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Original scientific paper

Comparison of Non-Linear and Linear Ho Models Applied for Copper Ions Sorption on Geopolymer

Mario Nikola Mužek*, Sandra Svilović, Jelica Zelić

Abstract: The Ho pseudo-second-order model is the best fitting model in describing the sorption of copper ions on synthesized geopolymer for the selected experimental conditions (particle size 0.071–0.090 mm at agitation speed of 240 rpm). For that reason, a comparison of one non-linear and five linear forms of the Ho pseudo-second-order model was made in the present study in order to obtain the optimum sorption kinetic parameters using the experimental kinetic data obtained for the copper ions sorption process on the synthesized geopolymer. Taking all the results into consideration, the non-linear Ho model proved to be more consistent in describing the copper ions sorption on geopolymer for various initial concentrations of sorbent, as well as for various temperatures.

Keywords: copper; geopolymer; Ho pseudo-second-order model; linear regression; non-linear regression

1 INTRODUCTION

Sorption processes have been proved to be an effective method for the removal of various pollutants such as heavy metals and dyes from wastewaters. Therefore, the prediction of batch sorption kinetics is important for sorption processes design. It is important to determine how sorption rates depend on the initial concentrations or temperature of solution and how rates are affected by sorption capacity or by the character of sorbent in terms of kinetics. The solute uptake rate – which determines the residence time required for completion of the sorption reaction – may be analyzed and established from the kinetic analysis [1]. The nature of sorption process will depend on physical or chemical characteristics of the adsorbent systems and also on the system conditions [2].

The most commonly used kinetic models to explain the sorption processes are the pseudo-first-order and pseudo-second-order kinetic models [3, 4].

The Ho pseudo-second-order model [5] explains the kinetics of the most of sorption systems very well for the entire range of sorption period and it has been successfully applied to the adsorption of metal ions, dyes, herbicides, oils, and organic substances from aqueous solutions.

In previous work [6], the Ho pseudo-second-order model showed the best fitting with experimental data gained for the copper ions sorption on prepared geopolymer. For that reason, a comparison of one non-linear and five different linear forms of the Ho model was made in the present study in order to obtain the optimum sorption kinetic parameters using the experimental kinetic data obtained for the copper ions sorption on prepared geopolymer.

2 MATERIALS AND METHODS

The appropriate weight of $Cu(NO_3)_2 \times 3H_2O$ (Kemika) was dissolved in distilled water in order to prepare solutions containing copper ions. The procedure of geopolymer synthesis is given elsewhere as well as the FTIR, SEM/EDS, and XRD analysis of geopolymer synthesized [6, 7].

The suspensions were prepared by mixing 1.0 g of prepared geopolymer (particle size 0.071–0.090 mm) with 0.2 L of copper (II) nitrate solution. The suspensions were mixed with a turbine impeller at 240 rpm in the batch reactors. The influence of initial solute concentration (3.881, 5.915, 7.780, 9.898, 11.763 mmol L^{-1}) on sorption process at constant temperature (298 K) was investigated. The influence of various temperatures (298 K, 308 K, and 318 K) on sorption process at constant initial solute concentration (11.763 mmol L^{-1}) was also investigated.

Suspension samples were taken out from the batch reactors at specific times in order to determine the concentration of copper ions. Samples were centrifuged and filtered so the copper concentration could be determined by UV/Vis spectrophotometer (Perkin–Elmer Lambda EZ 201). Sampling was more frequent in the initial period of sorption process, however, as sorption slowed down, the frequency of sampling also decreased.

The copper amount sorbed on the prepared geopolymer at time t, q_t, is determined by Eq. (1). It represents the difference between the concentration of copper ions present in the solution at the beginning of the experiment and in the sampling times.

$$q_t = \frac{(c_0 - c_t)V}{m} \tag{1}$$

where c_0 is the initial concentration of copper in solution (mmol L^{-1}), c_t is concentration of copper in solution at time t (mmol L^{-1}), V is the volume of solution (L), and m is the mass of the synthesized geopolymer (g) [8].

The chi-square test χ^2 was used to examine the fitting of different forms of the Ho pseudo-second-order model with experimental data. It is usually applied when the resulting correlation coefficients are very close and high [9]. The least square method was used to obtain parameters of the linear forms of the Ho pseudo-second-order model and non-linear regression analysis for the parameters of the non-linear form.

3 RESULTS AND DISCUSSION

3.1 Comparison of Non-Linear and Linear Forms of the Ho Model for Various Initial Concentrations

The Ho model is presented as [1, 10]:

$$\frac{\mathrm{d}q_t}{\mathrm{d}t} = k_2(q_\mathrm{e} - q_t)^2 \tag{2}$$

where q_t is amount of metal ions sorbed after time t (mmol g^{-1}), t is time (min), q_e is equilibrium (maximum) amount of copper ions sorbed (mmol g^{-1}), and k_2 is the rate constant of the model used (g $mmol^{-1}$ min^{-1}).

In the present study the experimental kinetic data for the sorption of copper ions onto synthesized geopolymer were fitted to the five different linearized forms of Ho pseudo-second order model, as well as its non-linear form. Both, non-linear and linear forms of Ho model were given in Tab. 1. The Ho pseudo-second-order kinetic constant k_2 (g $mmol^{-1}$ min^{-1}) and maximum amount of copper ions retained on geopolymer can be calculated from the plots given in Tab. 1.

The Ho pseudo-second-order kinetic parameters gained for various concentrations are calculated and presented in Tab. 2. According to the values obtained it could be noticed that values for kinetic parameters are different among the linear and non-linear forms. The best values of χ^2 – test among linear forms of Ho pseudo-second-order model were gained for linear type 2 for all the concentrations analyzed (Fig. 1).

Table 1 Linear and non-linear forms of the Ho pseudo-second-order model

	Equation	Plot	Parameters
Non-linear form	$q_t = \frac{t}{\frac{1}{k_2 q_\mathrm{e}^2} + \frac{t}{q_\mathrm{e}}}$	q_t vs t	q_e, k_2
Linear type 1	$\frac{1}{q_t} = \frac{1}{k_2 q_\mathrm{e}^2} + \frac{1}{q_\mathrm{e}} t$	$\frac{1}{q_t}$ vs t	$q_\mathrm{e} = \frac{1}{slope}$, $k_2 = \frac{slope^2}{intercept}$
Linear type 2	$\frac{1}{q_t} = \left(\frac{1}{k_2 q_\mathrm{e}^2}\right)\frac{1}{t} + \frac{1}{q_\mathrm{e}}$	$\frac{1}{q_t}$ vs $\frac{1}{t}$	$q_\mathrm{e} = \frac{1}{intercept}$, $k_2 = \frac{intercept^2}{slope}$
Linear type 3	$\frac{1}{t} = \frac{k_2 q_\mathrm{e}^2}{q_t} - \frac{k_2 q_\mathrm{e}^2}{q_\mathrm{e}}$	$\frac{1}{t}$ vs $\frac{1}{q_t}$	$q_\mathrm{e} = \frac{-slope}{intercept}$, $k_2 = \frac{intercept^2}{slope}$
Linear type 4	$\frac{q_t}{t} = k_2 q_\mathrm{e}^2 - k_2 q_\mathrm{e} q_t$	$\frac{q_t}{t}$ vs q_t	$q_\mathrm{e} = \frac{-intercept}{slope}$, $k_2 = \frac{slope^2}{intercept}$
Linear type 5	$q_t = q_\mathrm{e} - \left(\frac{1}{k_2 q_\mathrm{e}}\right)\frac{q_t}{t}$	q_t vs $\frac{q_t}{t}$	$q_\mathrm{e} = intercept$, $k_2 = \frac{-1}{slope \times intercept}$

Table 2 The calculated parameters of the Ho pseudo-second-order model for copper ions sorbed on prepared geopolymer by linear and non-linear regression analysis for various initial concentrations

	Parameter	3.881 mmol L^{-1}	5.915 mmol L^{-1}	7.780 mmol L^{-1}	9.898 mmol L^{-1}	11.763 mmol L^{-1}
	$q_{eexp.}$	0.775	1.058	1.099	1.114	1.136
Linear type 1	q_e^*	0.770	1.063	1.108	1.126	1.153
	k_2^Δ	25.7345	0.999	0.719	0.691	0.567
	χ^2	0.013	0.174	0.294	0.233	0.376
Linear type 2	q_e	0.778	1.017	1.033	1.045	1.047
	k_2	9.136	2.115	1.807	1.568	1.455
	χ^2	1.760×10^{-3}	0.014	0.032	0.044	0.070
Linear type 3	q_e	0.780	1.026	1.051	1.069	1.082
	k_2	8.408	1.920	1.521	1.292	1.114
	χ^2	0.450	0.564	0.160	0.165	0.413
Linear type 4	q_e	0.780	1.033	1.064	1.085	1.105
	k_2	8.542	1.782	1.357	1.138	0.952
	χ^2	0.341	9.066×10^{-3}	0.185	0.132	0.072
Linear type 5	q_e	0.778	1.023	1.044	1.060	1.067
	k_2	9.430	1.992	1.651	1.412	1.279
	χ^2	1.069×10^{-3}	0.014	0.035	0.048	0.077
Non-linear type	q_e	0.783	1.031	1.061	1.084	1.100
	k_2	9.544	1.776	1.358	1.111	0.933
	χ^2	9.624×10^{-4}	0.010	0.025	0.033	0.054

*q_e (mmol g^{-1}) $^\Delta k_2$ (g $mmol^{-1}$ min^{-1})

Nevertheless, values gained for maximum amount of copper ions sorbed on prepared geopolymer, q_e, for linear type 2 are not in a good agreement with experimentally obtained values except for the initial concentration of 3.881 mmol L^{-1}.

All the linear and non-linear types showed good agreement with experimentally obtained values for maximum amount of copper ions sorbed on geopolymer for the lowest initial concentration of heavy metal (3.881 mmol L^{-1}). Values gained for maximum amount of copper ions sorbed on prepared geopolymer, q_e, for linear type 1 are in better agreement with experimentally obtained values apart from values gained for other linear forms but calculated values of χ^2 – test for linear type 1 are also among the highest ones.

