device and 3D Objet 350 Connex [12].



Figure 2 Research prototypes produced in technology: a) FFF, b) PolyJet



Figure 3 Measurement using the optical 3D scanner Atos II Triple Scan: a) Gear, b) shaft

The measurement processes were conducted using the Atos II Triple Scan optical 3D scanner (Fig. 3, 4). Consequently, in order to be able to digitize the contact surface of the detail with the measuring table and the geometry located outside the camera observation area, it was necessary to measure it in two independent measurement series. The measurement process was configured in such a

way that each of the two series was carried out for the position of the part placed in a given plane of the table as well as in a plane rotated by 180 degrees [13]. However, this required the arrangement of reference points such that at least three of them are visible in both measurement series to enable individual geometries to be aligned [14].



Figure 4 Measurement data

### 3 EXPERIMENTAL AND RESULTS

The Atos II Triple Scan optical coordinate scanner software enables analysis of the accuracy of machine parts, presenting results both quantitatively and through colorful deviation maps. The use of an optical 3D scanner and the methodology developed for measuring gears [14] is adaptable to other geometrically complex machine parts manufactured using additive techniques. The software ensures metrologically precise measurement of characteristic geometric features determining measured geometry accuracy.

By overlaying the surface geometry obtained through optical scanning onto the reference 3D-CAD model, a global analysis was conducted to visually assess the impact of spline geometry modification on dimensional shape changes resulting from manufacturing technology and materials used. Additionally, geometry analyses in sections normal to the axis were presented for individual cases. These tests were conducted for all samples analyzed in relation to the nominal geometry (Fig. 5-24). The deviation maps provided in the drawings offer information about their distribution both visually and quantitatively, facilitating comparison with the nominal model for better analysis.

# 3.1 Analysis of the Geometry of Prototypes Manufactured using PolyJet Technology

First, prototypes made using PolyJet technology were analyzed. The geometry of the gear bore was used as the assembly reference base. It was in relation to it that analyzes of the possibility of correct installation were carried out. According to the tests conducted, the gear wheel hole was reduced by +0.03 to +0.13 mm (Fig. 5, 6). It depends on the complexity of the geometry and its location on the manufactured object. Additionally, the type of material and the degree of its flow have an influence. To visualize geometry deformation better, analyses were performed in three sections. However, due to space limitations, only one example is presented, depicting deviation maps in half the width of the opening (Fig. 6), with similar values observed in other cross-sections. Preliminary information obtained from the analysis indicates the inability to achieve correct connection for models without geometry correction.



Figure 5 Global analysis of the gear geometry - PolyJet nominal model



Figure 6 Cross-sectional analysis of the gear model- PolyJet nominal model



Figure 7 Global analysis of the shaft geometry – PolyJet nominal model

In order to determine the values of clearances necessary for the correct assembly of the splined connection, the geometry of individual shafts was analyzed. Initially, global surface deviation maps were prepared for each geometry (nominal and offsets of 0.1 mm, 0.15 mm, 0.2 mm) (Fig. 710). These revealed that only increasing clearance to 0.15 mm enabled connection assembly (Fig. 9).

The deviation values for the nominal geometry and an offset of 0.1 mm do not ensure connection mounting feasibility. Modifying geometry by 0.2 mm (Fig. 10) results in excessive play, leading to incorrect assembly.



Figure 8 Global analysis of the shaft geometry - PolyJet offset 0.1 mm



Figure 9 Global analysis of the shaft geometry – PolyJet offset 0.15 mm

In order to detail the analyzes performed, additional detailed maps of deviations were prepared in the form of inspection cross-sections (Fig. 11-14). This article includes representative analyzes performed at half the length of the shaft. In total, three cross-sections along the entire length of each prototype were made, and the results obtained are consistent with those presented.

As a result of comparing sample analyzes performed for individual research models, it is possible to observe the occurrence of geometry changes confirming and specifying the global analyzes (Figs. 9-11). The distributions of deviations presented in the figures below do not require detailed commentary, as they clearly illustrate the differences between the individual cases examined.



Figure 10 Global analysis of the shaft geometry - PolyJet offset 0.2 mm





Figure 11 Cross-sectional analysis of the shaft model - PolyJet nominal model



Figure 13 Cross-sectional analysis of the shaft model - PolyJet offset 0.15 mm

Additional analyzes in the form of inspection sections showed that a geometry correction of 0.15 mm ensures correct assembly of the connection. As depicted in Fig. 13, the geometry deviations in the range -0.14 to -0.03 mm provide compensation for hole production errors. Thanks to this, preliminary analyzes in the form of global deviation maps were confirmed. Additionally, this was confirmed by tests on real models. The result was the inability to assemble the connection for nominal geometries as well as models made with an offset of 0.1 mm, and excessive clearance for prototypes made with an offset of 0.2 mm.



Figure 14 Cross-sectional analysis of the shaft model - PolyJet offset 0.2 mm

# 3.2 Analysis of the Geometry of Prototypes Manufactured using FFF Technology

Similar to prototypes manufactured using PolyJet technology, analyses were conducted for models produced using the FFF method. Analyzes performed for the geometry of the gear wheel hole showed geometry deviations ranging from -0.14 to +0.1 mm (Fig. 15, 16). These results suggest

the occurrence of partial shrinkage for the material and manufacturing technology employed.

To determine necessary clearance values for correct splined connection assembly, individual shaft geometries were analyzed. Initially, global surface deviation maps were generated for each geometry (nominal and offsets of 0.1 mm, 0.15 mm, 0.2 mm) (Fig. 17-20). The findings indicated that increasing clearance to 0.1 mm might facilitate connection assembly (Fig. 18).



Figure 15 Global analysis of the gear geometry - FFF nominal model



In this case, only deviation values for nominal geometry do not ensure the possibility of mounting the connection. With geometry modifications of 0.15 mm and 0.2 mm (Fig. 19, 20), connections exhibit excessive looseness, resulting in

incorrect assembly. For detailed analyses, additional deviation maps were prepared in the form of inspection cross-sections (Fig. 21-24).

Comparing sample analyses for individual research models reveals geometry changes, confirming and specifying global analyses (Figs. 17-20). Similar to previous analyses, deviation distributions in the figures below do not require detailed commentary, as they clearly illustrate differences between examined cases.



Figure 17 Global analysis of the shaft geometry - FFF nominal model



Figure 18 Global analysis of the shaft geometry - FFF offset 0.1 mm



Figure 19 Global analysis of the shaft geometry - FFF offset 0.15 mm



Figure 20 Global analysis of the shaft geometry – FFF offset 0.2 mm



Figure 21 Cross-sectional analysis of the shaft model - FFF nominal model



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Further analyses through inspection sections indicated that a 0.1 mm geometry correction ensures correct

connection assembly. As depicted in Fig. 22, geometry deviations ranging from -0.25 to -0.02 mm compensate for hole production errors, confirming preliminary analyses through global deviation maps. Additionally, this was confirmed by tests on real models. The result was the inability to assemble the connection for nominal geometries and excessive clearance for prototypes manufactured with offsets of 0.15 mm and 0.2 mm.



Figure 23 Cross-sectional analysis of the shaft model - FFF offset 0.15 mm



Figure 24 Cross-sectional analysis of the shaft model - FFF offset 0.2 mm

### 4 CONCLUSIONS

The methodology outlined in this article facilitates a swift and efficient assessment of the impact of modifying the geometry of a spline connection on its assembly possibilities. The results of the analyzes were presented, taking into account the selected manufacturing technologies and materials used. Through comprehensive analyses and inspection cross-sections, any geometric irregularities were graphically visualized, allowing for the determination of their deformation extent. Based on the conducted tests and the results presented, it is evident that the outcomes vary for the designed geometry, contingent upon the manufacturing technique and material employed. In the case of Fused Filament Fabrication (FFF) technology using PLA material, modifying the geometry by a 0.1 mm offset was sufficient to ensure proper assembly, as depicted by the deviations illustrated in Figs. 16 and 22. This resulting connection guarantees correct assembly with slight perceptible resistance, validated through physical model testing (Fig. 25).



Figure 25 Checking the correctness of the prototypes geometry made using the FFF method

Regarding the results pertaining to PolyJet technology with RGD720 material, achieving correct assembly necessitated modifying the geometry by a 0.15 mm offset, demonstrated by the deviations shown in Figs. 6 and 13. Similarly to PLA, the connection thus obtained ensures proper assembly with slight perceptible resistance, as confirmed through physical model testing (Fig. 26).



Figure 26 Checking the correctness of the prototypes geometry made using the PolyJet method

The research, analyses, and tests conducted on physical models demonstrate consistent findings. However, it should be noted that geometry deviations increased for prototypes manufactured using PolyJet technology. In the case of FFF technology, increasing the offset of the shaft spline profile by 0.05 mm was necessary for proper connection assembly.

The tests and examinations conducted exhibited repeatability and yielded convergent results across all samples. Building upon this foundation, further research endeavors are planned to explore various manufacturing clearance sizes across a broader range of spline connection dimensions.

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### Quality of Courier Services from the Customer Perspective in the Republic of Serbia

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Abstract: The recent growth of the e-commerce sector—especially during and after the COVID-19 pandemic—has led to the expansion of the Courier, Express and Parcel (CEP) market. To remain competitive, courier companies had to adjust their business models to meet not only high demand but also customer expectations. The aim of this work is to assess the quality of courier services in the Republic of Serbia from the customers' perspective. The relevant data was obtained via an electronic survey, which was informed by a comprehensive literature review. The online questionnaire was distributed via social networks (Facebook and Viber) in February 2023 and the subsequent statistical analyses revealed that, in the Republic of Serbia, satisfaction with courier delivery services is affected by the use frequency, customer characteristics (employment status, level of concern regarding personal data security) as well as the courier service characteristics (e.g. responsiveness, timeliness, delivery status, payment options).

Keywords: courier companies; courier services; customer satisfaction; delivery; Serbia; survey

### **1** INTRODUCTION

Courier services are among the fastest-growing ecommerce sectors owing to the increased popularity of online shopping. While online platforms for purchasing clothes, shoes, electronic devices, household devices, cosmetics, car spare parts, bags, books, etc. have existed before the COVID-19 pandemic, the demand for this service has rapidly increased in recent years.

In 2023, 185 billion parcels were shipped worldwide, and their volume is expected to reach 256 billion in 2027 [1]. According to the data provided by the companies operating in the Serbian Courier, Express and Parcel (CEP) market— A2B Express, AKS, Bex Express, City Express, DHL Express, Express Courier, FedEx, Serbian Post, TNT, Union Sped, YU/PD, and others—in Serbia, with a population under 7 million, about 51.2 million parcels were delivered in 2022 [2]. Clearly, such a large number of courier companies in a relatively small CEP market has resulted in intensive competition.

As third-party service providers, courier companies are completely dependent on the logistics, and the efficiency of parcel collection and delivery will determine their overall profitability, but customer satisfaction. For example, upon the receipt of a customer request, they typically deploy a relatively small vehicle/van to collect the item from the sender to the central depot [3]. At these premises, all parcels are assigned a unique number, which provides accurate data about the recipient and the sender, and are sorted by addresses and assigned to delivery vehicles.

At the beginning of e-commerce development, courier companies provided standard services for customers and cooperated with big online stores. However, they now need to offer an extensive range of services—such as online tracking capabilities, along with proof of delivery, payment collection, and return services—to stay competitive. In terms of the logistics organisation, e-commerce companies can be classified into one of the following categories [4]:

1) Own logistics – retailers independently perform all logistics operations, except the delivery to the customer,

which is performed by a courier company. This form is effective for small businesses.

- Dropshipping the product is directly shipped via courier from an external warehouse (belonging to the manufacturer or distributor) to the customer. This form is mainly adopted in medium-sized businesses.
- One-stop e-commerce the entire process (warehousing, inventory management, receiving orders, packing parcels, preparing documents, handling returns, and cooperating with carriers) is executed by an online store owner.

While these models differ, courier services remain the vital last link in the online shopping, and their quality determines the level of customer satisfaction with the entire process. Accordingly, extensive research has been conducted on the different dimensions of courier service quality and their relative importance for customer satisfaction. Nonetheless, given the optimistic predictions regarding the CEP market growth, additional empirical studies are needed to gain a greater understanding of this new social phenomenon. The present study aims to contribute to this endeavour by examining the quality of courier services from customers' perspective in the Republic of Serbia. The purpose is to gain new insights into the factors that motivate or hinder courier service usage, as well as those that are most relevant to the customers, thus facilitating further improvements in this sector.

The remainder of the paper is organised into four sections. Section 2 is designated for the literature review, while the research methodology is outlined in Section 3. The obtained results are presented and discussed in Section 4. After sharing some further observations in Section 5, the paper closes by stating the study limitations and proposing some beneficial directions for future research in this domain.

### 2 LITERATURE REVIEW

In extant research, courier service quality is typically examined from customers' perspective, couriers' perspective, and/or online retailers' perspective. For example, based on the work of Kamble and colleagues [5], in 2020, Hendayani and Dharmawan [6] derived the following nine dimensions of courier service quality from the customer perspective: information quality, ordering procedures, ordering release quantities, timeliness, order accuracy, order quality, order conditions, order discrepancy handling, and personnel contact quality. Information quality relates to the accuracy and timeliness of information provided by the courier. Ordering procedure encompasses receiving customer orders, collecting and sending the parcels, and similar processes. Ordering release quantities pertain to the shipping quantity that allows the courier to achieve a lower transport price and the company policy. Timeliness is defined as the time that elapses from the creation of shipping order to the delivery to the customer. Order accuracy involves timely information provision to customers, allowing their parcels to be tracked in real time. Order quality is related to the courier service quality standards promised to the customers. Order conditions refer to the parcel damage protection and transport prices. Order discrepancy handling pertains to the way differences in the expected and delivered services are resolved. Personnel contact quality refers to the conduct of the courier company representatives when communicating with customers.

On the other hand, Gulc [7] used exploratory factor analysis to develop a courier service quality scale from the ecustomers' perspective comprising seven dimensions reliability, visual identification, service complexity, relational capital, social responsibility, responsiveness, and technical quality—and the corresponding variables. Ejdys and Gulc [8] concurred with this perspective, but also emphasised the importance of trust and technological aspects in the customer assessment of courier service quality.

Gulc [9] subsequently developed a relational model of courier service quality in the B2C e-commerce sector considering the multi-stakeholder perspective of e-shops, courier companies, and e-customers. According to the proposed model, courier service quality is determined by factors that can be classified as crucial, determinant, result, autonomous, or external. The author considered efficient and fast order processing as the crucial factor. The determinant factors comprised courier responsiveness to reported problems, easy contact with the courier, and efficient communication between courier employees and customers. The result factors are delivery timeliness and effectiveness, and positive customer experience with the courier service. The autonomous (order compliance and completeness) and external factors (e.g., delivery mode and schedule flexibility) were found to exert a smaller influence on the courier service quality [9].