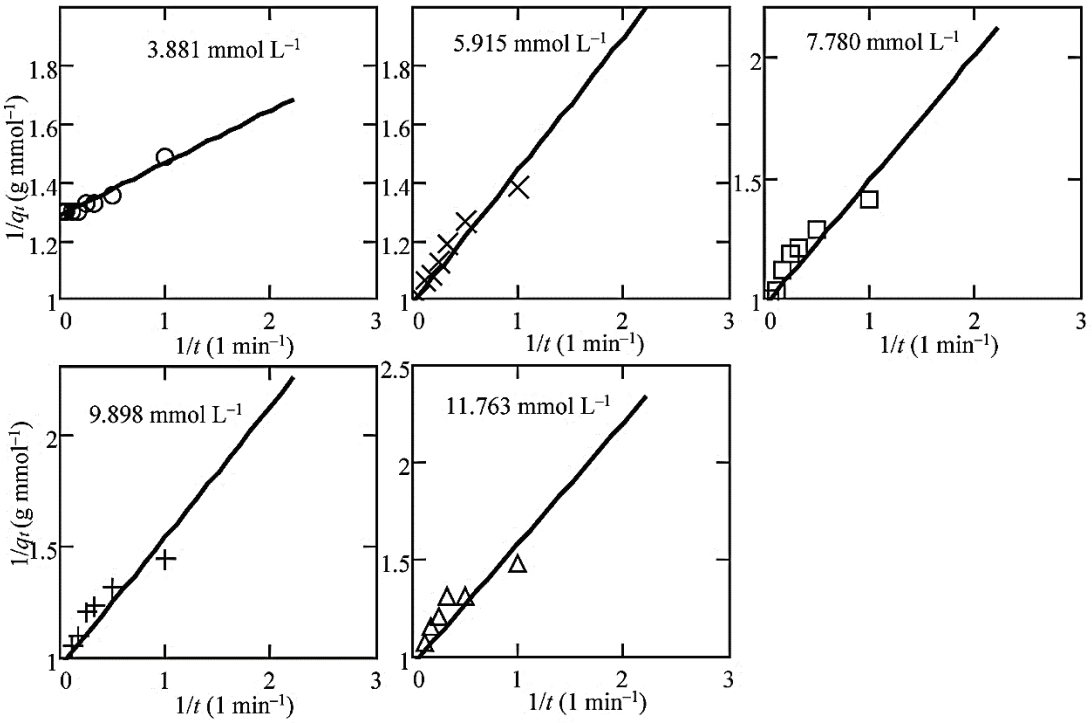

Figure 1 Linear type 2 of Ho model for the sorption of copper ions on prepared geopolymer for various initial concentrations

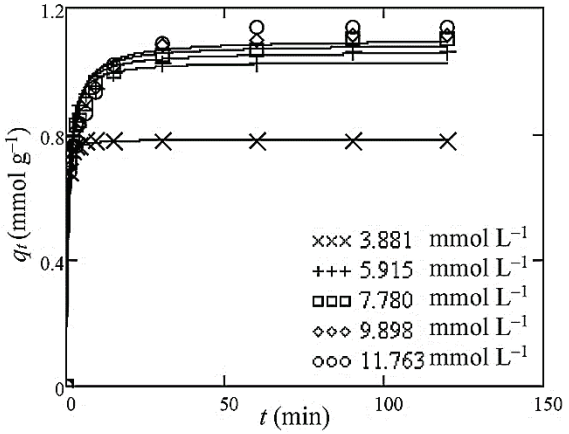

Figure 2 Non-linear Ho model for the sorption of copper ions on prepared geopolymer for various initial concentrations

Nevertheless, non-linear form is better for describing a copper ions sorption process on prepared geopolymer (Fig. 2); values of χ^2 – test are lower than ones gained in linear forms of Ho pseudo-second-order model. The values of maximum amount of copper ions retained on geopolymer are also in good agreement with those gained experimentally (Tab. 2). For all the reasons mentioned, the non-linear form is more suitable and precise in describing the sorption process of copper ions on prepared geopolymer for various concentrations.

3.2 Comparison of Non-Linear and Linear Forms of the Ho Model for Various Temperatures

The best values of χ^2 – test among linear forms of Ho pseudo-second-order model were gained for linear type 2, Fig. 3, but the values obtained for maximum amount of copper ions sorbed on prepared geopolymer, q_e, are not, again, in a good agreement with experimentally obtained values. Linear type 1 showed best agreement for the values of maximum amount of copper ions sorbed on prepared geopolymer, q_e, but values obtained for χ^2 – test are among the highest ones for linear types.

Non-linear form once again confirmed to be good for calculation of kinetic parameters of sorption process tested. Values of χ^2 – test for non-linear form are lower than ones gained for linear forms of Ho pseudo-second-order model. The values of maximum amount of copper ions retained on geopolymer are in a good agreement with those gained experimentally (Tab. 3).

The Ho pseudo-second-order kinetic parameters gained for various temperatures are calculated and presented in Tab. 3.

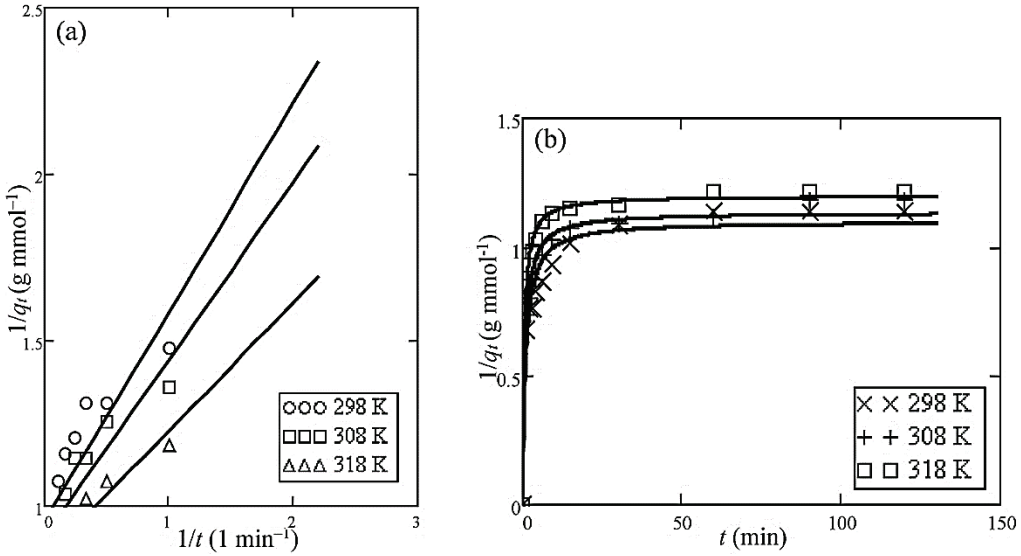

Figure 3 Ho model for the sorption of copper ions on prepared geopolymer for various temperatures: (a) linear type 2, (b) non-linear form

Table 3 The calculated parameters of the Ho pseudo-second-order model for copper ions sorbed on geopolymer by linear and non-linear regression analysis for various temperatures

	Parameter	298 K	308 K	318 K
	$q_{eexp.}$	1.136	1.183	1.217
Linear type 1	q_e^*	1.153	1.191	1.225
	k_2^Δ	0.567	0.568	1.067
	χ^2	0.376	0.466	0.071
Linear type 2	q_e	1.047	1.101	1.185
	k_2	1.455	1.550	1.856
	χ^2	0.070	0.035	9.072×10^{-3}
Linear type 3	q_e	1.082	1.123	1.194
	k_2	1.114	1.297	1.714
	χ^2	0.413	0.158	0.107
Linear type 4	q_e	1.105	1.138	1.200
	k_2	0.952	1.157	1.613
	χ^2	0.072	8.179×10^{-3}	0.107
Linear type 5	q_e	1.067	1.114	1.191
	k_2	1.279	1.413	1.763
	χ^2	0.077	0.044	0.013
Non-linear type	q_e	1.100	1.135	1.200
	k_2	0.933	1.146	1.600
	χ^2	0.054	0.029	8.921×10^{-3}

*q_e (mmol·g^{-1}) $^\Delta k_2$ (g·mmol^{-1}·min^{-1})

4 CONCLUSIONS

Linear forms are more or less successful in describing the sorption process of copper ions on geopolymers. Linear type 2 of Ho pseudo-second-order is the most suitable taking the values of χ^2 – test into account. Nevertheless, q_e values are not in a good agreement with experimentally obtained values.

Taking all the results into consideration, the non-linear Ho pseudo-second-order kinetic model form is much better and consistent for fitting the copper ions sorption process on synthesized geopolymer for the selected experiment conditions for various initial concentrations of sorbent, as well as for various temperatures.

5 REFERENCES

[1] Ho, Y. S. & McKay, G. (1998). The kinetics of sorption of basic dyes from aqueous solution by sphagnum moss peat. *The Canadian Journal of Chemical Engineering, 76*(4), 822-827. https://doi.org/10.1002/cjce.5450760419

[2] Kumar, K. V. (2006). Linear and non-linear regression analysis for the sorption kinetics of methylene blue onto activated carbon. *Journal of Hazardous Materials, 137*(3), 1538-1544. https://doi.org/10.1016/j.jhazmat.2006.04.036

[3] Ho, Y. S. & McKay, G. (1998). A two-stage batch sorption optimized design for dye removal to minimize contact time. *Institution of Chemical Engineers Trans IChemE, 76*(B), 313-318. https://doi.org/10.1205/095758298529678

[4] Kumar, K. V., Ramamurthi, V., & Sivanesan, S. (2005). Modeling the mechanism involved during the sorption of methylene blue onto fly ash. *Journal of Colloid and Interface Science, 284*(1), 14-21. https://doi.org/10.1016/j.jcis.2004.09.063

[5] Ho, Y. S. (2006). Review of second-order models for adsorption systems. *Journal of Hazardous Materials, 136*(3), 681-689. https://doi.org/10.1016/j.jhazmat.2005.12.043

[6] Mužek, M. N., Svilović, S., & Zelić, J. (2014). Fly ash-based geopolymeric adsorbent for copper ion removal from wastewater. *Desalination and Water Treatment, 52*(13-15), 2519-2526. https://doi.org/10.1080/19443994.2013.792015

[7] Mužek, M. N., Svilović, S., Ugrina, M., & Zelić, J. (2016). Removal of copper and cobalt ions by fly ash-based geopolymer from solutions-equilibrium study. *Desalination and Water Treatment, 57*(23), 10689-10699. https://doi.org/10.1080/19443994.2015.1040077

[8] Svilović, S., Rušić, D., & Žanetić, R. (2008). Thermodynamics and adsorption isotherms of copper ions removal from solutions using synthetic zeolite X. *Chemical and Biochemical Engineering Quarterly, 22*(3), 299-305.

[9] Arshadi, M., Amiri, M. J., & Mousavi, S. (2014). Kinetic, equilibrium and thermodynamic investigations of Ni(II), Cd(II), Cu(II) and Co(II) adsorption on barley straw ash. *Water Resources and Industry*, 6, 1-17. https://doi.org/10.1016/j.wri.2014.06.001

[10] Ho, Y. S. (2003). Removal of copper ions from aqueous solution by tree fern. *Water Research, 37*(10), 2323-2330. https://doi.org/10.1016/S0043-1354(03)00002-2

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Original scientific paper

Implementation of a Location Services Based Android Application and Accompanying Server Backend

Kristijan Lukaček, Matija Mikac*, Miroslav Horvatić

Abstract: This paper is focused on the usage of location services in mobile applications that were developed for the purpose of reporting different events that are based on their location. The event that is intended to be generic and universal can, as in examples used in this paper, be the reporting of some occurrence to a city's communal affairs office. Such a generic event can include both multimedia and textual data, in addition to location information obtained using mobile device running the app. The software solution that is described in this paper consists of a mobile application that was developed for the Android operating system and a web application that includes a series of PHP scripts that run on a dedicated server. The web application consists of a backend scripts that facilitate the communication of a smart phone and the server and frontend related scripts used by users and administrators to access and check the data and process the reported events.

Keywords: Android; backend; event reporting; frontend; geomap; location services; mobile application; web application

1 INTRODUCTION

The main aim of the project described in this paper was to implement a mobile application that can fetch a device location and visualize it. Later, the possibility of sending that location and other data (pictures and text) was implemented in order to extend the functionalities and redefine the purpose of the application. Initially, the goal was to define and implement a generic system that could be applied to different real-world situations. Possible real-case scenario and the purpose of the developed application is to send reports of some event occurrence to a city's communal affaires office. To implement full functionality of the system, an additional server-side web application had to be developed, including both back- and front-end subsystems. That web app consists of a series of server PHP scripts facilitating the communication and processing of data being transferred between server and the smartphone. Additional set of scripts was developed, being responsible for administration of reported events. Server data storage used for the project is based on standard MySQL or compatible (MariaDB) database management systems.

The mobile application prototype was developed as a native application for the Android operating system, which was chosen because it is currently the most wide-spread mobile operating system in the world [1]. The mobile application was developed using the Java programming language – until recently Java was preferred language for native Android development, being used in our education classes too (in May 2019, Kotlin language was announced by Google as preferred language for Android developers [2]).

Alternatively, hybrid mobile application could serve the same purpose in proposed system. Most probably, that kind of implementation will be checked in future, but that is out of scope of this paper.

The paper is organized as follows – after this introductory section, developed system overview is given. After that, the third section is used to describe the basics and the most important parts of the mobile application development process, while the fourth section describes the server-side development included in the project. Fifth section describing the project related future work is followed by the final, conclusions section.

It is important to state, that the project described in this paper started as a simple practical extension of mobile application development student class [3], being extended and finally presented as a student final thesis [4]. Local authorities were informed about the project itself and gave a positive feedback with interest of practical implementation for real-world usage in communal affaires office.

2 SYSTEM CONCEPT OVERVIEW

The basic idea of the developed system is shown in Fig 1 – starting from a simple mobile application being able to collect and process user location information, it grew to a complete generic system that can be used, with minor on-demand adaptations, in different real-world scenarios.

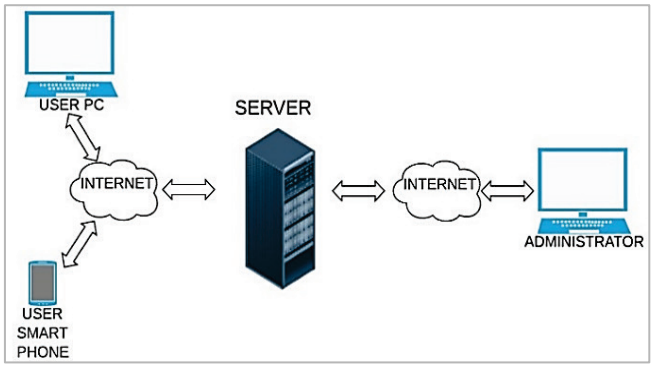

Figure 1 The developed system concept

In general, the system differentiates only two kind of users – standard users (mobile app users) and administrators. Standard users generate the systems inputs – they report certain events, including both the photo and the location information of the events. Administrators are responsible to

take actions on reported events, and, finally, provide a feedback to the users. The initial idea, implemented in the system, is that users use their smartphones to report and check the status of the events (mobile app prototype developed), while administrators use web-based interface to response.

In order to allow the anonymity of the users (of course, that could be limited in some real-case scenarios) the mobile application has the ability to be used without user authentication. Otherwise, users have to register to the system (feature included in mobile app) and authenticate prior sending the report (the feature of anonymous reports remain for the registered users, too).

2.1 Technologies Used

Overall, as already pointed out in the introduction, the system was developed using different technologies. Most, or all, of the used technologies are completely free, being available as open-source. The mobile application was developed as a native mobile app for the Android operating system, using Java programming language and the Android Studio integrated development environment (IDE) [5]. The web application (administration interface and registered user overview interface) and server back-end scripts were developed using plain PHP on the server-side, and HTML5, CSS (with additional Bootstrap styles) and Vanilla JavaScript on the client-side. Since no advanced frameworks were used, it is expected that the system will function on all HTTP servers – Apache HTTP server [6] was used for development and testing purposes. For data storage, MySQL database system, or compatible MariaDB was used. The implementation of PHP data management was accomplished using PDO (PHP Data Objects) making it almost database independent (all PDO supported database systems could be used with minor or no-change to source code). As a development environment for server-side scripts and web pages, NetBeans [7] was used. All the development was done using Windows operating system, while server packages were installed using integrated environments such as XAMPP [8] or WAMP [9].

3 MOBILE APPLICATION DEVELOPMENT

The mobile application was developed as native application, using Java and Android Studio IDE. Currently, a new programming language, Kotlin is stated as preferred language for the Android development, but the project described in this paper started much earlier and was therefore developed in Java. Due the interoperability of Java and Kotlin in Android environment, it could be expected that some parts of the app may be rewritten to Kotlin. In addition to Java, the XML markup language was used when defining graphical user interface (GUI) and other application resources.

In contrast to the native application developed, modern mobile applications can be developed as, so-called, hybrid applications. Native applications, as the one presented as the end-user-oriented part of the proposed system, are developed for specific operating system and are considered to be more efficient than hybrid apps – the downside of native apps is that they cannot be directly ported and used on other operating systems (current duality of the mobile platforms, as seen in results in [1] suggests iOS as only valid alternative to Android). Hybrid apps, on the other hand, are usually fully portable and can be used without any significant changes and additional development efforts on literally all platforms (supporting HTML5 and JavaScript). Since the functionalities of the developed app are not so device-specific, and since the hybrid approach includes basic support for most device features required for our application, the development of the, functionally the same, hybrid application will be considered in future.

As already suggested in 2.1, most of the implementations were done as plain as possible, without usage of any additional frameworks. The same approach was used in the mobile app development – no advanced techniques or architecture patterns were used – the simplest, old-fashion architectural approach was used, without any real view and model separation. Basically, `Activity` classes were used to control the GUI and call the functions required.

Since explaining and in-depth coverage of all implemented features and related source-code is out of the scope of this paper, this section will be used to point-out the most important parts of mobile app development process – in addition to basic GUI development introduction, it will include some details about using location services, networking and location visualization using integrated maps.

3.1 User Interface

Each new version of Android operating systems tends to include some new user interface "look-and-feel", new themes and even new GUI objects offering some new features. Even though that is a great fact for end-users, delivering faster, nicer and often more functional apps, in our project we tried to keep the focus on functionalities, while using only the simplest GUI elements. Of course, when preparing the prototype app for real-world usage, that can be adapted, based on customer requirements and needs.

Therefore, the basic GUI elements implemented as native classes in Android API were used in the prototype app – standard `Button`, `TextView`, `EditText`, `ImageView`, `Menu` and `WebView` objects. Basically, the GUI consists of a "screen" (window) facing the user – in Android, the class representing the screen (usually, full-screen of the device) is *Activity*. GUI elements are positioned in the `Activity` – in Android that is called `Layout`. Currently, the preferred layout in Android Studio is `ConstraintLayout`. Our prototype app uses `ConstraintLayout` to "draw" the user interface and define the relations among the objects (all the layouts and object data are stored as XML resource files). Describing the basics of "connecting" programming source code and GUI elements is out of the scope of the paper, but shortly – in order to use certain GUI element programmatically, one has to get a reference to it – it can be done when needed or once-per-activity in a predefined `onCreate` function, for example by using `findViewById` method. That way, a programmer can

obtain a variable (object) referencing to a certain GUI element and use it when needed (each element in the application can be referenced using its unique resource identifier). Interestingly, Kotlin language overcomes that by using so-called synthetic binding, allowing the programmer to access each GUI element directly using element identifiers, with no additional coding required (while waiting for the reviews of this paper, during 2020, synthetic binding become obsolete and Google suggests another view-binding approach for accessing UI elements – however, for basic purposes `findViewById` still remains a solid solution).

In addition to mentioned basic GUI elements, in order to provide a better user experience (UX) to the end-user, some little more advanced visual elements had to be included – but, we tried to include only those really necessary, keeping in mind to stay focused on standard Android API elements – actually, only two "complex" visual elements were used – `RecyclerView` and `MapView` (or `MapFragment`). The list of the visual elements used in the application is given in Tab. 1. In case of commercialization of the developed system, it can be expected that more advanced GUI elements shall be included to additionally improve UX and modernize application looks.

Table 1 Used GUI elements and feature important non-visual API classes

Android API class	Usage
`Button`	Standard button, touch/click sensitive
`TextView`	Showing simple unformatted text on screen
`Menu`	Android menu
`EditText`	Input field allowing user input via keyboard
`ImageView`	Showing image resource/file on the screen
`WebView`	HTML viewer – part of the screen
`RecyclerView`	Optimized multiple item scrollable element
`MapView` or `MapFragment`	Visualization of Google map and locations

The `RecyclerView` class is used to optimize a display of multiple items (it offers certain optimizations in contrast to, functionally similar, `ListView`). Items visualized in `RecyclerView` can be customized and described with a complex XML defining its layout. Recycler lists are more efficient than standard lists, because they do not load and redraw the entire list at once, but only the visible list items. To properly use lists (connect the visual part and the data being actually shown), Android uses special classes called adapters. As many other Android API based "tricks", the only way to properly use it is to check the official documentation and adapt to the usage needed.

`MapView` class and elements used to work with geographic maps will be described and shown in action in 3.3, so it will be skipped here. But, there is one non-visual class important when working with user interface – the class `Intent`. Intents are an abstract description of an operation to be performed – in the application they are used to open and show other activities (screens). Another very important usage of `Intent` in our application is when obtaining photo related to the reported event – in addition to text and location information, multiple images (files available on the smartphone or direct camera photo shoots) can be attached – activating camera and obtaining a fresh photo is done using `Intent`, which connects our app with system camera and returns a result. This may be considered the simplest way to use generic, device related, camera software without additional programming – for some more complex project, when camera has to be integrated in the main application, Camera API or CameraX *JetPack* extenstion could be used.

3.2 Retrieving the Location

Device location in Android is retrieved using so called `LocationProviders`. Application presented in this paper uses the GPS `LocationProvider`. To use a location provider in the app, special permissions are necessary. Permissions required for an application to run on the device are defined in so-called application manifest file (XML document). Permissions are necessary because the location of a device is potentially sensitive data and in order to be able to access position data the user has to grant the permission prior using the app. The permission (predefined constant) `ACCESS_FINE_LOCATION` is used to allow access to precise satellite location data (GPS, GLONASS or other device supported location systems), while `ACCESS_COARSE_LOCATION` allows access to less precise location data obtained from network location sources (WiFi or mobile network data, IP geolocation or similar). The application must have permission `ACCESS_FINE_LOCATION` allowed – this kind of permission is considered "dangerous level" permission and has to be additionally processed at run-time since Android 6.

Android architecture and Android API define different kind of management classes used to communicate with certain subsystems. That applies to location services too - to access the device location a class `LocationManager` is used. It controls and connects to location services and implements programmatic events related to location services. Another important class, `LocationListener`, listens for events that are connected to a specific `LocationManager` and then triggers the predefined functions like in the case of a change of the current location. The `onLocationChanged` function is then triggered, as shown in source code in Fig 2.

```
1     LocationManager lm = (LocationManager)
          this.getSystemService(Context.LOCATION_SERVICE);

2     LocationListener li = new LocationListener()
3     {
4       public void onLocationChanged(Location loc)
5       {
6          lat = Double.valueOf(loc.getLatitude());
7          lon = Double.valueOf(loc.getLongitude());
8          vis = Double.valueOf(loc.getAltitude());
9       }
10    }

11    lm.requestLocationUpdates(LocationManager.GPS_PROVIDER, 100, 0, li);
```

Figure 2 Implementation of *onLocationChanged* method

In the code given in Fig. 2, the application connects to available location service of the device (via `LocationManager`, line 1) and creates new `LocationListener` (line 2) with implementation of `onLocationChanged` (line 4) function that will execute when current location changes – in this simple example (lines 6-8) new location will be fetched and stored in (global) variables `lat`, `lon` and `vis`. The last line of code (11) connects a manager `lm` with previously created listener `li` - the parameters given are a provider (GPS), update frequency of the listener (every 100 ms in this case), and

minimum distance required to detect new position (related to previous).