In 2020, Wang [10] conducted a survey of Australian courier companies in order to assess their logistics capabilities based on which operation flexibility-oriented capability (courier's ability to provide flexible logistics services), process optimisation-focused capability (courier's ability to improve business processes with the aim of providing the best logistics services for customers), and innovation-focused capability (courier's ability to implement new technologies and solutions in business processes) emerged as the key elements in this sector.

Based on a survey conducted by Marcysiak [11] in 2021, the main factors Polish customers consider when choosing a courier company are delivery interval, price, and safety. When it comes to individual elements of customer service quality, the customers give precedence to delivery flexibility, followed by reliability, communication with the operator, and delivery punctuality.

As a part of another study conducted in Poland, Swircz and Racz [12] also focused on the customers' decisionmaking process when using courier services. They assessed the importance of shipping price, order completion time, availability of delivery time slots, waiting period, staff communicativeness, order placement flexibility, complaint options, order integrity, delivery integrity, technical support, ease of order placement, interaction with company staff, delivery timeliness, availability of different payment options, tracking information, warranty on shipment, company origin, company reputation, personal experience, and customer service. Their findings revealed that Polish consumers are most influenced by shipping price, delivery timeliness, waiting time, order integrity, and tracking information.

In 2020, Rajendran [13] analysed online reviews of four world-leading courier companies posted on social networks during the preceding eight-year period. Using text analysis tools, the author identified the most common causes of customer dissatisfaction with courier services, namely product mishandling (lost parcels, deliveries left outdoors, or items thrown over the fence), delivery issues (delivery to a wrong address, late delivery, and missed delivery), customer support issues (long wait and hold times, disrespectful employees, lack of immediate response, and poor communication), problems with delivery drivers (stealing parcels, mishandling parcels, and lying about customer availability), website and online tracking issues (incorrect tracking system and non-user-friendly interface) and other issues related to services (unable to talk to humans, no dropbox system, and no flat rate boxes).

Based on the aforementioned findings, the courier service quality is primarily determined by: delivery timeliness [6, 7, 9-12], communication with the courier [6, 7, 9-13], delivery tracking information [6-8, 10, 12, 13], parcel handling [6, 7, 9, 11-13], shipping price [6, 10-12], payment options [12], and customer data security [7, 8]. Delivery timeliness refers to the time period between the shipping order creation and the parcel delivery to the customer. Communication with the courier encompasses accurate and timely provision of information to the customer in an honest and polite manner. Delivery tracking information relates to the real-time access to the delivery status. Parcel handling refers to careful and safe parcel handling during the entire delivery process. Shipping price is the monetary amount customer is charged for the courier service. Payment options refer to the various means by which customers can pay for courier services. Customer data security is measured by the level of confidence customers have in the courier's capability to safeguard personal and sensitive data from misuse.

#### METHODOLOGY 3

The aim of this study is to assess the quality of courier services in the Republic of Serbia from the customers' perspective. Accordingly, the following main research questions are formulated:

- 1) What is the level of satisfaction with and relative importance of individual courier service characteristics?
- What are the key reasons for dissatisfaction with courier 2) services?
- 3) How often do respondents use courier services?
- What payment method do users of courier services 4) prefer?
- 5) Do users have confidence in the security of personal data they provide to courier services?

Additional, more specific, research questions are also addressed as a part of this investigation:

- 1) Is there a link between customer age and courier service use frequency?
- Is there a link between the employment status (student, 2) employed, unemployed, and retired) and courier service use frequency?
- 3) Is there a link between customer age and the method of payment for courier services?

Table T basic information about the survey methodology				
Characteristics of the survey methodology	Description			
Location:	Republic of Serbia			
Timeframe for research implementation:	February-April 2023			
Participants/Respondents:	Courier service users			
Type of sample:	Simple random sample			
Overall number of responses:	426			
Number of valid responses:	379			
Research method:	Survey			
Survey technique:	Survey questionnaire in Google Forms			
Survey questionnaire distribution:	Facebook and Viber (no specific focus group)			

Table 1 Basic information about the survey methodology

The methodology adopted for addressing these questions included desk research, an electronic survey, and statistical data analysis. First, literature review was conducted to identify the key factors affecting courier company choice. These findings were subsequently used to develop a 19-item questionnaire probing into the respondents' gender, age, employment status, prior courier service use, courier service use frequency, last usage of courier services, delivery interval, payment method, satisfaction with delivery time, satisfaction with communication with the courier, satisfaction with package status updates, importance of courier service provider selection, importance of payment card option, importance of delivery speed, importance of communication with the delivery driver, importance of package status updates, confidence in the security of personal data provided to the courier company, negative experience in personal data abuse, and reasons for dissatisfaction with courier services. The respondents were instructed to provide their general views, i.e., without reference to a specific

courier company or time period. The questionnaire was posted online through Google Forms on Facebook and Viber in February 2023. On Facebook, the questionnaire achieved 2,486 clicks. The participation in the survey was voluntary and individuals that submitted completed questionnaires did not receive any compensation. The basic information about the survey methodology is given in Tab. 1. The collected data were subsequently analysed using SPSS software in order to gain new insights into the Serbian customers' level of satisfaction with the courier service quality.

### STUDY RESULTS

The present study, exploring the quality of courier services from customers' perspective in the Republic of Serbia, was conducted from February to April 2023. While 426 individuals completed the survey, only 379 valid responses were retained for analysis. The sample comprised 68.60% females and 31.40% males, whereby those in the 18-24 age group predominated (55.7%), followed by those aged 25-34 (22.4%), the 35-44 age group (11.6%), and those aged 45-60 (9.5%) and over 60 (0.8%). Moreover, 49.1% of respondents were employed, 43.5% were students, 3.7% were pupils, 2.4% were unemployed, and 1.3% were retired.

Although the survey was intended for courier service users, 334 (88.1%) questionnaires were completed by those that have previously used a courier service. The remaining 45 respondents, who indicated that they do not use courier services, provided the following reasons for this decision:

- Courier companies are not accurate; delays are frequent (4.2%)
- Courier companies do not handle packages adequately (3.2%)
- Courier companies are not reliable (2.9%)
- Delivery drivers are rude (1.6%).

Tab. 2 provides findings regarding the courier service use frequency, last usage of courier services, delivery interval, and payment method. According to the tabulated data, 41.4% of the sample uses courier services once per year or several times per year, while 28% of respondents require this service once a month. Most of the respondents used courier services a month ago (28.5%) or a few days ago (23.5%), and in the majority of cases the parcel was delivered within 2-5 working days (62.3%) and payment was made in cash upon delivery (65.2%).

Although 93.1% of respondents had no direct experience of personal data abuse, only 65.3% of the sample felt confident that the courier company would keep their information safe.

According to the Chi-squared test of independence, age was statistically significantly related to the courier service use frequency ( $\chi^2(15, n = 379)=33.452, p < 0.01$ ). To assess the strength of this relationship, statistical power analysis was conducted, yielding phi = 0.297. According to Cohen's guidelines [14] this coefficient value is indicative of a moderate effect size. Cramer's V = 0.172 also showed moderate effect size according to [15]. This indicator is particularly relevant for cross tabulation analyses involving more than two variables with two categorical answers, which is the case here.

On the other hand, the relationship between users' employment status and the courier service use frequency was not statistically significant ( $\chi^2(4, n = 334)=4.173, p = 0.383$ ).

Table 2 Some im	portant categorical	l variables and the	corresponding	frequencies
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Ca	ategorical variables ( $N = 334$ )	Frequency (1)	Percentage (%)
Frequency of	Once per year or several times per year	157	41.4
courier services	Once per month	106	28
usage	Several times per month	57	15
	Several times per week	11	2.9
	Every day	3	0.8
Last usage	A few days ago	89	23.5
	A few weeks ago	59	15.6
	A month ago	108	28.5
	Three months ago	46	12.1
	Six months ago	22	5.8
	A year ago	10	2.6
Delivery period	One hour	5	1.3
	Few hours	4	1.1
	One day	37	9.8
	2-5 working days	236	62.3
	5-10 working days	34	9.0
	More than 10 working days	18	4.7
Payment	Cash payment on delivery	225	65.2
method*	40	10.6	
	Payment by bank transfer before delivery	47	12.4

\*The number of respondents varies for this variable

*Chi-Square test of independence* further revealed that the method of payment for courier services significantly differs depending on the user's age ( $\chi^2(6, n = 334) = 12.367, p = 0.05$ ). The statistical power analysis yielded *phi* = 0.192, which is considered between small and moderate effect size [14]. On the other hand, *Cramer's V* = 0.136 is indicative of moderate effect size [15].

The payment method choice also significantly differed based on the employment status ( $\chi^2(15, n = 334) = 9.923, p < 0.05$ ). Once again, strength of this relationship is between small and moderate effect size based on *phi* = 0.172 [14], and is indicative of moderate effect size based on *Cramer's* V=0.122 [15].

It is also noteworthy that 79.7% of those aged 18-24 and 56.8% of those aged 35-44 pay cash on delivery, while the payment by card on delivery (16.2%) and payment by bank transfer before delivery (27.0%) options are most likely to be chosen by those in the 35-44 age group.

These findings were further explored by conducting *Bonferroni-adjusted pairwise z-tests*. According to the obtained results, in the 18-24 age group, the frequency of cash payment on delivery (n = 157 or 79.7%) significantly differed from that related to payment by bank transfer before delivery (n = 19 or 9.6%). Significant difference also emerged between cash payment on delivery (n = 21 or 56.8%) and payment by bank transfer before delivery (n = 10 or 27.0%) in the 35-44 age group. Other pairwise comparisons were not statistically significant.

Next, respondents' ratings on a 5-point Likert scale for the level of satisfaction with delivery speed, communication and package status updates, as well as the importance of courier service characteristics (such as courier service provider, payment card option, delivery speed, communication with the delivery driver, and package status updates) were analysed and the findings are shown in Fig. 1.

As students and employed were the most frequent users of courier services, their responses were subjected to further analyses to determine their satisfaction with and perceived importance of individual courier service characteristics. For that purpose, it was necessary to verify the following assumptions:

- Independence of observations independent observations were achieved because each observation in the database was obtained from one respondent. There were no respondents who filled out the questionnaire more than once. Respondents were selected randomly.
- Normality of distribution *Kolmogorov–Smirnov* test indicated that three variables—level of satisfaction with delivery speed, level of satisfaction with communication, and level of satisfaction with package status updates—were not normally distributed. However, for a sample larger than 30, this assumption does not have to be met.
- Homogeneity of variance Levene's test of equality of variances was performed. According to the Tabachnick and Fidell's guidelines [16], the significance values in *Levene's test* need to be greater than sig > 0.05 in order to reject the assumption that variances are not equal. For the two groups of scale variables, the obtained significance levels were: level of satisfaction with delivery speed (sig = 0.073), level of satisfaction with communication (sig = 0.00), level of satisfaction with package status updates (sig = 0.000), importance of courier service provider selection (sig = 0.509), importance of payment card option (sig = 0.780), importance of delivery speed (sig = 0.000), importance of communication with the delivery driver (sig = 0.474), and importance of package status updates (sig = 0.536). For variables where the assumption of homogeneity of variance was violated (sig < 0.05), Welsh test was used, as it is robust to violations of the assumption of homogeneity of variance.

Next, *independent samples t-test* was performed to compare the satisfaction level of students and employed. As can be seen from Tab. 3, their satisfaction with the delivery speed was comparable at M = 3.80, SD = 1.14 vs. M = 3.97, SD = 1.06 (t(323) = -1.390, p = 0.165). No statistically significant differences emerged between their ratings for the satisfaction with communication with courier service providers—students (M = 3.48, SD = 1.15), employed (M = 3.71, SD = 1.27), (t(323) = -1.520, p = 0.129). On the other hand, employed respondents rated their satisfaction with package status updates (M = 3.91, SD = 1.10) statistically significantly (p < 0.01) higher than did students (M = 3.30, SD = 1.49), t(300,4) = -4.227, p = 0.009. Based on  $\eta^2 = 0.0524$ , this represents a medium effect size [14].



Independent samples t-test was also performed to compare the level of importance that students and employed assign to individual courier service characteristics (Tab. 3). Students provided statistically significantly lower ratings (M = 3.51, SD = 1.35) than employed (M = 3.83, SD = 1.37) for the importance of payment card option (t(323) = -2.120, p = 0.05) with small effect size ( $\eta^2 = 0.014$ ). They also found the delivery speed statistically significantly less important (M = 3.70, SD = 0.66) than employed users (M = 4.51, SD = 0.79), (t(310.62) = 2.298, p = 0.022) with small effect size ( $\eta^2 = 0.016$ ). For other indicators, no statistically significant differences (p < 0.05) between these groups were noted.

Table 3 Mean values for variables that measure the satisfaction level and the perceived importance of courier service characteristics

	User status		
Variables and mean values	Students	Employed	
	N = 164	N = 161	
Level of satisfaction with delivery speed	3.80	3.97	
Level of satisfaction with communication	3.48	3.71	
Level of satisfaction with package status updates	3.30**~	3.91**~	
Importance of courier service provider selection	3.41	3.64	
Importance of payment card option	3.51*¬	3.83*¬	
Importance of delivery speed	4.70* ¬	4.51* ¬	
Importance of communic. with the delivery driver	4.31	4.40	
Importance of package status updates	4.42	4.35	
Stat. significance:	**p < 0.01 (t-test) *p < 0.05 (t-test)		
Eta squared $(\eta^2)$ :	• 0.11-0.14 (large effect size)  ~ 0.05-0.10 (medium effect size)  ¬ 0.01-0.04 (small effect size)		

The participants' survey responses to multiple-choice questions were also analysed to identify the main reasons for dissatisfaction with courier services in the Republic of Serbia and the results are provided in Tab. 4.

As would be expected, students and pupils were most concerned with high delivery costs (42.5%), but also indicated that delivery speed could lead to dissatisfaction (36.6%), which was the primary issue for employed individuals (47.8%), followed by high delivery costs (35.7%). Somewhat surprisingly, only 28.6% of pensioners and unemployed cited high delivery costs as the main cause for dissatisfaction.