The obtained geographic location is packed using the class `Location` [10] which implements many useful functions – as in lines 6-8, function for obtaining geographical longitude, latitude and altitude/elevations.

In time of writing this paper and developing the mobile app, *LocationManager* as part of Android Location API was considered a standard approach for obtaining device location. However, lately Google suggested using a little different approach – Google services with *FusedLocationProvider* class and related API as more battery-efficient approach [11].

3.3 Location Visualization on the Device

Locations are best visualized on a map. The maps used in the developed prototype application are Google Maps, the most common map type used in Android applications. Simply, `GoogleMap` class that is part of extended Android API (Google API for Android – Google Play Services additional libraries have to be installed and included in Android Studio project when developing that kind of applications) is used as an object for manipulating the geographic map, while `MapView` or `MapFragment` visual user-interface elements are visualizing that map and additional user elements as markers. There are multiple types of maps used – the application uses hybrid maps. These are satellite maps with elements of classic road maps. Maps are implemented as a view or as a fragment (part of the screen/activity) in the activity layout. Map data is contained on online servers, so, to successful load maps, a device must have access to the Internet (there are some ways of using offline maps, but these were not analyzed during the presented project and therefore not supported in the application).

In order to use maps, some prerequisites are necessary – the developer has to prepare the environment and the end-user has to allow the application to access the location services. Additionally, developer has to obtain so-called API key to allow his applications to access Google online services [12] and define it in application manifest file.

Maps can have added elements such as markers. Markers can be predefined system markers or custom made. These markers can be interactive. Also, an important issue regarding the map user interface is the "camera", which represents the view a user has on the map or where is it centered and to which level is it zoomed in. Since maps are network dependent elements and as such they are susceptible to delays. Therefore, it is not recommended to do operations with maps before they are completely fetched from the network. When a map is successfully loaded a predefined function called `onMapReady` is triggered [13].

The code piece in Fig. 3 gives an example of how to initialize and display a map (in a `MapFragment` visual element, which is simpler to implement, since it automatically handles lifecycle functions, while when using `MapView` the developer must handle and implement all lifecycle functions manually [14]) – usually, that is done in `onCreate` function of the activity containing the map – the example code gets the reference to a `MapFragment` with resource identification `map1` and calls the `getMapAsync` function.

```
MapFragment mapFragment = (MapFragment)
                  getFragmentManager().findFragmentById(R.id.map1);

mapFragment.getMapAsync(this);
```

Figure 3 Source showing how to get a reference to a *MapFragment*

This standard API function (`getMapAsync`) shall trigger the `onMapReady` callback function where developer should obtain reference `mMap` to `GoogleMap` object (line 3) related to the map shown in `MapFragment` or `MapView` and start manipulating it (in example shown in Fig. 4 – code line 4, defining the map type).

```
1    public void onMapReady(GoogleMap googleMap)
2    {
3      mMap = googleMap;
4      mMap.setMapType(GoogleMap.MAP_TYPE_HYBRID);
5    }
```

Figure 4 Implementation of *onMapReady* callback function

Using that reference, the variable `mMap` in our example, map can be manipulated – for example, adding markers, changing and zooming the map camera etc.

```
mMap.addMarker(new MarkerOptions()
            .position(moja_lokacija).title("TRENUTNA LOKACIJA"));

mMap.moveCamera(CameraUpdateFactory newLatLngZoom(moja_lokacija,15));
```

Figure 5 Example code for map manipulation – new marker, zoom change

The example in Fig. 5 shows how to add a standard marker to a certain location (`moja_lokacija` variable – `Location` object), and how to "center" the map to that location using `moveCamera` function – in addition to the location, `newLatLngZoom` function defines the zoom level, based on predefined constants (for this example, zoom set to 15 relates to internal street-based view, as documented in [15]).

The prototype application also includes the feature of using a so-called geocoder, which is used to retrieve an address based on location coordinates. That can be useful in real-case usage where the manual input of the address related to the reported event could be automated or at least speed up (user takes a photo for a report using the camera, the app gets the location and tries to obtain the address – which may succeed in populated areas and cities – if that succeeded, the user does not have to input address information manually). Example of usage of the geocoder trying to get an address of certain location (`try-catch` block is used to prevent possible exception in cases of geocode unavailability or other critical issues) is given in Fig. 6.

```
1   Geocoder gc;
2   gc = new Geocoder(getApplicationContext(),Locale.getDefault());
3   try
4   {
5     adrese = geocoder.getFromLocation(latitude, longitude, 1);
6     adresa = adrese.get(0).getAddressLine(0);
7   } catch (IOException e)
8   {
9     e.printStackTrace();
10  }
```

Figure 6 Source code for obtaining geocoder information

In given example, the function `getFromLocation` in line 5 returns an array of `Address` objects (to collection variable named `adrese`). In line 6, only the address line of first (most probably the most relevant one) of the obtained objects.

3.4 Network Operations

Since the proposed system requires that the report data is sent to a central location, it is clear that the prototype smartphone app must be able to send requests and get responses from the server. Android API provides common data communication features based on `HttpsURLConnection` class (and `HttpURLConnection` if using unsecure connections). There are some additional libraries included in API and *JetPack* framework, but for the prototype app only the basic class was used. As already explained in 2.1, server-side is based on HTTP (web) server, so that the only communication protocol required to contact and exchange data with the server is HTTP, meaning that `HttpsURLConnection` class should be sufficient for our implementation.

Theoretically, network operations may be time consuming and, as with all time-sensitive operations, it is required to execute those tasks in working (background) thread in order to prevent well-known "Application not responding" (ANR) exceptions due to the blockage of main UI thread! Network operations, in general, include sending HTTP request to the server and waiting for response. In Android applications written in Java, the "waiting part" is mostly done using the `AsyncTask` Android API class[16]. All the sensitive and time-consuming operations in the `AsyncTask` are done in the `doInBackground` function, while the user-interface related functionalities are implemented in other predefined class functions such as `onProgressUpdate`, `onPreExecute`, `onPostExecute` function. To access the main UI thread from the `doInBackground` function the `runOnUiThread` function can be used, representing an interrupt - interrupts are put in a waiting line and are executed from first to last.

When using HTTP, requests sent to the server are most often standard POST or GET requests. Since the proposed system itself includes quite simple functionalities (at least for now), all the server scripts were implemented as simple POST or GET requests processing scripts – no advanced REST API or similar approaches were used on server-side. Most calls to the prototype system are POST based – client-side requests in the mobile application are simply sent to the server and returning results are obtained using the function containing the code similar to one given in Fig. 7.

Unique resource locator (the addresss, URL) (line 1) and data transferred (line 8) are defined as the parameters `urlString` and `dataString`, while the results obtained from the server (line 15) are stored in variable `res` (in case of implementation as a function, function could return the string value of `res`). The response from the server is, as usual with HTTP, formatted as a string. Our server-side implementation uses a JavaScript Object Notation format (JSON) as response format. That kind of response results shall be processed after receiving it in variable `res`, and UI thread should update the GUI accordingly.

```
1   url = new URL(urlString);
2   veza = (HttpURLConnection)url.openConnection();
3   veza.setRequestMethod("POST");
4   veza.setDoOutput(true);
5   veza.setDoInput(true);
6   izS = veza.getOutputStream();
7   bfW = new BufferedWriter(new OutputStreamWriter(izS,"UTF-8"));
8   String post_data = URLEncoder.encode(dataString,"UTF-8");
9   bfW.write(post_data);
10  bfW.flush();
11  bfW.close();
12  izS.close();
13  ulS = veza.getInputStream();
14  bfR = new BufferedReader(new InputStreamReader(ulS,"UTF-8"));
15  res = bfR.readLine();  // Single line or loop to get multiline result
16  bfR.close();
17  ulS.close();
18  veza.disconnect();
```

Figure 7 Implementation of standard HTTP request and response operation

3.5 User Interface and Implemented Functionalities

The prototype mobile application uses the simplest possible, generic, user interface. It is completely customizable for different real-case usage scenarios. This section will depict only the most used activities (screens) and comment the functionalities implemented. Some activities (e.g. settings/options activity) are not shown due the limited paper length.

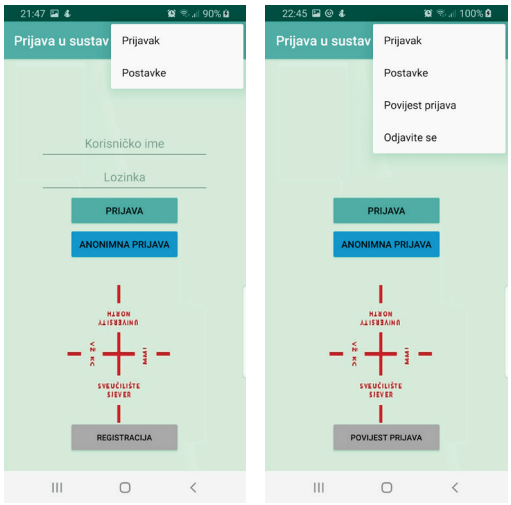

Figure 8 Adapted appearance of the main activity

The main app activity (with additional ability to include initial splash screen when customizing for real-world usage) is used for user authentication and starting a procedure of sending the report. The user interface is adapted to current app and user status – Fig. 8 depicts two varieties, the first on the left shows "logged out" screen, where the user can authenticate by entering username and password, register to the system, or directly send anonymous report without being authorized. The application menu is also adapted, based on current user and app status. The second appearance of main activity, on the right of Fig. 8 shows the activity when user is properly authenticated – standard and anonymous report is enabled, including the overview of reports history.

The most important activity, by its functionality, is the activity representing the report submission form, as shown in Fig. 9. It is a scrollable activity offering all required report features – selecting multiple existing photos from device

gallery or taking new photos with integrated system camera (implemented as `RecyclerView`), custom text input for describing the reported event, automatic location processing and geocoder address lookup. The address data will contain the street address, postal code, municipality and region of the location. In case when a geocoder cannot fetch the address, the location address data is left empty.

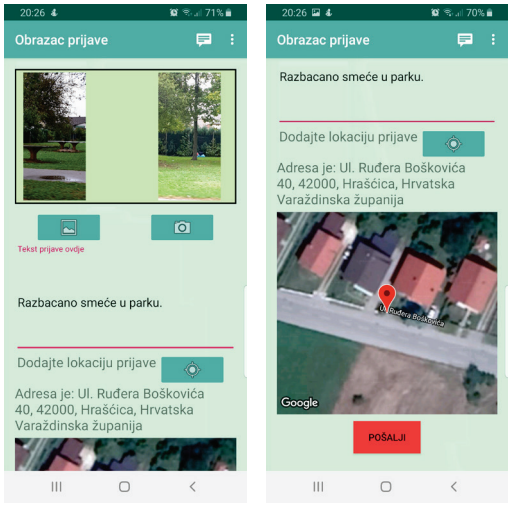

Figure 9 Activity with the report submission form

At the bottom of the report submission activity a map view which is moved to the reported location is included, with a location spot being marked using a standard marker. After manually (button) sending the report to the server, the end-user is informed about the progress of the reporting operation via `Toast` or `Snackbar` GUI messages and finally sent back to the main activity.

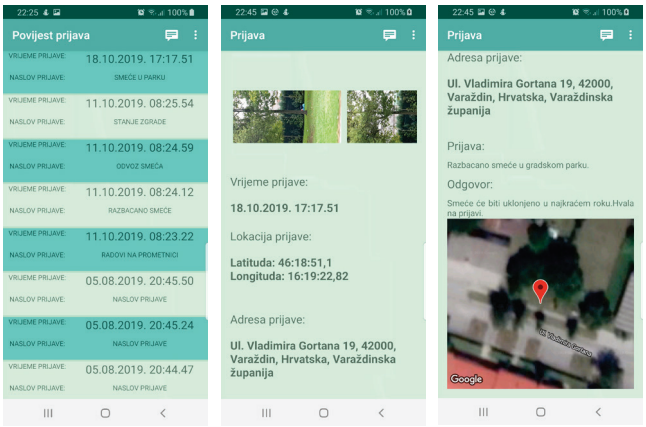

Figure 10 Reports history and overview activities

The prototype application does not include any special notification services that would periodically check the status of the reported events – instead, it offers simple reports overview (Fig. 10) allowing the end-user to check if the system administrator responded to the reported issues. Independent from the smartphone application, registered users sending authenticated report events could be informed of status changes via e-mail (server-side implementation).

The list of reported events is sorted by decreasing report date and time. Each report can be overviewed, showing the current data from server including administrator response.

4 SERVER-SIDE DEVELOPMENT

Two-way communication is expected in the proposed system – user reports shall be accepted and processed, if necessary, by the system administrator(s). Additionally, tracking, analysis and different kinds of back-office reports may be required. That is where the server-side development comes into the focus. Server-side subsystem requires a HTTP server and database server – the proposed concept uses server-side to upload reported events from mobile users and implements processing of the scripts using the PHP programming language. Also, it includes the web application for the administration (responding to reported events) and alternative authenticated user reports overview.

Plain PHP, with no usage of any frameworks was used for server-side scripts. Front-end (user interface for the web application) uses HTML5, CSS and plain JavaScript – additionally, some stylesheets and GUI widgets from Bootstrap [17] were used.

4.1 Mobile Application Accompanying Server Scripts

As explained in section 3, the mobile application uses the device (smartphone) to collect and prepare data related to a certain event and send a report and all prepared data to the server. Data handling and processing is managed on server-side using backend scripts described in this subsection. Additional server scripts were developed as part of web application and frontend (4.2).

Main functions implemented as PHP scripts, required by the mobile application are listed in Tab. 2. Please note that for the prototype and test purposes, only the plain .php files/scripts were used, with no advanced API or any server-side routing enabled – this can be setup easily when adapting the system for real-world usage, allowing more "fancy" and user-oriented API and addressing.

Table 2 Server scripts required by the mobile application prototype

Script name	Functionality
`login.php`	App user authentication check
`register.php`	New user registration
`update.php`	Multipurpose script for disabling or changing user account details
`report.php`	Script for receiving reported event details
`photos.php`	Script for managing and receiving images related to certain reported event
`fetch.php`	Multifunctional script for fetching list of reported events or details and complete data for a single event

The scripts respond with JSON formatted messages that are parsed and processed by the mobile app. To process user authentication the `login.php` script is used. It receives a POST request from the mobile device and returns a success or failure message depending on user status. The `register.php` script receives data from the mobile applications registration activity and proceeds to register a

new user. After a successful registration it returns a success message to the mobile device. The `update.php` script receives a request containing an operation type and some operation specific data, making it multipurpose – it implements few functions - the user deletion or deactivation and user data modifications. To receive a report on server, the `report.php` script is used. It receives the entry data excluding multimedia files (photos or pictures, mainly, as tested in prototype system). Each reported event receives new unique ID number which is sent back with script response. If pictures (most usual case) are related to the report and prepared on the device, the device will send the pictures to the `photos.php` script – it will store the pictures to a file on the server, not directly in the database. Generated picture ID number, picture filename and additional data associated with the picture are, of course, saved in the database. Since the pictures are sent as part of a HTTP request, *base64* encoding is used. Prior to storing the picture as a file on the server, decoding has to be performed, using simple PHP code, as depicted in Fig. 11.

```
1    $dekodPic = base64_decode($picStr);
2    $loc = 'photos/'.$name;
3    $file = fopen($loc, 'wb');
4    $res = fwrite($file, $dekodPic);
5    fclose($file);
```

Figure 11 PHP code for decoding and storing photo received from user device

To get the list and details of previously sent reports, the `fetch.php` script is used. It will send a structured list of JSON formatted data, based on the operation required – it can be used to obtain the list of all events reported by the authenticated user of the app, or to get all details of a certain reported event. Also, the same script is used to get report related images from the server.

4.2 Web Application and Frontend

The web application developed as part of prototype system is used primarily for administration purposes (the system administrator has to respond to end-user reports and give a feedback), but it was decided to extend it for a simple show-case, allowing authenticated users to check their reported events via a web-based interface (the same functionality is included with the mobile application). As already mentioned when describing backend scripts, on the server-side plain PHP with no frameworks or special routing API was used, while frontend uses HTML5 and plain JavaScript. The main web page is implemented in `index.php` and it is used to provide user login interface (Fig. 12). Authentication status is remembered using super global `$_SESSION` variables (additional improvements could be implemented prior to public release of prototype app).

If the login succeeds, it redirects the user to the `list.php` using simple PHP `header("Location:list.php")` directive.

The `list.php` script shows the list of all user entries. If the user has administration rights all the entries of all the users will be shown (Fig. 13).

Each entry in the list can be opened and all the details can be shown – location, description, uploaded images and all related data are visualized using `show.php` script, as depicted in Fig. 14. If an authenticated user is the administrator, response field will be available, with corresponding button to save the response to the database – the `admin.php` script is used to make an update.

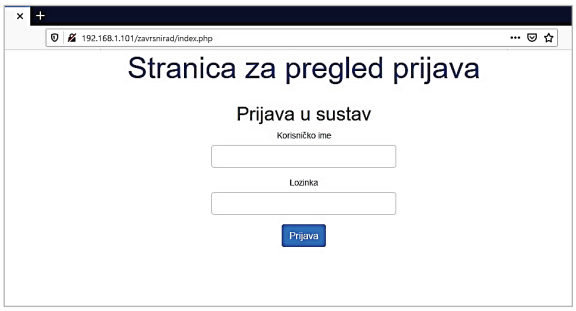

Figure 12 Login screen of the web application

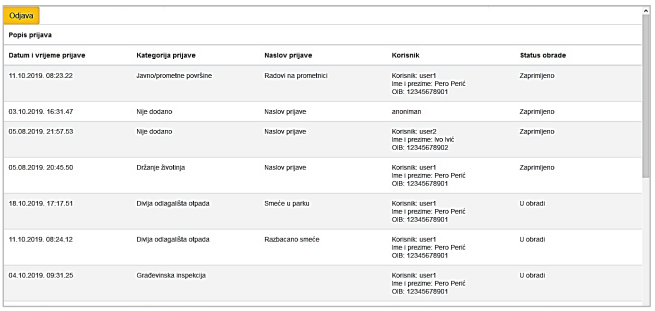

Figure 13 List of reported events

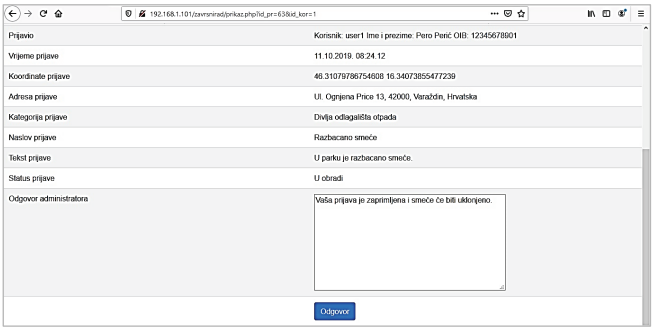

Figure 14 Reported event overview and administrator response

```
1    var xhttp = new XMLHttpRequest();
1    xhttp.onreadystatechange = function() {
2       if (this.readyState == 4 && this.status == 200) {
3          if(this.responseText=='testOk') {
4             alert('Data updated successfully!');
5          }
6       }
7    }
8    var addr =
9    xhttp.open('GET','http://server/admin.php?id_rpt='+id),true);
10   xhttp.send();
```

Figure 15 Vanilla JavaScript AJAX implementation

As usual, in order to make the web application more responsive, asynchronous JavaScript (AJAX) requests are used – standard `XMLHttpRequest` is implemented in plain JavaScript, as shown in Fig. 15.

The `logoff.php` script is activated when the user sends as request to logoff from the web application – it will basically destroy all the session data and reload `index.php` to allow the next user to login.

5 FUTURE WORK

From the beginning of the project, the system described in the paper grew and finally ended up with the development of both the mobile application and the server backend. The project started as a student project, non-commercial and educative – therefore, the deliverables actually consist of generic applications which could be extended with additional features. Through tests and analysis of possible real-case scenarios, the authors collected numerous ideas related to functional and user-oriented improvements of the implemented apps.

Even so, the mobile application already provides some enhancements over the functionally similar apps being used by some public institutions (e.g. multiple photos can be sent with single reported event).

Of course, additional tests have to be done, especially considering scalability of the system. The described initial steps and implementation can be considered a fundament of the future system or product.

6 CONCLUSION

Modern mobile platforms allowed the developers to use available location services and other platform subsystems in their applications. This paper describes the implementation of a system that uses location services in mobile application developed for the purpose of reporting different location related events to the central servers. The event that is intended to be generic and universal can be applied in different real-world scenarios.

The prototype system proposed in this paper was fully implemented, both as end-user mobile application and administrative web application. The complete system was developed from scratch, using only the basic and standardized technologies, most of them being free and open-source, making initial costs of the system stay low. Generic applications are quite adaptable and their practical usage can be considered quite wide. One real-case scenario that was already negotiated was a usage of the system to send reports to a city's communal affairs office.

The applications (both native mobile app for Android platform and web application) are fully functional, with ability to be expanded in the future, based on authors ideas or demands from potential customers and users. The design and user-interfaces of the applications are also completely adaptable, but, for now, that was out of the scope of the project.