To situate these findings in the right context, they were compared with the results obtained in other studies. For example, in 2020, Dones and Young [17] conducted a survey in Philippines and found that 93.3% of the respondents used courier services, which is comparable to 88.1% obtained in Serbia. On the other hand, frequency of courier service usage in Poland is much greater than in Serbia, as Marcysiak [11] reported 54.6%, 28.5%, and 16.9% for several times a month, once per month, and several times a year, respectively, while Swirz and Racz [12] noted 35%, 26%, and 22%. In Serbia, most courier service users (65.2%) prefer cash payment upon delivery, concurring with their counterparts in Philippines (82.5%) [17]. As in the present study satisfaction ratings were given on a 5-point Likert scale, the average of 3.89 for the delivery speed can be considered high, concurring with the results obtained in Poland, where 56.2% and 11.1% of respondents provided high and very high ratings, respectively [11]. In the present study, high delivery prices were the most important cause of dissatisfaction with courier services, supporting the findings obtained for Polish consumers [11, 12]. Similar surveys have shown that users also expect better communication with the courier [6, 18], as well as adequate handling of their packages [6, 11, 18].

Table 4 Frequency of reasons for dissatisfaction with the package delivery process

Reasons for dissatisfaction	Students and pupils	Employed	Unemployed and retired
High delivery price	42.5%	35.7%	28.6%
Delivery speed	36.6%	47.8%	7.1%
Poor communication	27.9%	21.6%	7.1%
Misunderstandings and delivery person's impatience	25.1%	21.1%	7.1%
Poor and inadequate package handling	20.7%	24.9%	0%
Non-compliance with the agreement	17.3%	22.2%	14.3%
Sense of insecurity	12.8%	13.5%	7.1%

### 5 CONCLUSION

The global demand for courier services is booming primarily due to the rapid e-commerce development and growth. This trend is also apparent in the Republic of Serbia where online purchases are on the rise, and consumers expect timely, reliable, and cheap delivery, for which they typically rely on courier companies. Although many courier companies operate in the Serbian market and the competition is very intensive, customers usually cannot choose their preferred courier, as the selection (if any) is determined by the e-retailers.

The aim of this study was to assess the quality of courier services in the Republic of Serbia from the customers' perspective. The obtained results reveal that courier services are usually used once per year or several times per year, but the usage frequency differs significantly based on customer age, rather than employment status. Most users receive their delivery within 2-5 working days and, while majority of respondents were satisfied with this delivery speed, they indicated that this interval should be shorter. Generally, Serbian consumers prefer to pay for courier services in cash upon delivery. As most users had no prior negative experience with personal data abuse, they have confidence that the courier company will keep their sensitive information safe. Based on their rating of courier service characteristics, delivery speed is considered the most important, followed by up-to-date information about the delivery status, and communication with the delivery driver. Moreover, users are least satisfied with high delivery costs, followed by delivery speed, and poor communication.

The findings of this study offer valuable insights into customers' satisfaction levels with various quality characteristics of courier services. While service quality in the courier industry is not as easily quantifiable as in the manufacturing sector, this research underscores the critical need to bridge theory and practice. For practitioners and managers, the results reported in this work pave the way for actionable recommendations and strategic plans for service quality enhancement. These findings can serve as a foundation for developing policies aimed at managing and improving service quality in service-oriented settings. Additionally, the statistical framework developed in this study can facilitate a deeper understanding of the factors driving and/or hindering consumer satisfaction by linking the structural parameters of service settings to practical solutions within the industry. This connection can aid the ongoing efforts at refining service delivery and addressing customer needs more effectively. In summary, this research not only contributes to the academic literature on service quality determinants but also offers tangible implications for improving courier services from both a theoretical and practical standpoint.

When interpreting these findings, some limitations of this study should be noted. First, the survey was conducted in one developing country—the Republic of Serbia—and in a relatively short time period in 2023. Second, only the courier service users' perspective was considered. Third, the sample size was relatively small (only 379 valid responses were received).

In the future, similar empirical studies about the quality of courier services in the Republic of Serbia and other countries from the customers', courier companies' and eshops' perspective should be conducted to address these shortcomings and provide a more comprehensive insight into the factors explored in this article. Likewise, it would be beneficial to examine the alternatives to courier services.

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## The Impact of the Use of VR on the Effectiveness of Training in the Field of Occupational Health and Safety and Ergonomics - the Perspective of Polish Enterprises

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Abstract: Enterprises are increasingly using modern solutions to train employees in the field of occupational safety and ergonomics. This is intended to encourage active participation in such training and to shape employees' awareness of these topics. One of the solutions used may be VR technology, which allows the employees to learn about issues by presenting situations as close to real ones as possible. The aim of this article is to present conclusions from the use of VR in Polish enterprises. The advantages of this solution were analyzed according to the OHS specialists, and the difficulties with implementing it in training were also indicated.

Keywords: ergonomics; occupational health and safety; OHS trainings; virtual reality

#### **1** INTRODUCTION

Occupational health and safety training is an important issue in providing basic safety information to employees in all countries, including Poland. The issues discussed therein, the method of conducting and the frequency of the training determine the safe performance of work by employees, the of appropriate protective measures and the use implementation of activities aimed at shaping high employee awareness in this area. This is even more important because many accidents at work are caused by inappropriate behavior of employees, e.g. in the use of protective equipment, inappropriate management of the work process and lack of caution while working (especially when using tools and machines) [1]. According to preliminary data on accidents at work in Poland in 2023, 41% of accidents were caused by employee's incorrect action. Additionally, the human-related causes of accidents include: inappropriate use of personal protective equipment (approx. 2% of accident causes), inappropriate use of work materials (approx. 10% of accident causes), non-compliance with occupational health and safety regulations and instructions (approx. 6% of accident causes). It can also be pointed out that the causes of accidents in Polish companies are often the responsibility of employers, especially in terms of: ensuring appropriate technical conditions and work ergonomics, incorrect work organization or inappropriate work tools [2]. For this reason, occupational health and safety training will be important not only in terms of achieving appropriate employee behavior, but also in shaping appropriate working conditions that will support, and in some cases even enable, these behaviors.

Occupational health and safety training (which also includes ergonomic topics) is often conducted in the form of a lecture with elements of practical exercises and task performance [3]. They often also include activating elements, such as case studies, instructional videos, and problem presentations. There is also an increase in interest in the use of VR elements in occupational health and safety and ergonomics training. The advantages of implementing this solution include [4, 5]:

- The ability to provide employees with teaching based on examples and in conditions as close to real ones as possible,
- Promoting modern technologies among employees, which can also be used outside occupational health and safety training,
- Active participation in the training through careful analysis of the examples presented,
- Encouraging employees to work in accordance with health and safety instructions and regulations by realistically showing the consequences of inappropriate behavior.

On the other hand, however, there are general disadvantages of using VR in occupational safety training in terms of: high costs of the solution, high organizational requirements, the possibility of employees experiencing discomfort related to the use of goggles (e.g. eye and headache), the need to provide a trainer with extensive knowledge about VR, the need to allocate time during training to explain how VR technology works [6].

Taking into account the developing trend of using VR in employee health and safety training, this article examines how it works in selected Polish enterprises. Five cases were analyzed (in the form of participant observation and informal interview), indicating the impact of the use of VR on the effectiveness of training, and the advantages and difficulties of implementing this solution were indicated.

#### 2 APPROACHES USED IN OCCUPATIONAL HEALTH AND SAFETY AND ERGONOMICS TRAININGS – LITERATURE REVIEW

#### 2.1 Obligation of Training in the Field of Occupational Health and Safety (Including Ergonomics)

According to the legal regulations in force in Poland, periodic training in the field of occupational health and safety is mandatory for every employee. They are performed at a specific frequency (e.g. for workers in blue-collar positions once every 3 years and for employees working in particularly hazardous processes once a year). The program of such training is established and includes the following elements [7]:

- Presentation of legal regulations related to occupational health and safety,
- Presentation of threats related to the workplace and ways to eliminate them or reduce their effects,
- Rules of conduct in the event of an industrial breakdown and accident at work,
- Basic rules on fire protection in the workplace,
- Basic principles of organization and providing first aid in the organization.

Training for workers in blue-collar positions should take place in a stationary form with the participation of a trainer specializing in occupational health and safety.

#### 2.2 Remote Training in the Field of Occupational Health and Safety and Ergonomics

Polish legal regulations allow for the organization of periodic occupational health and safety training for employees remotely, but only for managing employees, administration and engineering and technical staff. It should take the form of a course, seminar or guided self-study based on materials received from the training organizer [7]. It is important to ensure the appropriate level of education and knowledge of the person conducting the training or providing training materials, as this largely determines the provision of the most important information in an appropriate form [8].

Organizing these training courses remotely has become more important during and after the COVID-19 pandemic [9]. This is also related to the development of the trend of remote work and its inclusion in Polish law [10], as well as the need to include in training issues such as: threats when working from home, appropriate, ergonomic adjustment of the workstation, reporting accidents that occurred during remote work [11].

# 2.3 The Use of VR in Training in the Field of Occupational Safety and Ergonomics

VR technology is increasingly being used in health and safety training taking into account ergonomics [12], also in Poland. This is intended to familiarize employees with real conditions (but without the risk associated with hazards at workplaces), but also to encourage committed participation in the training (e.g. by using gamification elements). Employees can also test their knowledge of what to do in emergency situations in which they were not previously able to take part, e.g. fire, spread of chemical substances, accident while working at heights, which allows them to supplement their theoretical knowledge about how to behave in such situations [13, 14]. A big advantage of using VR in occupational health and safety training is the ability to shape appropriate employee behavior by showing them in real terms the possible consequences of their incorrect behavior while working (e.g. if they do not protect themselves while working at heights, they can see the effects of a fall). It is not possible to achieve this effect by conducting training only

theoretically, which is why companies are increasingly turning to virtual reality solutions (also in the context of shaping safety culture of work) [15-17].

In Poland, VR solutions in occupational health and safety training are implemented in many industries, especially for employees in production positions, where there are many risk situations and a particularly quick response to noticed dangers and irregularities is required [18, 19]. Such training is characterized by a specific order in which individual topics are presented, which results mainly from the curriculum in this area imposed by legal regulations. It is possible to compare various aspects of traditional occupational health and safety training and that using VR (Tab. 1).

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Source: own elaboration based on: [7, 18, 19].

There is a designated time in which topics should be discussed in order to conduct the training within one working day. For this reason, it is possible to propose VR implementation in some training sessions (Fig. 1).

It is important to devote more time to issues in which VR can be used - time is necessary to organize the station and complete the module.

Companies offering the use of VR provide various modules that can be implemented in occupational health and safety and ergonomics training, e.g. [20-22]:

- Fire protection and behavior in case of fire,
- Working at heights and the risks associated with it,
- First aid in the event of a threat to life and health,
- Ergonomics at work stations (mainly basic principles).

The topics of occupational health and safety training using VR can therefore be adapted to the company's capabilities but also to the real problems occurring in it.



Figure 1 Possibility of implementing VR elements at individual stages of occupational health and safety training. Source: own elaboration based on: [7, 13].

#### 3 METHOD OF RESEARCH

The undertaken research was carried out on the basis of the cases of five Polish manufacturing enterprises. They were selected due to the lack of use of VR in occupational health and safety and ergonomics training in the past (the research training was the first attempt to use this technology), as the aim was to test the feasibility of its use. The research was carried out in three main stages:

1) Analysis of the method of conducting training in the field of occupational health and safety and ergonomics in the enterprise and the method of verifying employees' knowledge (in the form of a test and questions regarding: legal provisions regarding occupational health and safety, fire protection, first aid, accidents at work and threats at workplaces).

- 2) Participant observation in training in the field of occupational health and safety and ergonomics (provided by an external company) using VR elements (participation in the theoretical part, participation in the practical part and participation in the test at the end of the training) - an example of the use of VR in training is shown in Fig. 2. Five employees from each selected company took part in the training.
- 3) Informal interview with health and safety specialists supervising health and safety training and analysis: possibilities of permanently implementing VR in health and safety training, organizational possibilities of VR implementation and barriers to implementing this technology in practice.



Figure 2 VR training example. Source: own photography.

The above-mentioned stages 1 and 2 took place during one working day, stage 3 was additionally supplemented with remote consultations with occupational health and safety specialists.

#### 4 RESULTS

In the first stage of the research, methods of conducting occupational health and safety training for workers were analyzed. The training was organized with the help of an external company, in a stationary form, at the time specified in the legal regulations (lasting one working day). The training ended with a knowledge test in the areas included in the training program (the tests were archived). Ergonomics was an integral topic discussed during the meeting with employees.

In the second part of the research, a practical part of the training in the field of occupational health and safety was carried out using various VR modules in this area. During the observations, it was noticeable that the employees participated in the training willingly and with interest, but on the other hand, organizing space for performing the task seemed to be problematic. Another disadvantage was the

small number of devices compared to the number of trained employees.

After completing the training, a knowledge test was conducted among employees, the results of which were then compared with the results of previous trainings (in which VR technology was not used). An increase in correct answers was observed in three parts of the test (first aid, ergonomics and fire protection), which were related to the VR modules used (Fig. 3).



Figure 3 A noticed increase in providing correct answers in the knowledge test after occupational health and safety training using VR. Source: own elaboration.

In the third part of the research, informal interviews were conducted with occupational health and safety specialists supervising OHS training to discuss the possibility of permanent implementation of VR technology into the training. The information obtained from these conversations can be divided into opportunities and obstacles to implementing this solution. Among the advantages, occupational health and safety specialists pointed out:

- Noticeable, greater involvement and interest of employees in the form of training (previous, mainly theoretical training did not engage employees in activities, which was later reflected in the application of the acquired knowledge in practice, e.g. in the context of using personal protective equipment),
- Better results of the knowledge test conducted among employees (which suggests better absorption of information provided during the training),
- The ability for employees to test emergency situations in conditions similar to real ones without the need to provide them, e.g. using artificial smoke simulating a fire.

On the other hand, however, occupational health and safety specialists have noticed many barriers to the permanent implementation of VR in OHS training. They pointed out the following difficulties:

- The need to provide plenty of space for employees to move freely in VR goggles (stationary traditional

training requires only a room with an appropriate number of chairs, the use of VR forces movement, often without employees being aware of it),

- The need to provide much more time for training than in the case of stationary training - completing each module with limited access to goggles extends the training, which usually lasts one working day,
- Reluctance of some employees to use modern technology and some employees experience headaches and nausea after using goggles for this reason, occupational health and safety specialists would consider VR as an optional addition to training, without replacing the traditional form.

An interesting remark is that occupational health and safety specialists did not indicate the costs of this solution as a barrier to implementing VR into OHS training. Although appropriate modules, their updates and goggles may constitute a significant expense, according to specialists, the profits in the form of greater employee involvement would be very important for the company and its safety.

#### 5 DISCUSSION

The use of VR in periodic training in the field of occupational health and safety and ergonomics in enterprises (especially manufacturing ones) in Poland is undoubtedly subject to legal provisions in this area, which specify both the training program and its minimum duration. The legal regulations have not been significantly changed since 2004, therefore they do not take into account progress in teaching methods (including the use of virtual reality). It should be noted that more and more emphasis is placed on the employee's practical skills (especially in crisis situations related to OHS), therefore drills as part of the training should be aimed at obtaining the appropriate response of the employee, which can be ensured by conditions similar to real life provided by VR. This may be a factor that will determine the search for ways to overcome contraindications to the use of VR (e.g. health problems or high costs of implementing this technology compared to training conducted in a traditional form).

Although the article did not focus on proving the advantages of using VR in training in the field of occupational health and safety and ergonomics, it can be undoubtedly stated that it may be of great importance in the context of better acquisition of knowledge, practical experience of emergency situations and conditions of operation similar to real ones [23]. For this reason, it would be recommended to focus the legal provisions regulating OHS training in Poland on the possibility of including newer technologies as opposed to the traditional form of training.

Setting the minimum duration of training as one working day is also not conducive to implementing changes in the way training is conducted in companies (providing more time for training involves reducing work during this time and therefore losses). An interesting direction in the development of research on the inclusion of VR in occupational health and safety training in Poland seems to be determining the optimal time to conduct training using selected VR modules. Research can also be developed to look for ways to encourage employees (especially older ones) to use VR during training and implement this solution also outside of training (e.g. providing VR stations close to employees so that they can get acquainted with its operation during breaks at work).

#### 6 CONCLUSIONS

The results of the literature review and research undertaken indicate that the use of virtual reality elements in occupational health and safety training (including ergonomics) may be an important factor influencing the quality of these trainings and the acquisition of knowledge by employees on the use of protective equipment, response to accidents and failures, and ergonomics of workstations. Adding a virtual, engaging factor to the activity promotes better absorption of the information provided during the training and introduces elements of gamification that employees like. The use of VR also makes the traditional form of conducting occupational health and safety training (which in Poland is subject to a detailed program resulting from legal regulations) more attractive. In addition to the advantages of using VR in occupational health and safety training, there are also difficulties in its implementation in terms of ensuring a sufficiently long training time and an appropriate place to conduct it, which may be a big problem for many companies if they have deficits in these areas.

Certainly, an important conclusion from the undertaken research is the observation that the results of tests among employees conducted after training using VR are better than in the case of traditional, mainly theoretical training. Of course, this may be due to many factors (e.g. an increase in employees' awareness and knowledge in response to current activities and campaigns carried out in the company), but certainly providing conditions for practicing work situations in conditions as close as possible to real ones may promote better response when these situations actually occur.

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## Modular, Vision-Based Control of Automated Charging Systems for Electric Vehicles

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Abstract: Contemporary vehicle fleets include a variety of both manually and automated operated vehicles. A significant shift involves the increasing use of electric powertrains. However, the current electric charging infrastructure predominantly relies on manual processes. There is an opportunity to automate the charging process for these cars, with the intent to enhance convenience, aid people with accessibility needs, to support MW charging where EV cables are heavy, and finally to enable autonomous driving. The charging standards are common but the mechanisms to access the charging ports are not i.e., lids and protectives. This could be a challenge in the automation process given the complexity of the manipulation task at hand. With the increasing variety of electric vehicle models, standardizing charging mechanisms becomes imperative to streamline the charging process and enable broader adoption. In summary, this paper presents a holistic approach to addressing the evolving needs of electric vehicle charging infrastructure, emphasizing the importance of automation in enabling efficient, accessible, and future-ready charging solutions.

Keywords: automated charging system; charging infrastructure; charging technology; electric fleet solutions; electro-mobility; megawatt charging; plug-and-charge

#### **1 INTRODUCTION**

Electrifying transportation has become a critical strategy for mitigating climate change and reducing dependence on fossil fuels. In this development, automated charging systems for electric vehicles (EVs) play an important role in improving comfort, efficiency and autonomous processes. The vast majority of vehicles registered today have a conductive side coupling system [1]. The approach taken here is complete automation of the charging process by use of the standardized interfaces, based on previously carried out research [2]. The use of modular, vision-based control systems promises positive prospects for improving the charging infrastructure ecosystem for certain applications, be it charging commercial vehicle fleets, industrial vehicles or passenger cars. Fig. 1 shows the prototype automated charging system including standardized CCS connector, sensors and actuators and lighting system.



Figure 1 ACCS modular end-effector

The aim of this paper is to investigate and analyse the application of modular vision-based systems in the context of automated charging for electric vehicles. By using a wide range of sensors and intelligent control algorithms, these systems offer the potential to optimize charging processes and improve the user experience. It also enables easier access to e-mobility, for example for people with disabilities who may have difficulties with the current charging infrastructure. In the first section, the key components, functionalities and operating principles are introduced and their roles in charging infrastructure are elaborated. In addition, the performance characteristics, advantages and limitations of these systems are examined in various real-world scenarios ranging from indoor charging facilities to outdoor environments with different lighting conditions. Through empirical evaluations, valuable insights are provided into effectiveness, reliability and adaptability. In addition, the effects of research findings on the further development of electromobility are discussed as well as innovation and optimization potential are illustrated in view of future development of the charging infrastructure.

#### 1.1 Abbreviations

Table 1 Abbreviations					
Abbreviation	Meaning				
ACCS	Automated Conductive Charging System				
CAD	Computer Aided Design				
CCS	Combined Charging System				
DC	Direct current				
EV	Electric Vehicle				
EVSE	Electrical Vehicle Supply Equipment				
LIDAR	Light Detection and Ranging				
ToF	Time of Flight				
VSC	Vehicle Side Coupler				
VW	Volkswagen				

#### 2 METHODS AND KEY RESULTS

Based on process- and design analyses of a pre-defined electric vehicle fleet of five mass production cars that were different in their design of the charging port, a robotic system was developed that completely automates the charging process. Laser scans, CAD space analyses and sensor tests were carried out to find a suitable setup. The process analysis has shown that the critical process steps are strongly related to the quality of image recognition. Based on experiments, Tab. 2 provides an overview of the current assessment of individual process steps.



Figure 2 Exemplary ACCS process [4]

CAD space analysis have resulted in a modular design of the end-effector, which is shown in Fig. 3. To support efficient testing, each component of the prototype can be replaced and functionalities can be added or reduced if necessary. A test plan was created for system validation. Two electric vehicles were tested for robustness with different test subjects on four consecutive days. The process was closely based on a manual loading process. Each individual process step was evaluated for successful implementation and data such as time, positions, images and user feedback were recorded. The system validation has shown that complete automation of the charging process using a cost-efficient 2D camera is possible under the condition of controlled lighting influences.

#### **3 THE AUTOMATED CHARGING PROCESS IN DETAIL**

Fig. 2 shows the operational sequences of the fully automated charging process from start to end, and Fig. 3 shows the design and main components of the experimental setup of the robotic actuation system. In the displayed ACCS sequence, the focus lies on the process within the defined system boundaries, which is represented by the blue blocks. In addition, the steps in which image recognition is involved are marked in red.

The ACCS waits in standby position until a wake-up trigger from the infrastructure is received. The robotic system (1) with its end-effector moves into a pre-defined location that enables charging lid position determination utilizing its camera system (2). The light system (3) supports in difficult light conditions. After the charging lid is correctly identified and crosschecked with the expected vehicle type, its position is determined and the charging lid is opened with the charging lid opening device (4). Optional, the authentication of the vehicle type can be managed by communication technologies, e.g., according to the communication standard (ISO 15518) [3]. Depending on whether inner protectives are present or not, the system continues with identification and the corresponding position determination (2). In case that the inner protection are protective plugs, the inner protectives handling device (6) is used to remove them. In case that protectives lid are present, the universal pusher (5) is used for opening. After the inner protectives are removed or opened, the position determination of the charging socket starts (2). Following the exact position determination, the ACCS moves into a position for plugging the connector (8) by use of a rail system (7) to connect the vehicle for charging. After the charging process is finished or aborted, the system carries out the process backwards to place the inner protectives and closed the main lid. All positions and movements are stored in the controller, so that no additional position detection is required for the closing procedure.

A detailed analysis of the charging process showed that all steps could be automated. Tab. 2 indicates the ACCS process steps including a rating of their complexity level from low (+) to high (+++) in relation to automation. The complexity per step is rated as a combination of:

- Robustness of image recognition
- Required logics

Required actuators.

Table 2 Complexity of automated steps [4]

Step	Description	Complexity per step
la	Detection and position determination of charging lid	+
1b	Opening charging lid	+
2a	Detection and position determination of protectives	+++
2b	Removal of protectives	++
3a	Detection and position determination of charging socket	+++
3b	Plugging of connector	++
4	Removal of connector	+
5	Re-attaching of protectives	++
6	Closing of charging lid	+

#### 4 MAIN COMPONENTS OF AUTOMATED CONDUCTIVE CHARGING SYSTEMS

In the preceding chapter, the fundamental functionalities required to automate the charging process of electric vehicles were elucidated based on the procedural workflow. This chapter now shifts focus towards delineating the primary system components necessary to enable this process.



Fig. 3 shows the setup of the ACCS including following key components:

- Control unit
- Robotic system (1)
- Camera system (2)
- Light system (3)
- Charging lid opening device (4)
- Universal pusher device (5)
- Inner protectives handling device (6)
- Rail system (7)
- Connector (8)
- Various sensors
- Interface to charging infrastructure.

#### 5 MODULARITY OF THE AUTOMATED CHARGING SYSTEM

The modularity of the automated charging system is an important part of its design philosophy and enables quick adaptation to a wide variety of application scenarios during experimental investigations. Each component within the system architecture is designed with a high degree of modularity, software as well as hardware. This modular approach extends to all functions of the system and ensures that individual components can be replaced or reconfigured to adapt to the respective requirement.

An important aspect is the ability to quickly adapt the system's functionalities to the specific requirements of different environments. Regardless of whether the charging system is used in a parking garage, on a public street or in a fleet management depot. This agility is particularly advantageous in dynamic urban environments, where the requirements for the charging infrastructure can vary greatly, as confirmed by inquiries in the industry. The sensors, which serve as eyes and ears of the system, play a critical role in accurately detecting and responding to the presence and positioning of electric vehicles. By adopting a modular sensor architecture in the research prototype, the system can easily integrate different sensor technologies and configurations. Whether LiDAR, ultrasonic sensors or camera-based solutions - the modular sensor system ensures adaptability and reliability, depending on the intended use. Using modular software modules and flexible programming interfaces, the system can be easily integrated into existing infrastructure and third-party applications. This interoperability promotes scalability and futureproofing and enables seamless upgrades and expansions as development occurs.

In summary, the modular design of the automated charging system emphasizes its adaptability and robustness in tackling the complexities of electric vehicle charging. It enables stakeholders to efficiently respond to evolving requirements, enhance operational efficiency, and effectively utilize sustainable transportation infrastructure.

#### 6 THE ROLE OF THE VISION SYSTEM

The vision system plays a pivotal role in the operation and efficiency of an automated charging system for electric vehicles. This chapter examines the profound influence of the vision system on various aspects of the charging process, encompassing detection, localization, and monitoring functionalities. As covered by Walzel, et al. [6], basic computer vision functionality, referred to as machine vision, is employed for detecting predefined features or object characteristics such as edges, corners, motion, and distance estimation. This functionality aids in tasks such as identifying objects and estimating distances and orientation. More advanced computer vision techniques enhance object recognition accuracy but require complex approaches involving machine learning to teach artificial intelligence (AI) systems to recognize and classify objects with high precision.

For the application of automated charging, depth information is essential to define the position of the target object sufficiently precisely. This depth information can be obtained by using different sensor systems: 2D cameras that provide only positional and size information of objects, and 3D cameras that offer depth information. Two methods for generating 3D information are highlighted here: structured light and time-of-flight (ToF) technology. ToF technology, in particular, is noted for its ability to provide accurate depth information with less sensitivity to lighting conditions and reflections. This technology is increasingly integrated into automotive applications for driver assistance, emergency braking systems, and pedestrian protection. Current research aims to combine 3D ToF technology with 2D image recognition to improve the accuracy of object identification and differentiation.

One of the primary functions of the vision system is the detection and recognition of electric vehicles within the charging environment. The vision system can accurately identify the presence of vehicles, distinguish between different vehicle types, and detect relevant features such as charging lids and ports. This capability is essential for initiating the charging process and ensuring compatibility between charging infrastructure and the vehicle. Tab. 3 compares common sensor systems in the automotive industry.

A majority of car charging ports are made of black plastic material with little texture. In this way, it is difficult to obtain useful characteristics in the camera image [7]. The working distance in the current process is between 0.25 m and 1.2 m. In this area, a very high level of accuracy is required because the plug-in tolerances of standardized charging interfaces are very small and in the range of  $\pm 0.4$ mm in the translational part. Fig. 4 shows technologies suitable for this purpose to enable position determination with the required accuracy. Cameras are evolving into a dominant positioning technology that covers a wide range of applications across all levels of accuracy [8].

Sensor	Bright light performance	Low light performance	Outdoor	Weather robustness	Vehicle classification	Vehicle adaptation	Material costs
Ultrasonic	Good	Good	Yes	Good	No	No	Low
Magnetic	Good	Good	Yes	Good	No	Yes	High
2D-camera	Good	Weak	Yes	Weak	Yes	No	Low
Laser and lidar	Good	Good	Yes	Good	Yes	No	Very High
3D-camera	Good	Weak	Yes	Weak	Yes	No	Low
Structured light	Weak	Good	No	Weak	Yes	No	Medium
Tof-cameras	Good	Good	Yes	Good	Yes	No	High

Table 3 Comparison of different sensor technologies [6]



#### 6.1 The Influence of Use Cases

The selection of the optimal camera system for a fully automated charging system for electric vehicles crucially depends on the specific use case. In particular, the use of a 2D camera system requires careful consideration of the requirements and challenges.



Figure 5 Position determination of a VW ID3 charging lid

Monochromatic 2D cameras offer several specific advantages that can be beneficial. The choice of a camera system depends heavily upon the specific requirements of the application. 2D cameras offer notable technical advantages that warrant careful consideration in this context. Their primary allure lies in their cost-effectiveness, which is a huge factor for scalability, attributable to simplified hardware and reduced computational demands. This renders them particularly suitable for deployments where budget constraints are paramount. Furthermore, owing to their monochromatic nature, these cameras exhibit heightened sensitivity in low-light conditions, facilitated by their ability to capture information without the complexity of colour processing. Additionally, the absence of colour processing overhead streamlines data acquisition and reduces computational load, enhancing overall system efficiency. Despite their apparent simplicity, they have advanced imaging capabilities and feature high-resolution sensors and sophisticated algorithms that deliver exceptional image sharpness and contrast. This enables precise object detection and localization, which is crucial for the accurate operation of charging systems. In Fig. 5, the position determination of the charging lid of a VW ID3 is shown as an example.