7 REFERENCES

[1] https://gs.statcounter.com/os-market-share/mobile/worldwide
[2] https://techcrunch.com/2019/05/07/kotlin-is-now-googles-preferred-language-for-android-app-development/
[3] Mikac, M. (2020). Introductory mobile application development course for undergraduate students experiences, ICERI2020 *Proceedings*, 5003-5011. https://doi.org/10.21125/iceri.2020.1084
[4] Lukaček, K. (2019). Implementation of Android location services based application. (Bachelor Final Thesis) https://urn.nsk.hr/urn:nbn:hr:122:213590
[5] Android Studio IDE, see https://developer.android.com/studio
[6] Apache HTTP Server, see https://httpd.apache.org
[7] NetBeans IDE, see https://netbeans.org
[8] XAMPP environment, see https://www.apachefriends.org
[9] WAMP environment, see http://www.wampserver.com
[10] Android API Location class, https://developer.android.com/reference/android/ location/Location
[11] Fused Location Provider API, https://developers.google.com/location-context/fused-location-provider
[12] Google API developer key, https://developers.google.com/maps/documentation/javascript/get-api-key
[13] https://developers.google.com/maps/documentation/android-sdk/intro
[14] https://developers.google.com/android/reference/com/google/android/gms/maps/MapView
[15] https://developers.google.com/maps/documentation/android-sdk/views
[16] AsyncTask in Android, https://developers.google.com/j2objc/javadoc/android/reference/android/os/AsyncTask
[17] Bootstrap library, https://getbootstrap.com/

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Original scientific paper

Improvement of the Heat Balance Equation Accuracy, in the Case of Saturation Diving

Anca Constantin*, Tamara Stanciu

Abstract: The body temperature of a diver is one of the most important aspects of the concept of underwater safety and comfort. The heat balance equation previously established, was improved in this paper by introducing a linear dependence of the absolute humidity on the body temperature, as the absolute humidity influences the latent heat flux needed for the humidification of the breathing gas. The solution of the new proposed heat balance equation is a step forward in assessing the body temperature in both cases of unitary and saturation diving. The paper presents the equation and its solutions in the case of breathing either air or Heliox and compares the theoretical results with the values measured in the frame of simulated saturation diving with Heliox 5/95, in the hyperbaic laboratory. The proposed equation predicts the body temperature of the diver, at the end of a 30 minutes immersion with a good accuracy. The relative error is up to 1%.

Keywords: body temperature; heat balance; saturation diving

1 INTRODUCTION

The diving technology has impressively evolved in the last decade allowing man to safely work in underwater sites for longer periods of time and with extended respiratory and thermal comfort. Beside the researches regarding breathing apparatuses and respiratory mixtures, the interest on thermal mechanisms in underwater environment has been the object of study for researchers from our country and from abroad. Depending on the diving plan, the temperature reached by the diver's body after the immersion time has to be assessed prior to the diving, so that the most appropriate thermal protection strategy to be taken to avoid hypothermia temperature (28 °C) [1]. Thermal protection strategies are passive and active. Passive strategies consist in covering the diver with an insulating layer (diving suit). Active strategies use an external source of energy to compensate for the body's heat loss, the most common being a hot water suit. Other systems use electrical resistors attached to the undergarment [2].

Tarlochan [3] studied the thermal comfort of a swimmer, which means the heat lost by a human body in seawater, but at atmospheric pressure and without any protection suit. The theoretical and experimental studies of Majchrzycka [4], and King [5] referred to a human body in pressurized facilities, but in dry environment. The temperature distribution in the atmosphere of the dry hyperbaric chamber, provided by the specific thermal conditioning installations [6], influences the heat losses of the divers at saturation.

The studies on heat loss mechanisms developed in the Diving Centre in Constanta refer to divers immersed in water, in controlled conditions which simulate the water pressure at different depths [7].

The experimental assessment of the heat lost by a diver showed thermal losses of a diver are approximately two times higher when using Heliox instead of air as breathing mixture, under similar conditions of water temperature and depth, in the first 15 min of simulated diving [8]. The density of the heat flux lost by a diver which breathes air is around 400 W/m^2 [9].

The working depth of more than 50 m requires the use of another diluent gas (usually helium) for oxygen, instead of nitrogen from the atmospheric air. The use of the binary respiratory mixture Heliox, that means oxygen diluted by helium, and the increase of the range of immersion depths, determine different thermal phenomena, due to the physical properties of helium, very different from those of nitrogen. Hyperbaric conditions and the range of saturation dives also influence the heat exchange between the diver's body and the environment. The phenomena are complex and have been studied both theoretically and practically, through a series of tests performed at the Hyperbaric Laboratory of the Diving Center.

In [10] it is proposed an equation that describes, with good accuracy, the variation of the diver's temperature, considering all categories of heat loss in the case of air as breathing mixture. The equation was written assuming the humidification of the inhaled air is made at a vapor pressure corresponding to the body temperature of 37 °C. It showed a good accuracy when the results were compared to the experimental data, but a correction coefficient was needed. Stanciu [10, 11] proposed the correction coefficient $c_{\text{air}} = -0.5$ °C.

In this paper, we continue the work regarding saturation diving and the diver's temperature during immersion in saturation, aiming to adapt the equation to the case the diver breathes Heliox 5/95, the binary mixture with 5% Hellium. The theoretical model is validated by the experimental results obtained in the Hyperbaric Laboratory.

2 THE EQUATION THAT GOVERNS THE DIVER'S TEMPERATURE VARIATION DURING IMMERSION

The heat balance equation considers the heat flux produced by diver's metabolism, the heat flux lost by the diver at the skin level, and the heat flux lost due to the heating and humidification of the respiratory gas during the inhalation process [9].

$$mc_{\text{b}}\frac{\text{d}T}{\text{d}t} = \\ = \dot{Q}_{\text{m}} - \frac{T-T_{\text{w}}}{R_{(p)}}A - l_{(p)}\rho_{(p)}x_{(p)}\dot{V}_{(p)} - \rho_{(p)}c\dot{V}_{(p)}(T-T_{\text{w}}), \tag{1}$$

were m - mass of the diver's body (kg); c_b - specific heat of the human body (3400 J/(kg·°C)); T - body temperature of the diver (°C); t - underwater exposure time (s); $\dot{Q}_m$ - metabolic heat flux (W); T_w - water temperature (°C); $R_{(p)}$ - human skin thermal resistance (m²·°C/W); $l_{(p)}$ - water specific latent heat (J/kg); $\rho_{(p)}$ - air density (kg/m³); $x_{(p)}$ - absolute humidity of the breathing gas(kg/kg); $\dot{V}_{(p)}$ - breathing flow rate in normal conditions of pressure (m³/s); c - air specific heat at constant pressure (1010·J/kg·°C). One may notice that the pressure is a parameter in this equation.

This mathematical model for temperature variation was built assuming the breathing gas is saturated with water vapors during an inhalation, considering the vapors saturation pressure of $p_v = 0.0628$ bar at the average human body core temperature of 37 °C. That means the absolute humidity x was considered constant with the temperature. But it depends on saturation pressure of vapors that means it depends on body temperature [12] and the body temperature is the variable of this equation.

$$x = \frac{m_v}{m_a} = \frac{p_v R_a}{p_a R_v} = \frac{R_a}{R_v} \cdot \frac{p_v}{p_{am} - p_v}, \tag{2}$$

where $R_a = 287$ J/(kg·°C) - air constant; $R_v = 462$ J/(kg·°C) - Heliox constant.

The solution of the Eq. (1) led to unsatisfying results when applied to Heliox as breathing mixture. Therefore, we dropped the assumption the breathing gas is saturated up to the core temperature of 37 °C, and replaced the constant absolute humidity $x_{(p)}$ with a function of the body temperature, T.

We considered a linear dependence of the humidity over temperature and obtained the following functions: (3) for air and (4) for Heliox 5/95, at a water depth of 60 m.

$$x_{(T)} = 0.0003 \cdot T - 0.005 \tag{3}$$

$$x_{(T)} = 0.0004 \cdot T - 0.0062 \tag{4}$$

Therefore, the Eq. (1) was reshaped and became, in the case of air breathing:

$$mc_b \frac{dT}{dt} = \dot{Q}_m - \frac{T - T_w}{R_{(p)}} A - \\ -l_{(p)} \rho_{(p)} \dot{V}_{(p)} (0.0003 \cdot T - 0.005) - \rho_{(p)} c \dot{V}_{(p)} (T - T_w), \tag{5}$$

and, in the case of Heliox breathing:

$$mc_b \frac{dT}{dt} = \dot{Q}_m - \frac{T - T_w}{R_{(p)}} A - \\ -l_{(p)} \rho_{(p)} \dot{V}_{(p)} (0.0004 \cdot T - 0.0062) - \rho_{(p)} c \dot{V}_{(p)} (T - T_w) \tag{6}$$

The solution of the Eq. (5) or (6) is:

$$T = \left(T_o - T_w - \frac{a}{b} \right) \cdot e^{-bt} + \frac{a}{b} + T_w \tag{7}$$

Where the coefficients a and b are written for the two breathing gases as follows:

Air

$$a = \frac{\dot{Q}_m - 0.0003 \cdot T_w l_{(p)} \rho_{(p)} \dot{V}_{(p)} + 0.005 \cdot l_{(p)} \rho_{(p)} \dot{V}_{(p)}}{mc_b}$$

$$b = \frac{\frac{A}{R_{(p)}} + \rho_{(p)} c \dot{V}_{(p)} - 0.0003 \cdot l_{(p)} \rho_{(p)} \dot{V}_{(p)}}{mc_b}$$

Heliox

$$a = \frac{\dot{Q}_m - 0.0004 \cdot T_w l_{(p)} \rho_{(p)} \dot{V}_{(p)} + 0.0062 \cdot l_{(p)} \rho_{(p)} \dot{V}_{(p)}}{mc_b}$$

$$b = \frac{\frac{A}{R_{(p)}} + \rho_{(p)} c \dot{V}_{(p)} - 0.0004 \cdot l_{(p)} \rho_{(p)} \dot{V}_{(p)}}{mc_b}$$

3 THEORETICAL RESULTS

The solution (7) was graphically represented in Fig. 1, considering a diver with the following features: body mass m = 84 kg, height h = 1.78 m, age a = 42 year; body surface S = 2.05 m² and a production of metabolic heat $\dot{Q}$ = 88 W. The diver is one of the four divers that participated in simulated saturation diving series in the hyperbaric laboratory of the Diving Centre [7].

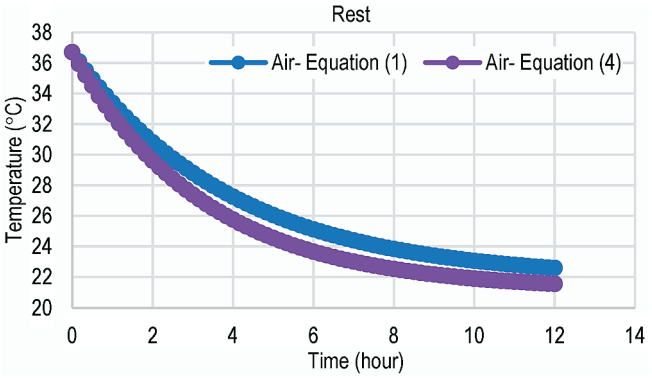

Figure 1 Body temperature variation during a saturation diving. Diver at rest

In Fig. 1 it may be noticed that the Eq. (5) gives smaller temperature values than Eq. (1), and the difference is quite equal to the correction coefficient c_{aer} = –0.5 °C, proposed by Stanciu [10, 11].

The Eq. (1) introduces errors as the temperature during air breathing diving decreases faster than during the Heliox breathing diving. The solution of the reshaped Eqs. (5) and (6) give an appropriate variation of temperature, in

accordance with the thermal flux lost by a diver in the above-mentioned conditions of gas breathing. The curves in Fig. 2 show a more realistic decrease of the human body temperature: the temperature decreases faster when the diver breathes Heliox. The body temperature settles at $T = 21$ °C, as the water temperature is $T_w = 19.5$ °C. The graphs in the Fig. 3 were theoretically plotted. The curves were plotted for a period of 12 hours, as the allure is more visible for such a long time. Actually, the time spent by a diver in immersion during saturated diving is much shorter. The experiments in the simulator lasted for only 30 min, which is a more realistic period.