The utilization of a monochromatic 2D camera proves to be sufficiently precise and robust, particularly in tightly controlled lighting conditions. However, when faced with fluctuating, uncontrolled lighting environments, such as outdoors, the monochromatic camera system within its current configuration might be no longer robust enough, and alternative solutions should be considered [9].

#### 6.2 The Influence of the Vision System on the Process

Precise localization and positioning of the EV relative to the charging station are critical for seamless and efficient charging operations. The vision system facilitates this by analysing captured images to determine the exact position and orientation of the charging port. Using sophisticated algorithms and geometric analysis, the vision system can calculate the optimal alignment of the charging connector, minimizing misalignments and maximizing charging efficiency. Additionally, the vision system can assist in obstacle detection and avoidance, ensuring safe manoeuvring of the robotic system during the charging process.

In an outdoor test series with two vehicles, 114 completed test runs were recorded and evaluated. Of the 114 test runs, 60 were conducted on a VW ID3, with a success rate, i.e., successful plugging and charging, of 90%. 54 test runs were carried out with a BMW iX40, with a success rate of 87.5%. All vehicles in this test series have a standardized CCS type 2 [10] charging socket. A HPC CCS connector from Phoenix Contact [11] was used at the charging infrastructure. Plugging was possible in 100% of cases, although the latching mechanism did not trigger in the failed test runs. It should be noted that outdoor tests were chosen because the limitations of the 2D camera system were to be examined. Fig. 6 shows the relative contribution of image recognition to the overall process. The grey part of the pie chart represents the temporal triangulation part of the overall process. The timing of the triangulation starts with reaching the first position until after the successful calculation of the combined pose from the previous 5 positions. The 5-point triangulation is shown in Fig. 11.

One can see that the proportion of triangulation is very large at 15.6% for the VW ID3 and 25.8% for the BMW iX40. On the one hand, this means that a relatively large amount of time must be invested in order to get sufficiently accurate and precise results and, on the other hand, this process step probably offers the most potentials in view of process time optimization.

Commercial image processing software is used to determine the position of the target object using a 2D camera by shape-based 3D matching. To do this, a CAD model of the object is made available. The 3D shape model consists of 2D projections in selected positions. This results in characteristic features such as edges, corners or similar structures, which are detected by the image processing software. An SBM algorithm is then used for the matching sequence. Calculated parameters include the distance and orientation of the object that result in a 3D pose, which then is used further in the process [12].



Figure 6 Relative proportion of triangulation using the example of two test vehicles

Fig. 7 shows the result of the image recognition of the inner protective plug of a VW ID3. Interesting to see in Fig. 8 is the constant duration of the triangulation of this detection. The number of tests is plotted on the abscissa and the duration of detection of the inner protectives is plotted on the ordinate. Over the course of all test runs, there were only a few outliers that indicate significantly changed lighting situations. On the other hand, it can also be deduced that the edges of the specific plug are relatively easy to process for the edge detection algorithm.



Figure 7 Position determination of the inner protective lids of a VW ID3

In comparison, the image recognition of the inner flaps of the BMW (Fig. 9) shows a significantly higher fluctuation in the detection times (Fig. 10) over the course of all test runs. The number of tests is plotted on the abscissa and the duration of detection of the inner lids is plotted on the ordinate.

This can be explained on the one hand by different lighting conditions, but on the other hand also by the design features of the orientation of the flaps (no shielding of light from above due to the orientation of the CCS socket). In general, it can be stated that the inner lids of the BMW took longer in the position determination process and show greater temporal variance than the protective plugs of the VW.



Figure 8 Detection time VW ID3 inner protectives



Figure 9 Position determination of the inner protective lids of a BMW iX40



Figure 10 Detection time BMW iX40 inner protectives

#### 6.3 Improved Position Determination Process

This chapter focuses on enhancing the position determination process using a monochrome 2D camera.

Through a specific process adaptation, the camera's performance limitations could be extended. This was achieved by implementing triangulation, analysing images from several different positions to compute a combined position. A cross method has proven particularly effective, varying only one angle. This methodological adjustment significantly contributes to increasing the accuracy and robustness of the position determination process, enabling more precise results across various application scenarios. The triangulation process is illustrated in Fig. 11.



Figure 11 Example triangulation

In each of these positions, several images were taken and combined into one. This results in a total of n positions, which are ultimately calculated into a combined one. This is based on a weighted, iterative averaging procedure. With this process, the influence of lighting can be significantly mitigated and both accuracy and precession increase.

#### 6.4 The role of artificial lighting

Artificial lighting plays a critical role in facilitating image recognition and precise position determination within the framework of a monochromatic 2D camera system.



Figure 12 2D camera setup with artificial direct light [13]

Artificial lighting is a fundamental tool for improving the quality of images captured by 2D cameras. Providing consistent and even lighting minimizes shadows reduces glare and improves contrast, improving the visibility of objects in the camera's field of view. This improved image quality is important to enable accurate object detection and positioning, especially in an environment with changing lighting conditions. Additionally, the use of directional lighting can aid in the precise localization of objects by providing depth cues and increasing the contrast between objects and their surroundings. This precise position determination is essential for the automated connection of charging plugs by robotic systems. An exemplary setup is shown in Fig. 12.

In outdoor or indoor environments with fluctuating ambient light levels, artificial lighting serves to mitigate variations and ensure consistent illumination for image processing. By supplementing ambient light with controlled artificial lighting sources, the camera system can maintain optimal visibility of objects and minimize the impact of unpredictable lighting fluctuations. This stability in lighting conditions is crucial for the reliability and robustness of edge detecting image recognition algorithms, enabling consistent performance across diverse operating environments. However, it should be noted that restrictions are to be expected in outdoor areas, as the artificial light intensity is simply not sufficient in many cases. Overall, artificial lighting plays an important role in expanding the application limits of 2D cameras and, under certain conditions, sufficiently ensuring the reliability of 2D camera systems for image recognition and positioning applications. Particularly noteworthy here is the provision of accuracy, precision, efficiency (related to the detection time) and robustness in the fully automated charging process.



Figure 13 LED light ring FLDR-i90A-W [14]

However, it must be taken into account that there are strong limitations due to the available installation space of the end effector. The lighting system must not be wider than a standardized CCS connector. This severely limits the lighting setup and, due to the working distance, only allows for direct, diffuse reflected light, although other configurations would probably deliver better results.

In conclusion, artificial lighting can cost-effectively expand the application limits of 2D camera systems. However, there are application scenarios in which other sensor systems are superior and should be considered, e.g., 3D points clouds combined with deep learning [15].

#### 7 OUTLOOK TO FUTURE RESEARCH

The modular, vision-based control approach presents a fertile ground for further research, offering opportunities to address existing challenges and to unlock new capabilities. This chapter delineates the potential directions for future investigations in this domain.

Advancements in computer vision techniques hold significant promise for improving the perception capabilities of automated charging systems. Future research will focus on integrating state-of-the-art vision algorithms, such as deep learning-based object detection and tracking, to enhance the system's ability to accurately identify charging connectors and vehicle interfaces under diverse environmental conditions, including low light and adverse weather. This also includes research of further sensor systems or combinations in order to achieve possible synergetic effects. The goal is to reduce costs while improving accuracy and precision. Further refinement of the modular architecture is essential to enhance system scalability, flexibility, and compatibility with diverse EV models and charging infrastructure. Future studies will explore innovative approaches to modular design, including standardized interfaces and protocols to facilitate seamless integration and interoperability across different charging scenarios and platforms.

Ensuring the robustness and reliability of automated charging systems is paramount to their widespread adoption and acceptance. It is important to focus on developing robust control algorithms and fault-tolerant mechanisms to mitigate uncertainties, disturbances, and hardware failures, thereby enhancing system performance and safety.

#### 8 CONCLUSION

In conclusion, the findings of this paper shed light on the efficacy of modular, vision-based systems for automated charging systems in the realm of electric vehicles. The investigations have demonstrated that monochromatic 2D camera systems exhibit promising potential in certain application scenarios, particularly indoors where lighting conditions are well-controlled. Within such environments, these systems can deliver sufficient accuracy and precision to facilitate effective charging operations.

However, it is crucial to understand the limitations of 2D camera systems, particularly when confronted with variable lighting conditions, especially in challenging outdoor settings. Fluctuating illumination can compromise the reliability and robustness of these systems, potentially leading to performance degradation and operational inefficiencies.

While monochromatic 2D camera systems represent a viable solution indoor applications, their suitability for outdoor use must be carefully considered. Future research will focus on developing adaptive strategies and integrating complementary sensor technologies to mitigate the impact of changing lighting conditions and enhance the overall robustness and versatility of automated charging systems for electric vehicles. By addressing these challenges, the evolution of modular, vision-based control systems will be realized towards greater effectiveness and applicability in various real-world scenarios, supporting an ultimately implementation of automated charging technologies in the electric mobility landscape.

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### Mobile ECG Devices Selection: A Comprehensive Review

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Abstract: Cardiovascular diseases are the main cause of death across the globe. Therefore, it is critical to detect them at an early stage, while an electrocardiogram (ECG) presents a widely used tool for making diagnosis. There is a large number of ECG devices on the market, with different features that suit a wide range of users, but simultaneously it poses a problem for the end user because they have a difficulty in selecting the appropriate device for their exact needs. Current trends in the usage of contemporary mobile ECG devices are identified and analyzed. In this study authors reviewed numerous mobile ECG devices with either FDA approval or CE mark that are currently available on the market. All listed devices are presented with all technical features that could be found. Furthermore, an interactive sunburst diagram for the selection of mobile ECG devices is created, and published, to help everyone easily make a selection.

Keywords: ECG device selection; Electrocardiography; sunburst diagram; wearable ECG

#### **1 INTRODUCTION**

Electrocardiography has undergone a transformation because of the evolution of portable health technology in terms of recording, storage, and use of electrocardiograms (ECGs) [1]. It has been demonstrated that ECG provides information that cannot be obtained from other tests, as well as having some advantages such as simplicity and convenience of use [2].

Detection of cardiovascular diseases (CVDs), disorders of the heart and blood vessels, as early as possible contributes greatly to medical treatment. The primary tool for identifying cardiac arrhythmias is ECG, commonly the standard 12-lead ECG that restrains patient mobility [3]. According to the need for remote monitoring and obtaining patients health data, the approval of a single-lead smartphone ECG occurred in 2013, when numerous companies presented their own smartphone ECGs [4]. In both inpatient and outpatient settings portable ECGs record the electrical activity of the heart, heart rhythm and other vitals. Nowadays, a plethora of ECG devices can be found: gadgets, smartwatches, and patches, portable medical and nonmedical ECG devices. Current trends imply that small portable medical ECG devices can fully replace big stationary ECGs in medical facilities since they have the same quality of acquired signals with superior connectivity and they can be utilized in a home environment.

The aim of this paper is to review contemporary mobile ECG devices that are currently available on the market. A large number of technical features is given for every device, so it is easier to make a proper choice when selecting one. Many researchers published ECG review papers, but it can be observed that few of them provide technical features. Usually, they describe a specific characteristic. In this work, authors aim to help other scientific researchers and medical professionals make the best device selection based on their personal needs. For example, researchers like the possibility of programming ECG devices in terms of changing features such as the sampling rate or resolution. On the other hand, for medical professionals it is important that the device has the possibility of interpreting ECG signals and to be able to easily print acquired signals. Another important aspect for medical professionals is the ease of usage, such as starting recording with fewer steps when operating the device. Therefore, different users have different needs and preferences. In order to make the choice of a particular ECG device based on technical features, an interactive sunburst diagram that can help in the process is created.

Firstly, a search for contemporary mobile ECG devices that are currently available on the market is performed in this review. Most of these devices are also presented in numerous research articles and reviews, which provided additional data besides the information from the manufacturer. The inclusion criteria were that the device has either CE mark or FDA approval. Only medical devices were taken into account, so ECG devices without CE mark or FDA approval have not been considered.

In general, handheld devices, patches and wearable gadgets possess the possibility to record and gather ECG data that is further transferred online to special accounts, applications or cloud-based portals that physicians can access for further evaluation. In order to maximize the device's clinical impact, healthcare providers should comprehend the sensitivity, specificity and characteristics of the device's algorithms when interpreting data from patient's devices [5].

The main contribution of this paper is that contemporary medical mobile ECG devices that are currently available on the market are reviewed with all the technical features that could be found. This study should be considered as the most comprehensive review of mobile ECG devices. A set of common device properties is created and used for comparison. In addition, developed interactive diagram for mobile ECG device selection is suitable tool for quick and proper choice of desired device. To the best of author's knowledge, there are no similar methods published in the literature.

The rest of the paper is organized as follows: Section 2 deals with the related published work, Section 3 contains an overview of current single-lead and multiple-lead ECG devices, and Section 4 describes an interactive sunburst

diagram for mobile ECG device selection. Finally, Section 5 represents conclusions.

#### 2 RELATED WORK

Previously published reviews of ECG devices are presented in this section. A large number of review papers were published in the past years, which is an indication how important topic are ECG devices all over the world.

Cosoli et al. [6] presented a work which provides details on wireless ECG and cardiac monitoring systems. The authors focused on wireless devices, since cables can often interfere with the user's free movement. As authors claim, when approaching the development of a wireless ECG system, some important aspects should be considered, such as: analog front-end, digital signal processing, electrodes, data acquisition system, wireless communication technology, and also power consumption. After describing these aspects, they described a number of commercially available devices with a table containing some of their features. However, they provided less features than it is the case with the presented study.

A comprehensive survey of wearable and wireless ECG monitoring systems for older adults is presented in [7]. The authors reviewed and classified ECG monitoring systems into: smart wearable, wireless and mobile ECG monitoring systems. Additionally, ECG signal processing software and algorithms were described. ECG systems were also discussed in terms of signal quality and system reliability, user acceptability and medical professional's feedback and finally security and privacy. This paper does not provide technical features for reviewed systems, so it is not easy to make a selection based on some technical characteristics, as opposed to the presented study.

A review of the use of wearable ECG devices in the clinical setting is presented in [8]. The authors investigated the use of wearable ECGs in the clinic and acute care setting, and their impact on patient care, particularly pertaining to the management of cardiac arrhythmias. They found that wearable ECGs demonstrated their non-inferiority in detecting arrhythmias when compared to the current standard of care. Reviewed devices were classified into two categories: FDA-approved and non-FDA-approved devices. In comparison to this study, they reviewed a small number of devices and with less technical features as it is the case with the previously mentioned paper.

A brief review on wearable ECG devices and processing techniques for fall risk assessment, prevention and detection is done in [9]. The paper takes a systematic approach on the analysis of wearable ECG devices. The authors state that studies show that patients with cardiovascular disorders are at a higher risk of falling. A small number of ECG devices were reviewed again with a smaller number of technical features than it is the case with this paper.

Another review of mobile ECG devices is presented in [10]. In this paper, the authors classified ECG devices similarly to the study presented as single-lead and multiple-lead devices, but there are no specific guides for device selection. Some of the devices are similar in both papers, again with less technical features. The authors search revealed a total of fifteen devices, from which only six were

described in more details because they featured in published medical literature as identified from PubMed search.

Bayoumy et al. recently published a review regarding smart wearable devices in cardiovascular care [11]. A large number of wearable devices were reviewed in this paper. Some of them are identical as in study presented, but they are described in a different manner – they examined the role of these devices in remote screening and diagnosis of common cardiovascular diseases. All devices were classified in these categories: chest strap, medical ear buds, smartwatch or band, ECG patch smart ring and clothing sensors. The authors stated that challenges such as clinical validity, device accuracy, and the absence of standardized regulatory policies and care for patient privacy are still hindering the widespread adoption of smart wearable technologies in clinical practice. Therefore, they presented several recommendations to navigate these challenges and proposed a simple practical guide for clinicians. In comparison to the study presented, they did not make any recommendations for the selection of any devices.

In [12], a systematic review was made to investigate if wearable devices provide a reliable and precise measurement of heart rate variability parameters in rest as well as during exercise. A search strategy was implemented to retrieve relevant articles from MEDLINE and SCOPUS databases, as well as through internet search. Results gave 31 different devices capable of measuring heart rate variability. Once again, not many technical features are provided for these devices, like it is the case with the presented study. The authors concluded that portable devices can give different solution for measuring heart rate variability.

Another review regarding the assessment of heart rate with wearable devices was published by Nelson et al. [13]. In this paper, the authors focused on wrist-worn consumer portable devices that be publicly found and purchased. They also discussed study design, biobehavioral, technological and demographic factors that can influence the accuracy of heart rate measurements. These devices have not been considered in the study since they are more often used for heart rate measurements than for ECG.

Wearable ECG devices that are capable of very longterm ECG monitoring (for example 14 days) are reviewed in [14]. These devices are connected straight to the skin, so wires and electrodes are not necessary for device operation. They are not restraining user's movements, which is a great benefit. Some of them are also described in the study presented with more technical details.

A review of wearable smart textile shirts is presented in [15]. These shirts have a sensor inside a textile which can record ECG data in a more comfortable way. As authors claim, they are not accurate and reliable as traditional ECG devices. For that reason, this kind of device is not included in the study.

In [16] authors provided a scoping review of mobile selfmonitoring ECG devices to diagnose diseases. Some of the ECG devices are the same as in study presented, but the difference is that they focused on the diagnosis rather than the features of ECG devices.

Faruk et al. published an extensive study on inexpensive ECG acquisition systems [17]. The authors described contemporary ECG devices for different applications. Some

of the ECG devices are the same as in this research, but the focus was not only on low-cost ECG devices. Another difference is that they do not provide a decision tree which could help home users and medical professionals to choose a certain ECG device based on their personal preferences.

Finally, work in [18] provided a detailed analysis of ECG systems which is based on schemes, monitoring environments and technologies. Furthermore, authors gave other details that comprises of a generic model and how to design and validate ECG systems.

As it can be concluded from this section, ECG devices are an active and attractive field of research generating many research materials. However, none of these previously mentioned papers provide a method for ECG device selection. Therefore, the authors of this research try to fill this gap with an interactive sunburst diagram as a method to make the choice of an ECG device. This can be a great help both for home users and medical professionals.

#### **3 CURRENT TECHNOLOGIES**

In this section, according to inclusion criteria, mobile ECG devices with either FDA approval or CE mark are presented. During the research, besides the information found on the Internet and from the manufacturers, available medical literature from SCOPUS, PUBMED and Google Scholar is considered. A vast number of ECG devices were found, but most of them do not have CE mark or FDA approval, which means that they could be suitable for researchers, but not for medical professionals. After including only devices that have CE mark and/or FDA approval a list of 25 devices is created. Other devices were excluded from this review study. This approach is more suitable for a wider target group.

# 3.1 Single-lead ECG devices 3.1.1 AliveCor KardiaMobile

KardiaMobile represents a handheld single-lead electrocardiogram recorder (Fig. 1).



Two electrodes are located on top of the KardiaMobile device, two fingers from the left hand are placed on one electrode while two fingers from the right hand are placed on the other electrode [19]. Users commonly place fingers on each electrode for 30 seconds and the results are shown on the phone that can be easily transferred by email to clinicians. Narasimha et al. compared KardiaMobile to an external loop recorder (ELR) for detecting arrhythmias, where results show that KardiaMobile is suitable for the identification of symptomatic arrhythmias because of its simplicity and portability [20].

#### 3.1.2 EPI Mini

EPI Mini is a single-lead device with three sensors that possess a display screen where the steps for recording of 30 seconds can be easily followed. ECG data is stored on the EPI Mini and can be transferred to a smartphone via Bluetooth to visualize the ECG tracing. A medical professional's prescription is required for the device [4]. Michael et al. compared EPI Mini to clinically approved EPI Life, which had previously been validated with standard 12lead [21]. Results of a comparison where participated 30 individuals aged 18 to 48 years have shown a high level of correlation between compared devices.

#### 3.1.3 NUVANT Mobile

The NUVANT Mobile Cardiac Telemetry system, developed by Corventis, incorporates a wearable device PiiX in combination with a transmission device zLink that receives data from PiiX and has a role to wirelessly transfer data to Corventis [22]. PiiX should be positioned on the left side of the chest, the upper left quadrant and a single blinking green light within the circle symbol is shown when the PiiX is working properly. PiiX should be worn for up to 7.5 days. When individuals have cardiac symptoms, patients use the Patient Trigger Magnet to record ECG [23].

#### 3.1.4 Omron HCG-801

Omron HCG-801 represents a single-lead handheld device with a display. The device's lower surface, which includes one electrode, is positioned to the chest for ECG recording, while it is held in place by the right index finger where the second electrode is positioned. After a 30-second recording, results are shown on display and it can be saved on an SD memory card or sent to a PC. Seven different types of cardiac rhythms are possible to be detected with this device [24]. Kaleschke et al. validated Omron HCG-801 as highly accurate to detect atrial fibrillation comparing to standard 12-lead ECG, and it is also stated that it could be used by patients without supervision by healthcare personnel [25]. Study including population above 65 and 75 years old resulted as cost-effective device in identifying new atrial fibrillation patients and decreasing the number of stroke occurrences [26].

#### 3.1.5 BodyGuardian Heart

BodyGuardian Heart possesses two inner electrodes which record a single-lead ECG [27]. Physician has to prescribe the device and the length of time that users are supposed to wear it. A box is equipped with two heart monitors, chargers, strip electrodes and a smartphone [28]. Strip electrodes are supposed to be attached to the chest either horizontally or vertically and can be angled at 30 degrees to avoid muscle or fat. The smartphone that is provided is only used for monitoring, not for calls or any other phone activities. Castelletti et al. validated the accuracy of QTc measurements of this device by comparison with 12-lead Holter recordings in long QT syndrome (LQTS) patients [29]. Results showed that the QTc measured by BodyGuardian was indistinguishable to the manual measurement.

#### 3.1.6 Easy ECG Monitor PC-80A

The Easy ECG Monitor PC-80A represents single-lead device with a display that consists of three embedded metal electrodes [24]. The user has four options for positioning the device either using both hands or only right hand and the chest, also it is possible to position using the right hand and the left leg, or to use lead wires for measurement [30]. Recording lasts 30 seconds and can be transferred to a PC with a proprietary data cable.

#### 3.1.7 Easy Monitor MD100B

Easy Monitor MD100B possesses two embedded metal electrodes and displays ECG in 30 seconds. Palm and chest measurement is provided, either between the right hand and left hand or between the chest and right hand. Additionally, the cable measurement is possible where electrode slices are positioned on the specific area [31]. Recordings can be transferred with a USB cable to a PC [24].

#### 3.1.8 QardioCore

QardioCore represents a single-channel chest strap with an electrode. Adjusting the length of the strap to adapt it for the chest size, switches on automatically the device and starts recording after a few seconds. It can be worn under clothes without being noticed [32]. Apart from recording ECG, it detects skin temperature, heart rate and respiratory rate [33]. ECG recording is transferred to the cloud-based portal. When QardioCore was compared to a 12-lead ECG, no significant differences were found, indicating that it is a clinically valid tool [34]. One of the limitations is that the patient was supervised by a study researcher while using QardioCore, whereas the patient would use it independently in real conditions.

#### 3.1.9 Zenicor ECG

Zenicor consists of two electrodes on which the thumbs should be placed for 30 seconds to obtain the recording, which is sent to a central ECG database via the mobile network [35]. Web-based service for storage and evaluation of results is the second component of Zenicor system and it can be accessed using a web browser. Zenicor was compared to the 12-lead ECG by Doliwa et al. where the examined approach showed a high sensitivity (96%) and specificity (92%) in detecting and diagnosing sinus rhythm and atrial fibrillation [36]. It was also compared to 24-hour Holter ECG to detect atrial fibrillation and paroxysmal supraventricular tachycardia (PSVT), twice daily for four weeks and when symptoms were present, Zenicor had a higher level of effectiveness [37].

#### 3.1.10 Reka E100

Reka E100 is a single-lead ECG device that records by placing both thumbs on the integrated electrodes or with adequate electrode placement. By connecting the device to a computer or a smartphone, the ECG data is transferred to the REKA Cloud online health record portal [38]. Reka E100 was compared to 24-hour Holter ECG monitoring, it resulted in greater consistency and efficacy for identifying and interpreting heart arrhythmias [39]. The majority of patients regard E100 as simple to operate, comfortable and secure.

#### 3.1.11 Zio XT/AT Patch

Zio Patch represents ECG adhesive patch monitor that is positioned on the left anterior chest wall for up to 14 days, while continuously recording. Prescription by a healthcare provider is needed, Zio XT (Fig. 2) is intended for low-risk patients while Zio AT is intended for high-risk patients.



Figure 2 Zio XT patch

Findings by Turakhia et al. suggest that extended Zio Patch monitoring is feasible and can detect arrhythmias that would otherwise be undiagnosed by traditional 48-hour monitoring [40]. Barrett et al. compared a conventional 24hour Holter monitor and a Zio adhesive patch monitor, where Zio patch resulted as less visible and more patient-friendly with 93.7% of patients finding it comfortable to wear and 81% of patients preferring it to the Holter monitor [41]. The patch can detect significantly more arrhythmia occurrences in comparison to the Holter monitor. It was evaluated on individuals who were under the age of 18, in pediatric patients [42, 43] both compared with Holter with positive outcomes.

#### 3.1.12 AfibAlert

AfibAlert records a single-channel ECG during a 45second period. Thumbs on the electrodes are used to obtain recordings or by utilizing the patient cable with a wristband or sticky electrodes. AfibAlert is only purchasable with a physician's prescription. The emission of red or green light represents a high or low level of probability of atrial fibrillation. Additional lights are the following: blue light means that data is being analyzed, while a yellow light indicates that recording should be repeated due to incapability of reading results [44]. ECG data can be transmitted by a USB cable to PC and uploaded to AfibAlert web site.

#### 3.1.13 Beurer ME90

Beurer ME90 represents a single-channel device with a display that obtains ECG recording in 30 seconds. There are three alternative ways to obtain an ECG [45]. The first approach involves placing the right index finger on the top electrodes and pressing the lower electrode towards the chest. The second way is similar to the first, but the left index finger is used instead of the right, while the third approach uses the right index finger on the top electrodes and a finger of the left hand on the lower electrode. The device can be connected to a PC via the USB port to transfer the data and display it in greater detail, or it can be connected to a smartphone via Bluetooth. Brito et al. compared Beurer ME90 with 12-lead ECGs for the presence of arrhythmia and their findings indicate that Beurer ME90 had a high level of sensitivity for detecting Atrial Fibrillation but a low level of specificity [46].

#### 3.1.14 SnapECG

SnapECG is a single-lead ECG device with dual electrodes, on the top side of the device, which should be pressed with fingers to start the 30-second recording. ECG recording is transmitted to mobile phones via Bluetooth. According to Guan et al., the SnapECG can accurately detect AF in patients aged between 65 and 74 years with high sensitivity and specificity [47]. They additionally state that SnapECG is currently used only in clinical practice, without screening procedures among wide population.

#### 3.1.15 ECG Check

ECG Check is a single-lead ECG recording device with two built-in electrodes pads where fingers should be placed for a 30-second measurement. A rhythm strip is displayed on a device screen, saved on a phone and sent to ECG Check Web Center via Bluetooth [48]. The ECGs are classified as normal or abnormal by the application's algorithm. According to Haverkamp et al., the ECG Check possesses acceptable sensitivities and specificities for detecting pathological rhythms [49].

#### 3.1.16 MyDiagnostick

MyDiagnostick is shaped like a stick and has electrodes on both ends. The device instantly turns on when it is hold with both hands and emits one short beep and starts ECG recording. After one minute of recording, lights should indicate the result. Green light indicates the case of normal cardiac rhythm and absence of atrial fibrillation, while red light is shown in case of rhythm irregularity suspicion for

#### 3.1.17 CardiBeat

CardiBeat is a single-lead device that records ECG by pressing the metal sheet with the thumbs and index fingers on both hands. Connection to a smart device via Bluetooth is necessary to take 30-seconds recordings. Recordings can be uploaded to SMART Monitoring reading service for evaluation reviewed by an ECG technician or a doctor [54].

#### 3.2 Multi-lead ECG devices 3.2.1 AliveCor Kardia Mobile 6L

KardiaMobile 6L is capable of recording both singlelead and six-lead ECG [55]. The device consists of three electrodes, two on the top side and one additional sensor on the bottom side. Electrodes on the top side are used for positioning thumbs, while the bottom electrode is used for positioning on the bare skin of the left leg, either on the left knee or the left ankle for 30 seconds. ECGs from the device are wirelessly transferred to a smartphone via Bluetooth, where recordings are displayed [56]. KardiaMobile 6L was compared to conventional 12-lead ECG in terms of QTc monitoring in COVID-19 Patients, stated that the time of recording was decreased with the use of KardiaMobile 6L and close contact was reduced which contributed to the prevention of virus dissemination [57]. No major differences in QTc measurements were found between devices. Frisch et al. state that the KardiaMobile 6L can be used to safely and effectively monitor patients at high risk for arrhythmia in both inpatient and outpatient settings [58].