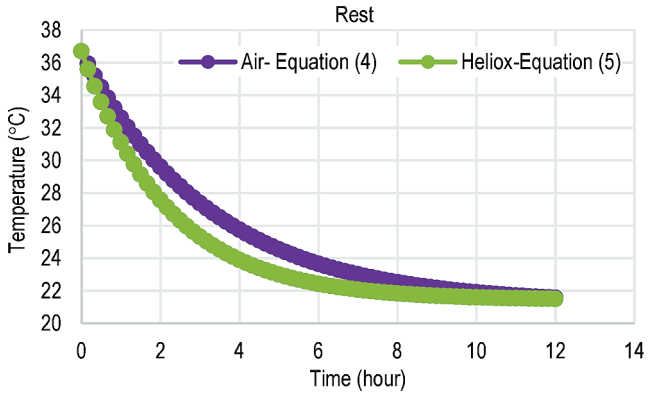

Figure 2 Body temperature variation, during similar saturation diving with air and with Heliox. Diver at rest

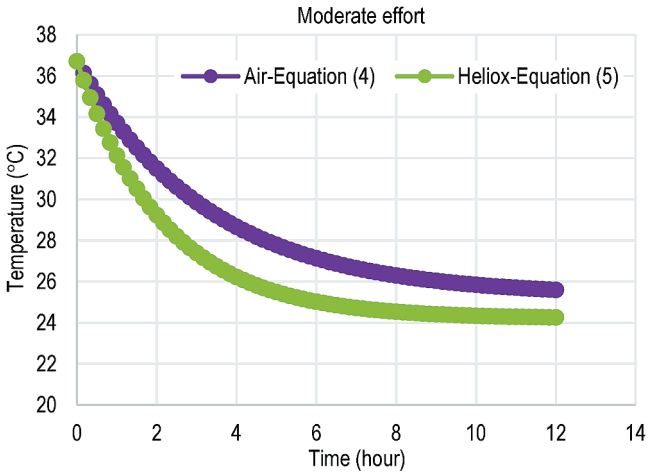

Figure 3. Body temperature variation during a saturation diving. Diver performs moderate effort (100 W)

Similar graphs were represented in Fig. 3, but it was taken into account an increased metabolic heat flux, produced by a moderate effort, of 100 W, performed by the diver during immersion. Temperature decreases more slowly, and it settles around $T = 26$ °C for air and $T = 24.3$ °C for Heliox.

4 EXPERIMENTAL MEASUREMENTS

The simulated diving series were carried out in the hyperbaric laboratory of the Diving Centre, Fig. 4.

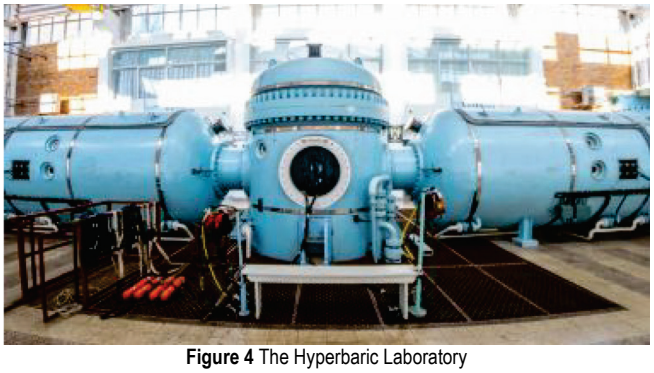

Figure 4 The Hyperbaric Laboratory
(Diving Center photo archive)

The experiments comprised simulated saturation diving both with air and with Heliox mixture, at surface level and at different depths, simulated in the wet chamber of the laboratory. The entrance of a diver in the wet chamber is captured in Fig. 5.

We have to mention that all the measurements made at surface level may be referred to as made in saturation, as the human body is saturated with Nitrogen in normal conditions of pressure when breathing air.

Three divers performed the air diving series and four divers, the Heliox 5/95 diving series.

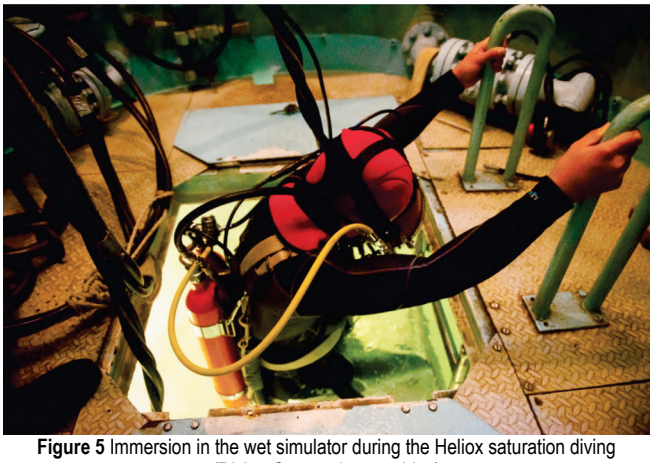

Figure 5 Immersion in the wet simulator during the Heliox saturation diving
(Diving Center photo archive)

The same physical amounts were measured at surface (0 m level) and at 61 m depth: t_i - the temperature of the inhaled breathing gas, t_e - the temperature of the exhaled breathing gas, t_c - the core temperature of the diver (°C).

To measure the temperature, we used a professional thermometer immersed in the simulator and another thermometer, a digital one, for the diver's internal temperature. Their characteristics are given below.

The sensor immersed in the PROBE RTD GEN PURP 10 ANSI simulator, connected to the digital thermometer, has the following features:

- Temperature range: −40 ÷ 150 °C
- Response time: 4 sec
- ANSI connector
- Immersed stainless-steel sensor.

The thermometer - mobile digital hygrometer features:

- Temperature range: –50 ÷ 200 °C
- Response time: 1 sec
- 1.5 V AAA batteries
- Immersed external sensor.

The surface technical team continuously monitored the divers inside hyperbaric chambers, during the two series of diving, as it may be seen in Fig. 6.

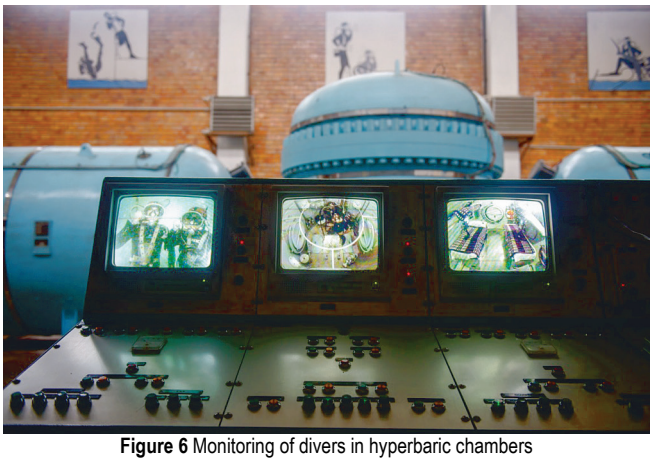

Figure 6 Monitoring of divers in hyperbaric chambers (Diving Center photo archive)

5 DISCUSSION OF THEORETICAL AND EXPERIMENTAL DATA

Experimental saturation diving is developed in the hyperbaric laboratory with a limited number of participants. Such experiments are hard to reproduce after a period, as the divers change, so it is difficult to compare the results. Therefore, we looked for divers with similar characteristics.

Only one of the divers that participated in the air diving series matched the main features of one of the divers diving in the Heliox series. They both had the same basic metabolic heat flux, of 88 W, the same height, of 1.78 m and the same body area, of 2.05 m^2. They were used to compare body temperature variation during air and Heliox diving, under name *diver 2,* in Tab. 1.

Table 1 Experimental data recorded during saturation diving with Heliox, at 61 m in depth. Divers performed moderate underwater effort (100 W)

Diver		1	2	3	4
Surface	t_i (°C)	24	24	24	24
	t_e (°C)	33.5	32.8	31	31.9
	t_c (°C)	36.5	36.7	37	36.5
Depth: 61 m	t_i (°C)	24	25	25	24
	t_e (°C)	34.5	34.1	34.1	34.2
	t_c (°C)	35.1	34.4	34.2	34.7
Exposure duration (min)		20	30	30	30

The data collected in Tab. 1 refer to the Heliox saturation diving, in water with the temperature T_w = 19.5 °C.

Regarding the body temperature variation during immersion, and the body temperature of a diver at the end of a certain exposure, it can be noticed a very good match between theoretical calculation and experimentally measured values, as shown in Tab. 2. The Eq. (6) proved a good prediction of the body temperature.

Table 2 Theoretical and experimental data at the end of a saturation diving with Heliox (61 m). Divers performed moderate underwater effort (100 W)

Diver		1	2	3	4
Initial body temperature (°C)		36.5	36.7	37	36.5
Exposure duration (min)		20	30	30	30
Body temperature at the end of the exposure (°C)	Theoretical	35.2	34.3	34.5	34.4
	Experimental	35.1	34.4	34.2	34.7

The relative error of the body temperature at the end of the immersion ranges between 0.3 and 1 %.

6 CONCLUSIONS

The interest in the diver's body temperature variation as a function of immersion duration, water temperature and the breathing mixture is justified by the importance of an appropriate preparation of the diver for diving, prior to immersion.

The multitude of physiological factors that influence the body temperature and the small number of subjects and experiments make the validation of the theoretical concepts very difficult.

Leaving the assumption that the absolute humidity depends only on pressure and not on body temperature, led to the improvement of the heat balance equation. The solution of the reshaped equation in which the absolute humidity has a linear variation with the body temperature proved to give a good prediction of the diver's body temperature. The experimental data measured during a saturation diving with Heliox 5/95, after 30 minutes of exposure showed a very good match with the theoretical values obtained for the body temperature, the relative error being comprised between 0.3 and 1 %. The new proposed equation may be used to assess the body temperature either with air or Heliox breathing mixture.

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7 REFERENCES

[1] Dinu, D. & Vlad, C. (1986). Scafandri şi vehicule subacvatice, Editura Ştiinţifică şi Enciclopedică, Bucureşti, pag. 88, 161-163.

[2] U. S. Navy. (2018). *Diving Manual*, Rev. 7, Vol. 1, Direction of Commander Naval Sea Systems Command, USA.

[3] Tarlochan, F. & Ramesh, S. (2005). Heat transfer model for predicting survival time in cold water immersion. *Biomedical Engineering: Applications, Basis and Communications - APPLICATIONS AND BASIS, 17*(04), 159-166. https://doi.org/10.4015/S1016237205000251

[4] Majchrzycka, A. (2011). Model of Thermal Comfort in the Hyperbaric Facility. *Polish Maritime Research*, 1(68), vol 18, pp. 37-44, 1233-2585.

https://doi.org/10.2478/v10012-011-0006-y
[5] King, F. G., Manson, H. J., Snellen, J. W. et al. (1984). Demonstration of a problem in estimating sensible heat loss from the respiratory tract by thermometry. *Can Anaesth Soc J, 31*, 460-465. https://doi.org/10.1007/BF03015426
[6] Volintiru, O. N., Scurtu, I. C., & Ștefănescu, T. M. (2018), Modeling and optimization HVAC system for special ships, IOP Conf. *Series: Journal of Physics Conf. Series 1122*, IOP Publishing. https://doi.org/10.1088/1742-6596/1122/1/012004
[7] Stanciu, T. & Diaconu, M. (2013). Experimental researches of thermal phenomenon during the saturation diving. *Annals of the Oradea University, Management and Technological Engineering, Oradea, XXII(XII)*(1), pp. 371. https://doi.org/10.15660/AUOFMTE.2013-1.2850
[8] Constantin, A. & Stanciu, T. (2015). Thermic transfers during saturation dive. *The 15th International Multidisciplinary Scientific GeoConference SGEM, Marine and Ocean Ecosystems*, Albena, Bulgaria, vol. 2, pp. 723-730, ISSN 1314-2704.
[9] Constantin, A. & Stanciu, T. (2013). Transient heat transfer in subsea hyperbaric environment. *The 13th International Multidisciplinary Scientific GeoConference SGEM, Marine and Ocean Ecosystems*, Albena, Bulgaria, pp. 871. https://doi.org/10.5593/SGEM2013/BC3/S15.008
[10] Stanciu, T. (2017). Validation of thermal balance equation of diver in hyperbaric environment at saturation with heliox. *Journal of Marine Technology, I*, pp. 45.
[11] Stanciu, T. (2018). Research on gas transfer in diving technologies, *PhD Thesis*, pp. 131, Library of Constanta Maritime University.
[12] Leonăchescu, N. (1981). *Termotehnica*, Editura Didactică şi Pedagogică, Bucureşti.