#### 3.2.2 Humeds

Humeds represent a device that records a three-lead ECG signal. Four dry electrodes are placed in the corners of a rectangle on the bottom side of the device [59]. Humeds gathers ECG signals on the body surface, where recording starts by placing four dry electrodes against the chest for 30 seconds [60]. ECG data is transferred from the device to the mobile device via Bluetooth.

#### 3.2.3 IEM Beam

IEM Beam records three-channel ECG and sends the results to the medical practice that uses HMS CS Evaluation Software. Four fixed electrodes are embedded within the monitor, which is put on the chest during symptoms [61]. Event recording with four fixed electrodes is possible as well as loop recording with four, cable, single-use electrodes [62]. IEM Beam can be worn by the patient for up to two weeks

using long-term monitoring electrodes, and recordings can be sent to the cloud database.

#### 3.2.4 CardioSecur

CardioSecur application that can generate a 12-lead or 22-lead ECG from four electrodes requires connection to a smartphone by cable. Placing the four adhesive electrodes on the chest allows obtaining results after a 10-second reading. A baseline reading should be done when patient does not have any symptoms and it is necessary to be taken for comparison with the next recordings. CardioSecur technology is based upon the EASI standard and has the ability to eliminate electrode misplacement and make ECG recording more accessible in athlete training and competition situations [63]. Spaich et al. compared CardioSecur to conventional 12-lead ECG and defined the device as userfriendly and practical for ECG acquisition [64].

#### 3.2.5 Schiller Miniscope MS-3

Schiller Miniscope MS-3 possesses a tripod electrode on the bottom side, which could be applied directly to the chest for a recording of 47 seconds [65]. Additionally, it has the option to connect the Miniscope to a 3 or 5 lead patient cable with the patient cable adapter [10]. The ECG signals are displayed on the wide monitor display. Therefore, an ECG and heart rate could be seen in a real-time.

#### 3.2.6 D-Heart

The D-Heart is a six-electrode device that records eight or twelve leads ECG. Number of leads for the measurement can be selected in the application. For the usage of 12 leads the physician must utilize D-Heart device and properly position the electrodes. On the other hand, using 8 leads recording, the smartphone should be linked to D-Heart and used to help position the electrodes. The smartphone camera algorithm can show the patient's own chest with proper electrode placement. Using camera and image processing technologies to locate the theoretical electrode placement on the patient's own chest facilitates the patient to position electrodes adequately [66]. D-Heart was shown to be as effective and reliable as 12-lead ECG in stratifying ECG abnormalities [67]. Fumagalli C. et al. states that D-Heart is effective and accurate and that it is able to diagnose ECG abnormalities with the same accuracy as a typical 12-lead ECG [68].

#### 3.2.7 Coala

In about a minute, the Coala records a 2-lead ECG and heart sounds. Coala Heart Monitor provides both thumb and chest ECG. The first recording is taken by placing the device on the chest followed by the thumb recording. To increase accuracy, a thumb ECG is always recorded after the chest measurement, where fingers are placed on the electrodes to perform the second recording [69]. The Coala device is wirelessly connected to a smartphone via Bluetooth. Olsson et al. compared Coala to a single lead thumb-based ECG, the 2-lead ECG and mobile application had substantially higher accuracy in detecting atrial fibrillation [70]. Coala's feasibility was demonstrated throughout a one-month period among patients who underwent chest and thumb ECG examination after a stroke [71].

#### 3.2.8 Cardions E2

CardioNS E2 represents a 12-channel ECG device with 10 leads and it is shown in Fig. 3. The ECG leads with distinct positions are identified by different colors. By connecting the device to an Android phone or tablet via a USB cable, the mobile application can show the ECG signal in real time [72]. The device is suitable for both patients and medical staff because it has two separate modes, normal and expert [73]. Device can be used independently or with remote monitoring center.



Figure 3 CardioNS E2 device

#### 4 ECG DEVICE SELECTION

For the purpose of this review, authors contacted with researchers, medical professionals and home users in order to find out which features are important to them when it comes to ECG device selection. For medical professionals following features were important: number of leads, CE mark, FDA approval, recording duration, thermal printer, sampling rate and resolution. On the other hand, home users valued these features: connectivity, positioning, disease detection, weight, display, application and battery. The next step was to find which of those can be publicly found. Combination of personal preferences and available information resulted with a list of 14 features. The list is given in Tab. 1. One of the considered features was the price of the device, but it was not included in the final list while it varies a lot between different regions, and values found in the websites are not confident.

All features can have up to three different values. Number of leads can be either single-lead or multi-lead. Most of the devices can be connected via USB or Bluetooth, but some devices use a different type of connection and they are classified as Other. CE mark and FDA approval have values Yes or No, but some devices have both. Recording duration is divided into 3 different values: less than or equal to 30 seconds, between 31 and 60 seconds, and longer than 60 seconds. All devices have one of two types of positioning: on chest or fingers, including some devices that can use both methods. Some of devices have the ability to automatically detect diseases and this feature has two possible values: Yes and No. Weight of devices is divided into three categories: less than or equal to 50 grams, between 51 and 100 grams, and more than 100 grams. Only a few devices have own display, but some of them do have, so the values are Yes and No. Regarding application that is used with a device, most of them work using both Android and/or iOS applications, but some of them are proprietary. The values for this feature are: Android, iOS and Other. The self-powered feature has a Yes value when the device is powered from the battery source, otherwise, when it is powered by the other device, like mobile phone, the value is No. Only one of the reviewed devices has the ability to print on a thermal printer and others do not have this feature. Since this is important to medical professionals, it is included in the list with values Yes and No. Sampling rate varies among devices and it is divided into three categories: less than or equal to 200 Hz, between 201 and 500 Hz, and more than 500 Hz. Similar case is with resolution, so it is divided as for: 10 bits, between 11 and 23 bits, and finally 24 bits.

All 25 mobile ECG devices that are previously described are listed in Tab. 2 and Tab. 3 with corresponding attributes from Tab. 1. In case where none of the options are available for the specific device, then attribute "Other" is assigned and shown with "O" in the table. For example, Schiller Miniscope MS-3 does not use an Android or iOS application because the device cannot be controlled with a smartphone, so its application is classified as "Other".

Table 1 Features with corresponding values						
Feature	ure Feature value					
Number of leads	Single-lead (S)	Multi-lead (M)				
Connectivity	USB	Bluetooth (B)	Other (O)			
CE mark	Yes	No				
FDA approval	Yes	No				
Recording duration	$\leq 30s$	31-60s	> 60s			
Positioning	Fingers	Chest				
Disease detection	Yes	No				
Weight	$\leq 50g$	51-100g	>100g			
Display	Yes	No				
Application	Android	iOS	Other (O)			
Self-powered	Yes	No				
Thermal printer	Yes	No				
Sampling rate	$\leq 200 \text{Hz}$	201-500Hz	> 500Hz			
Resolution	10 bits	11-23 bits	24 bits			

For some devices it was not possible to find information about its sampling rate or resolution. For those devices attribute "n/a" is assigned meaning that the information for that feature is not available. These two features are listed in the last two columns of Tab. 3.

Table 2      ECG device features – part 1								
ECG device	Number of leads	Connectivity	CE	FDA	Recording duration	Positioning	Disease detection	
AliveCor KardiaMobile 6L	М	В	Yes	Yes	> 60 s	Fingers	Yes	
AliveCor KardiaMobile	S	В	Yes	Yes	> 60 s	Fingers	Yes	
Humeds	М	В	Yes	No	≤ 30 s	Chest	No	
EPI Mini	S	В	Yes	Yes	≤ 30 s	Fingers	No	
Nuvant Mobile	S	0	Yes	Yes	> 60 s	Chest	Yes	
Omron HCG-801	S	0	Yes	No	≤ 30 s	Chest	Yes	
BodyGuardian Heart	S	В	Yes	Yes	> 60 s	Chest	No	
IEM Beam	М	B,O	Yes	No	> 60 s	Chest	Yes	
Easy ECG Monitor PC-80A	S	USB	Yes	Yes	≤ 30 s	Fingers, Chest	No	
ECG Monitor MD100B	S	USB	Yes	No	≤ 30 s	Fingers, Chest	No	
CardioSecur	М	0	Yes	No	> 60 s	Chest	Yes	
QardioCore	S	В	Yes	No	> 60 s	Chest	No	
Zenicor	S	0	Yes	No	≤ 30 s	Fingers	No	
Schiller Miniscope MS-3	М	0	Yes	No	31-60 s	Chest	No	
Reka E100	S	USB	Yes	Yes	31-60 s	Fingers, Chest	No	
Zio XT and AT patch	S	0	Yes	Yes	> 60 s	Chest	No	
AfibAlert	S	USB	No	Yes	31-60 s	Fingers	Yes	
Beurer ME 90	S	USB,B	Yes	No	≤ 30 s	Fingers, Chest	No	
D-Heart	М	В	Yes	No	31-60 s	Chest	No	
SnapECG	S	В	Yes	Yes	> 60 s	Fingers	No	
ECG Check	S	В	Yes	Yes	≤ 30 s	Fingers	No	
Coala	М	В	Yes	Yes	≤ 30 s	Fingers, Chest	Yes	
MyDiagnostick	S	USB	Yes	No	31-60 s	Fingers	Yes	
CardiBeat	S	В	No	Yes	> 60 s	Fingers	Yes	
CardioNS E2	М	USB	Yes	No	> 60 s	Chest	Yes	

In order to make a choice for one of selected 25 mobile ECG devices, an interactive sunburst diagram for easier selection is created. It is available online on the following URL [74].

A sunburst diagram displays ranking in a form of series of slices which are shown for every rank. Each slice correlates to ranking and the central slice represents the source. Slices are divided according to their correspondence with the parent slice. The angle of the slice can be divided equally under its parent node, or can be proportional to some specific value [75]. The initial idea was to create a standard decision tree diagram, but this was not a convenient method since the tree would have too many branches that cannot fit on one page and it would be cumbersome for a user to navigate through it. Therefore, an interactive sunburst diagram was a much more appropriate choice for displaying large amounts of data. Interactive means that the sunburst diagram responds to user input when a part of the diagram is clicked. When a particular sector is clicked, diagram changes in a manner that the selected sector becomes the root of the diagram and displays only slices that are connected with it. It is possible to zoom in and zoom out on the diagram. When a feature is selected on the diagram, all mobile ECG devices that fulfil the selected criteria are listed on the right side of the diagram. To the left of the diagram filters show which features are selected. A toolbar for navigation is also included on the left side containing two buttons for navigation through the diagram. The first button is for getting one step back in the process of selection, removing the last feature from selection. The second button acts as a home button which will take the user to the root of the diagram or simply just reset and start over the selection process. In this way it is easy to navigate through the diagram and see in every moment which devices are selected with which features. The first step is always to choose the number of leads, the second is to choose connectivity type, and so on, in the order as it is given in Tab. 1. This is given as a case study to show one path for ECG device selection. For future work it is planned to make the diagram fully dynamically interactive. That means the user will not have to follow only one feature order, but rather select features in the order they prefer. Full sunburst diagram based on data from Tab. 2 and Tab. 3 is shown in Fig. 4 and the initial diagram shows all ECG devices on the right side. The root of the diagram is labeled with "ECG" decision.

Table 3 ECG device features – part 2	
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ECG device	Weight	Display	Application	Selfpowered	Thermal printer	Sampling rate	Resolution
AliveCor KardiaMobile 6L	$\leq 50g$	No	Android, iOS	Yes	No	201-500Hz	11-23 bits
AliveCor KardiaMobile	$\leq 50g$	No	Android, iOS	Yes	No	201-500Hz	11-23 bits
Humeds	51-100g	No	Android, iOS	Yes	No	> 500Hz	11-23 bits
EPI Mini	51-100g	Yes	Android, iOS	Yes	No	n/a	n/a
Nuvant Mobile	$\leq 50g$	No	0	Yes	No	$\leq$ 200Hz	10 bits
Omron HCG-801	>100g	Yes	0	Yes	No	$\leq$ 200Hz	n/a
BodyGuardian Heart	$\leq 50g$	No	0	Yes	No	201-500Hz	11-23 bits
IEM Beam	>100g	No	0	Yes	No	$\leq$ 200Hz	11-23 bits
Easy ECG Monitor PC-80A	51-100g	Yes	0	Yes	No	$\leq$ 200Hz	n/a
ECG Monitor MD100B	>100g	Yes	0	Yes	No	201-500Hz	10 bits
CardioSecur	$\leq 50g$	No	Android, iOS	No	No	201-500Hz	n/a
QardioCore	>100g	No	Android, iOS	Yes	No	> 500Hz	11-23 bits
Zenicor	>100g	Yes	0	Yes	No	n/a	n/a
Schiller Miniscope MS-3	>100g	Yes	0	Yes	Yes	201-500Hz	10 bits
Reka E100	>100g	No	0	Yes	No	201-500Hz	10 bits
Zio XT and AT patch	$\leq 50g$	No	Android, iOS	Yes	No	201-500Hz	10 bits
AfibAlert	>100g	Yes	Other	Yes	No	> 500Hz	n/a
Beurer ME 90	$\leq 50g$	Yes	Android, iOS	Yes	No	201-500Hz	n/a
D-Heart	>100g	No	Android, iOS	Yes	No	> 500Hz	24 bits
SnapECG	$\leq 50g$	No	Android, iOS	Yes	No	n/a	n/a
ECG Check	$\leq 50g$	No	Android, iOS	Yes	No	$\leq$ 200Hz	n/a
Coala	$\leq 50g$	No	Android, iOS	Yes	No	201-500Hz	24 bits
MyDiagnostick	>100g	No	Other	Yes	No	n/a	n/a
CardiBeat	$\leq 50g$	No	Android, iOS	Yes	No	$\leq$ 200Hz	n/a
CardioNS E2	$\leq 50g$	No	Android	No	No	> 500Hz	24 bits

Fig. 5 shows two examples of the sunburst diagram. Fig. 5 (b) shows when features multiple-lead and USB connectivity are selected. Those features are displayed to the left of the diagram. To the right of the diagram is displayed CardioNS E2 as the only device that has multiple leads and USB type of connection. Fig. 5 (c) shows an example of a diagram when four features are selected: Single-lead, Bluetooth connectivity, CE mark and FDA approval (shown to the left of the diagram). In that case, four devices have these features: AliveCor KardiaMobile, EPI Mini, Snap ECG and ECG Check (shown to the right of the diagram).

As it was mentioned in the previous section, for some devices data regarding sampling rate and resolution could not be found. For that reason, these two features are put in the last two columns of the Tab. 3. ECG devices without this information are not shown in the diagram when sampling rate and/or resolution are selected. Putting these two features in the last two columns enables the user to select them based on all other features before these last two are selected.

None of these 25 devices can be chosen as the best among them. Personal preferences are different for each medical professional, as well as for each home user. Based on their individual needs and preferences, everyone can find the best device for themselves.

#### 5 CONCLUSION

In this paper the authors made a review of contemporary medical mobile ECG devices including analyses of different features devices are equipped. It could be considered as the most comprehensive review of medical mobile ECG devices containing data acquired from manufacturers, Internet presentations and publicly available academic papers databases. In order to make a proper selection of specific ECG device based on technical features, an interactive sunburst diagram that can support a selection process is created. This poses a new approach for selection of best suited device for different purposes for researchers, physicians and other medical staff.



Figure 4 Full sunburst diagram with the list of all ECG devices



Figure 5 Full sunburst diagram (a) with an example when two features are selected (b) and with an example when four different features are selected (c).

Motivation for and the aim of the research along with contributions is highlighted in the introduction section. Related work is given to show the current trends in the literature. The results imply that this is an active area of research. Section three lists all mobile ECG devices that were found based on the inclusion criteria. The interactive sunburst diagram which is created for mobile ECG devices selection followed by several examples is presented and explained. All covered devices are included in the interactive diagram which is publicly available online as a free mobile ECG selection tool.

The main contribution of this paper is that currently available contemporary mobile ECG devices are reviewed with as much as possible technical features including the development of an interactive diagram for mobile ECG device selection. Proposed method for ECG device selection and comparison based on provided set of features is also a contribution. Another contribution of the paper is the addition of value on a practical side for choosing a particular mobile ECG device based on personal doctor, home user or researcher preferences.

Regarding future work and according to presented study results, there is a plan to extend the list of mobile ECG devices, their related features, and to develop a smart survey which will help stakeholders to choose an appropriate device. Finally, these steps lead to the creation of a complete decision support system for selection of mobile ECG devices.

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## Building Models for a Scientific Approach to Problem Solving in Production Systems

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Abstract: The paper presents a model of scientific approach to problem solving. The model is based on a gradual approach, preparation, resolution, verification and improvement of solutions. Each of the steps in the process of solving a problem or task requires thorough consideration and analysis after which the question "satisfied?". The affirmative answer points to the next, while the negative requires further analysis or a return to one of the previous steps. The presented approach can be successfully used to solve problems and tasks in economic systems and in scientific research in general. The presented model confirmed its simplicity and practicality in concrete scientific research.

Keywords: improvement; model; process; problem; scientific approach

#### **1** INTRODUCTION

Disturbances in the functioning of any process are common. Simply put, there are no ideal processes that turn inputs into exits without difficulty. The difference between the ideal and the real is often called an imbalance or problem. These phenomena cause negative reactions in employees and in economic terms they are unacceptable because they are associated with various wastes. In addition to the above, it is important to emphasize that the functioning of any process can always be improved. Regardless of whether it is a noticeable disorder that requires quick resolution or a decision to improve an activity or process, there is always a problem that requires action. A systematic approach to these actions requires a defined order of execution, i.e. a way of solving problems. The process approach to these and similar activities has proven to be the most effective, and that is problem-solving technology.

The most general problem can be called any imbalance in the work environment [1]. This is, for example, the problem of loss in business as an imbalance between income and expenditure, environmental pollution as an imbalance between environmental aspects, the problem of quality as an imbalance between the defined and achieved level of quality, etc.. Eliminating this imbalance requires activities in order to achieve the desired goals, so the term problem is often said to be an obstacle on the way to the goal [2].

#### 2 BRIEF VIEW AND DESCRIPTION OF THE MODEL

The knowledge about the meaning of the correct approach to solving problems began to grow a few decades ago, which there are records in the literature, so these insights began to be used in our country. By applying these other people's, well-known technologies, experiences have also grown in our country, which have been incorporated into the existing knowledge of our experts and scientists in various institutions. Figure 1 shows one of the possible approaches for solving more complex problems, which is adapted for specific needs related to problem solving in production systems.

As with other methods and procedures that solve problems, the presented model should not omit the sequence phase. Otherwise, it is possible to expect new problems and difficulties and the solution of the primary problem [2, 3] is questionable. These phases (Fig. 1), as well as the associated activities, can be called by other names, but in any case, it is necessary to include all the listed contents and apply their sequence to solve a specific problem. 7 stages are observed in the process of solving, where after each stage the logical question "satisfied?" is asked. The answers can be "yes" and "no." If the answer is yes, it is moved to the next stage, and if it is negative, it is necessary to return to one of the previous ones. The method is based on the studious study of each stage during the problem-solving process where the smallest omission results in additional engagement of people and resources. This problem approach allows you to look at and solve problems through dominant factors and their interactions and does not allow the solver to move away from the problem being solved, which enables the realization of set goals through selected criteria and benchmarks.

#### 2.1 Noticing the Problem of Research

The "Problem Spotting" phase in the context of the troubleshooting process is shown in Fig. 2, showing inputs, tools and techniques and outputs as well as flowcharts.

The term "problem" is not clear. As a term, it is used on different occasions and takes on different meanings, which is evident in everyday conversation, and in discussions of experts and scientists of different fields. All this can result in occasional misunderstandings and difficulties in understanding the term "problem". In linguistic terms, the problem arises where doubt, uncertainty and difficulty arise to which there is no immediate answer [1]. In this paper, the problem implies a theoretical or practical question that requires a solution. To put it more simply, the "problem" is the gap between the current and the eager state. In doing so, desires are tied to the goals that are desired to be achieved.

To identify and understand problems, there must be information, data or events. For example, in the papers [2, 3] it is stated that there must be:

- someone who has a problem, which is an individual or group that is dissatisfied with some condition;
- their desire, that is, they need to know what they want, as opposed to what they have;
- system and working environment and
- the possibility of choosing a solution, i.e. alternate directions of action.



#### 2.2 Problem Orientation and Task Setting to Solve

The logical continuation of the work after noticing the problem is to orient the problem and set the task. Orientation is the orientation of the "solver" about the problem that has been observed. This means, in other words, that the solver(s) must perform: scientific, professional, personal, temporal, financial and other types of orientation in order to transform successfully the problem into a task [4]. The "Problem Orientation and Research Task Setup" phase in the context of the problem-solving process is shown in Fig. 3, showing a process that has input, activity and its output.

While the first stage is devoted to the problem and the area in which it is located, the problem orientation phase considers the knowledge needed to solve successfully the problem. The concept of orientation is taken from geography according to which orientation is orientation in nature, which means that using the concept of orientation for the purpose of solving problems means determining where the problem is in the available knowledge, and what knowledge is needed to solve the problem. For these reasons, the first part of this stage is also called problem orientation. The scientific and professional orientation of the solver is to look at the perceived problem in order to declare it a professional or scientific problem. In addition, it is very important to position the problem in segments of science with which it could have points of contact or its solution would require specific knowledge.



The theoretical basis of the orientation of the problem is its versatility, completeness, novelty, merit, optimality and correctness [4, 5].

#### 2.3 Defining Criteria and Criteria for Research

After the orientation about the problem has been carried out, or already during its execution, a comparison of the results is made with the results of the problem detection phase. The increase in the knowledge of the problem acquired in the phase of orientation enables its better perception so that it can be concluded whether the realized activities satisfy or not. In case of a negative answer to this question, it is necessary to supplement or repeat the previous activities. This control activity can be repeated until satisfaction is achieved. Only after that, it is recommended to define the criteria and criteria with which to start the research (Fig. 4).

Criteria are the value points of view based on which the assessment or assessment of the state of fulfillment of the set objectives or the achievement of the results achieved is carried out [5, 6]. If, for example, the cost of the life cycle or the reliability of a product are important criteria of excellence, then the manufacturer who achieves lower costs and greater reliability for the production of the observed product will undoubtedly be more successful. The criteria enable comparability of products and services as well as solutions obtained by studying a specific problem in essential elements and properties based on predefined and objectified ways, methods and procedures. A better product or solution that meets the criterion function to a greater extent [6]. Closely related to the criteria are the benchmarks. They represent quantitative or value statements to determine the degree of fulfilment of certain criteria. If, for example, the criterion is the distance of point A from point B, then the scale can be millimeters, centimeters, meters, kilometers, nautical miles but also light years, depending on the level of observation.

In general, it can be said that the chosen criteria in some research and problem solving should enable [2]:

- easier choice of alternatives,
- evaluation of the validity of alternatives,
- comparison of alternatives, and
- defining the procedure for collecting data.

The criteria should be compatible with the benchmarks and they clearly state the degree of its realization [6].





#### 2.4 Determination of the Current Situation of the Problem

The three stages described above represent a preparation for solving the problem. This is followed by stages that represent the process of solving it. The first of the stages in this resolution process is the determination of the existing situation of the problem (Fig. 5).

The goal of this phase is:

- Get the starting state, i.e. the starting point, so that the new solutions are no worse than the existing ones.
- To enable the organization (work environment) to learn the objective truth about the problem.
- Prepare the environment to accept the new solution.
- To gain a good basis of knowledge about the problem being solved [7, 8].



The finding of the current situation on the problem is usually carried out through three procedures, namely [9]:

- 1) Activities of elaboration of the procedure for recording the current state of the problem,
- 2) Data collection, i.e. recording the current state of the problem, and
- 3) Identifying the achievements of others (previous research on the problem and similar activities).

#### 2.5 Study, Optimization and Design of the Solution

The study or analysis of the existing state of the problem is carried out for a more complete cognition, i.e. to increase knowledge about the problem, and the primary goal is to find a connection between cause and effect according to the selected criteria and benchmarks (Fig. 6), which will serve in choosing and shaping a solution. In other words, at this stage of the paper, the aim is to determine as accurately as possible which factors, in this particular case, are the causes of the problem, how they work, whether they are connected and how, from where they appear, what enhances and what reduces their impact – their description and the way they act are determined. Very often, the concepts of cause and effect are confused because it is easier to determine the consequences (they are visible) than the causes, so sometimes solutions are built on the basis of consequences and suboptimal or even wrong solutions are obtained [10, 11, 12].

Study is the stage where influential factors on the consequence are determined, that is, the observed problem that is being solved. Symbolically this can be depicted as:

$$Y = a + bx_1 + cx_2 + dx_3 + ex_1x_2 + fx_1x_3 + gx_2x_3 + \dots$$
(1)

where is: Y – consequence (expressed through the selected criterion and ion);  $x_1, x_2, x_3$  – influencing factors (example for three influential factors); a, b, c, d, e, f, g – coefficients that indicate the influence of a factor or their interaction.

During the study of the problem (analysis and synthesis), there are more possibilities for its solution. Some of the possibilities are mutually exclusive. Other options for solving the problem, not any of them being excluded, are incorporated into a possible variant. In this way, a very large number of variants are obtained. According to the criteria and benchmarks adopted, it is necessary to evaluate each variant [13, 14].



Based on the conducted evaluation, the best variant (solution optimization) is adopted. The adoption of the

conceptual variant is carried out in order that each proposed variant is not fully developed with all the elements, which would significantly extend the work and research time. The design of the solution is in fact the grooming of the chosen variant. In other words, writing, drawing, photocopying, etc. This is where the project, that is, the solution gets its form. A larger number of contributors can also be involved in the realization of this stage in order to form a solution as soon as possible.

#### 2.6 Application of the Solution

Without the application, there is no true solution to the problem [15] Otherwise, the problem remains solved, and the goals and other settings that were defined at the very beginning of the work cannot be realized. For these reasons, this stage can be declared as the most significant, the most difficult but also the "most beautiful" if it succeeds (Fig. 7).



Figure 6 The stage of problem study, optimization and design of a new solution

The significance of this phase is great and requires adjustment of the procedures of the previous stages so that all activities undertaken in them must have a projection in these activities, i.e. they must be treated in such a way that there is a vision of implementing the solution in advance [16, 17].

#### 2.7 Improving the Solution

At this stage, shortcomings and omissions in the applied procedures are observed and you become aware that it could be done better. This stage of the work represents the improvement of research in all its stages (Fig. 8).



WORKING STAGE PREVIOUS STAGE IN NEXT STAGE IS INTRY INTO THE WORKING STAGE EXT FROM THE WORKING STA Figure 8 Stage of improving the results of work

The essence of the improvement of the solution is to monitor its application in practice, in order to reasonably, step by step, find a way to apply the solution better, easier and more economically [18]. It should be borne in mind that no solution is the best solution. There is always a better solution, that is, a better way. Therefore, it needs to be continuously sought and improved [19, 20].

#### 3 CONCLUSION

The presented methodology is one of the possible solutions for successful problem solving in business systems on a scientific basis. Verification and validation was carried out on several practical problems where simplicity and effectiveness were confirmed. In the paper, it was not possible to describe all the details related to practical application as well as its theoretical background. Adjustments of the presented approach are possible according to specific situations, but taking into account its basic principles and stages of realization. Improvements to the shaped method are the reality expected of scientists because of its concrete application. Reference [3] shows the application of the described method from a research perspective. Authors of the article used the above-mentioned method in their professional work to solve the problem of improving machine maintenance and reducing production losses.

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Ivan Horvat, Thomas Johnson, Marko Marić (Style: Arial Narrow, Normal, 10pt)

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Titles of chapters are written in capital letters (uppercase) and are aligned in the centre. The titles of subchapters (and smaller units) are written in small letters (lowercase) and are aligned left. If the text in the title of the subchapter is longer than one line, no hanging indents. 10pt

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- Item 1
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- 1) Item 1
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	1	2	3	4	5	6		
ABC	ab	ab	ab	ab	ab	ab		
DEF	cd	cd	cd	cd	cd	cd		
GHI	ef	ef	ef	ef	ef	ef		
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Table 1 Table title aligned centre

Equations in the text are numbered with Arabic numerals inside the round brackets on the right side of the text. Inside the text they are referred to with equation number inside the round brackets i.e. ".... from Eq. (5) follows ...." (Create equations with MathType Equation Editor - some examples are given below).

10pt

$$F_{\text{avg}}(t, t_0) = \frac{1}{t} \int_{t_0}^{t_0 + t} F[q(\tau), p(\tau)] \,\mathrm{d}\tau, \tag{1}$$

$$\cos \alpha + \cos \beta = 2\cos \frac{\alpha + \beta}{2} \cdot \cos \frac{\alpha - \beta}{2}, \qquad (2)$$

$$(\boldsymbol{A}\boldsymbol{B})^{\mathrm{T}} = \boldsymbol{B}^{\mathrm{T}}\boldsymbol{A}^{\mathrm{T}}.$$
 (3)

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Variables that are used in equations and also in the text or tables of the article are formatted as *italics* in the same font size as the text.



Figure 2 The texts under figures (Style: Arial Narraw, 8pt, Align Centre)

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