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Original scientific paper

Physical Asset Management in Equipment-Oriented Industries Using the Equipment Life Cycle Management Approach

Hassan Adshirinpour, Mohammad Mehdi Movahhedi*, Hedieh Divsalar, Shahla Sohrabi

Abstract: Proper assets management and maintenance, especially equipment in the value chain of an organization, the failure of which leads to interruptions in the system and waiting in the production line, are very vital and of special importance in "equipment-oriented" organizations, including industries such as oil, gas, petrochemicals, steel, minerals, companies involved in the production and distribution of water, electricity, etc. Usually such organizations have a constant need to create an efficient and effective life cycle in order to achieve an efficient physical asset management system. The present study aimed to investigate the physical assets management in equipment-oriented industries with the equipment life cycle management (resource-based) view in oil and gas industries with a case study in an upstream oil industry company (namely North Drilling Company). For this purpose, first 15 criteria have been obtained based on literature review and research literature for evaluating the performance of physical asset management in oil and gas companies. Then, eight of the most important performance evaluation criteria were determined based on experts' opinions and the fuzzy Delphi method, and in the next step, these criteria were weighted using the fuzzy SWARA method. According to the results, the most important criterion is the cost of maintenance and the least important is the cost of service-support. Finally, solutions are presented in the form of practical suggestions to improve the physical asset management system in this company.

Keywords: fuzzy Delphi; fuzzy SWARA; equipment life cycle; oil and gas equipment-oriented industries; physical asset management

1 INTRODUCTION

As one of the most important organizational assets, physical assets include financial, human, knowledge, and information technology assets that have four life cycle periods, namely acquisition, operation, maintenance, and retiring (decommissioning), which indicates the life of an equipment or a part from birth to the end of its life, in terms of the quality of operation of the equipment (less down time and more up time). The result of monitoring and managing the life cycle of equipment is to achieve high work efficiency and low cost of equipment life cycle, which will increase the profitability of stakeholders in the value chain of organizations in addition to creating high safety in equipment [1]. Accordingly, the organization's resources are grouped into five categories as follows, including financial, human, information technology, knowledge and physical assets:

1) Knowledge asset management
2) IT asset management
3) Human resource asset management
4) Financial asset management
5) Physical asset management

The physical asset management system has been studied from two perspectives in the United Kingdom and Canada. In the first model, Jon Wood House follows the Life Cycle Management emphasizing low equipment cost (LCC) and increased equipment efficiency (up time). In the second method, Jon Campbell from Canada applies the method of increasing the equipment reliability and accessibility so that the operation does not stop and the production line continues operating. In the present paper, a physical asset management system evaluation model is developed with an emphasis on the oil and gas industry and the Northern Drilling Company, as a leading company in the upstream oil industry, is investigated as the case study.

2 LITERATURE REVIEW AND RESEARCH BACKGROUND

In Standard Norg (2014) research, asset management is defined as "coordinated activity of the organization to realize the value of assets" and then an explanation is provided on the term "activity" and the term value realization. Activities can take many forms, tangible and intangible. Examples of activities related to the realization of asset value can include different sets of approach, planning and implementation of programs. When it comes to generating and gaining value because of improving asset management, it often includes balancing opportunities and risks as well as cost and performance [2]. Close attention should be paid to asset management by all stages of the life cycle, including planning, design, procurement, construction, operations, and disposal. Existing EAM processes are usually planned and executed during the asset life cycle. Therefore, the effectiveness of processes is reduced despite many efforts to introduce the process. An important operational task in the drilling industry, with high cost considerations worldwide, is effective management of drilling assets.

As an important operational task in the offshore environment, effective management of drilling assets is along with numerous cost considerations around the world. Offshore rigs, especially vessels, have far more valuable assets than a conventional or offshore drilling operation, including very valuable submarine assets. Although these assets have been attached to rigs for a long time, they are still brought from dock to rig and from rig to maintenance operations and inspection programs, as well as to support variable operational needs.

Today, oil and gas companies are deploying new technologies to achieve higher efficiency, and management is pushing engineers and maintenance to reduce budgets, labour, and operating costs as the production levels increase. There is also more exposure to a variety of risks in terms of health safety and the environment due to new challenges

facing operators in unusual and new geographical areas. Now more than ever, it is important to set the right policies and measures to meet compliance requirements and manage risk and security breaches efficiently and with cost-effective policies and measures for good asset management.

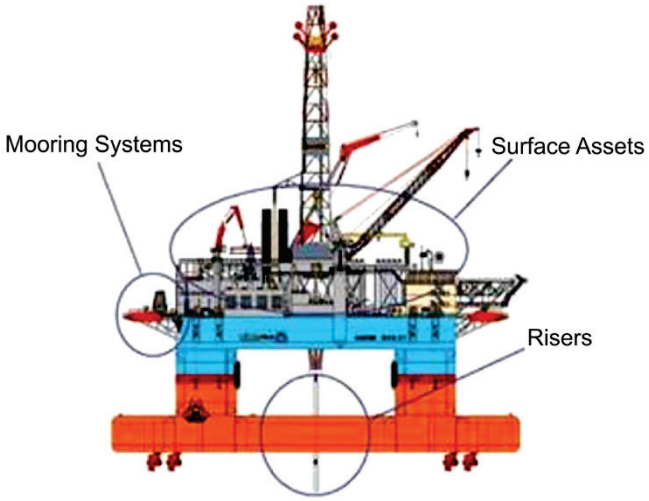

Figure 1 MR Riddle- NOV M / D Totco [3]

The following can be mentioned regarding the recent research on this issue [4].

Advanced maintenance management system by Vahedi et al. (2017) has been evaluated with the approach of physical asset management in South Pars Oil and Gas Complex of Iran. In this research, the combined method of balanced scorecard evaluation system and fuzzy hierarchical analysis process model have been used. According to the hexagonal system of balanced scorecard, evaluation criteria include internal processes, financial, organizational stakeholders, learning, employee satisfaction and the organization's environment. Measuring effectiveness coefficients of the evaluation criteria were performed through a fuzzy hierarchical analysis process model. Data were collected through interviews with oil industry experts in the field of physical asset management. Using a hexagonal score card system increases the probability of correctness of the results of the evaluation system. According to the results, internal and financial processes, organizational environment, learning, stakeholders of the organization, and satisfaction, with weights equal to 29%, 18%, 17%, 5%, and 2% show the performance of physical asset management system in the organization, respectively [5, 6].

Management performance in the field of physical asset management (PAM) has been evaluated by Khojastehpour et al (2020) in Iran Khodro Company. The researchers concluded that due to the existence of extensive and expensive equipment and the need for careful planning for their life cycle in the industries such as oil and gas, petrochemicals and automobiles, indicators related to evaluating asset management performance should be carefully selected and evaluated. Hence, it is better to consider items such as the extent to which objective goals are achieved, the timing of monitoring and measurement, quality and reliability in the performance evaluation [5].

A conceptual model of procurement strategy for the physical asset management framework has been developed by Joa et al. (2014) and the researchers believe that little research has been done on the physical asset management framework in the oil and gas industry. They developed a framework in this regard considering the theory of reliability and the Business Continuity Theory (BCT) and proposed their conceptual model from two perspectives of supply risk and strategic purchasing.

Physical asset management in the oil and gas industry with the smart asset management approach has been considered in the research of Nell et al. (2016). This article discusses the use of new concepts in the Internet of Things (IoT) and block chain in physical asset management. Also, by reviewing the management of intelligent physical assets in this industry, an attempt has been made to achieve the goal of the research, i.e. to make the industry aware of the potential of combining SAM with these concepts in strategic management decision making [6].

In a study conducted by Nixon et al. (2019), the evolution of physical asset management with respect to the topics of digitalization and new sciences has been studied and various analyses have been performed in this field. These researchers used the use of the Internet of Things and other new technologies, such as artificial intelligence, etc., in effective physical asset management, and found, for example, that insurance costs lead to a reduction and cost-effectiveness using the digitization approach. It saves about $750 billion in insurance companies around the world [7].

The challenges of asset integrity management in offshore rig drilling has been addressed in Mayang et al. (2016). In this paper, the challenges and possible factors affecting the management of asset integrity in offshore facilities have been identified and analysed in order to obtain the main reasons for these challenges and solutions to solve them using this research [8].

Accordingly, research on physical asset management and performance appraisal in the oil and gas industry is very limited. Therefore, the present study aimed to develop a model for evaluating the physical asset management system in oil and gas companies.

3 RESEARCH METHOD

The present study is an applied research, which is conducted with the descriptive survey and correlational approach. This research presents a model for evaluating the physical asset system, for which first the physical asset management evaluation indicators are extracted and selected using literature review and interviews with experts in this field and using the Delphi method. Then, with the help of ranking methods, it weighs these indicators to measure the performance of the physical asset management system in the oil and gas industry with an emphasis on the oil upstream and extraction industries. Finally, a case study of North Drilling Company as an oil upstream industry is provided and the evaluation of the physical asset system and its effects on key performance indicators identified in this study are discussed. Therefore, the present research method will be as follows:

- applied research in terms of the purpose
- descriptive-survey and correlational research in terms of data collection.

The statistical population of the present study includes all companies active in the field of oil and gas, and the statistical sample consists the Northern Drilling Company, which is one of the upstream oil companies in Iran.

4 DATA ANALYSIS

After a thorough review of the research theoretical foundations and a detailed review of recent research in the field of implementation and evaluation of physical asset system in companies with more focus on upstream and equipment-oriented oil and gas industries, the researcher has identified and extracted physical asset management indicators in equipment-based industries with the equipment life cycle management approach as follows (in Tab. 1).

Table 1 Physical asset management indicators in equipment-based industries

Row	Indicator	Reference
1	Maintenance and repair costs	[2], [5], [9], [10]
2	Success of asset management strategies	[12], [13], [3]
3	Equipment life cycle costs	[3], [13]
4	Improving waste management	[4], [14], [15]
5	Increasing sales volume	[5], [6]
6	Cost of capital	[6], [2], [1], [4]
7	Accessibility and reliability levels	[16], [17]
8	Manpower costs	[10], [2], [5]
9	Equipment risk taking	[18], [19], [2]
10	Facilitating observance of regulations	[20], [21]
11	Annual logistics fee	[22], [23], [5]
12	Cost of support services	[24], [9]
13	Reducing environmental warnings etc.	[4], [2], [5]
14	Increasing return on investment	[2], [17]
15	Spare parts service level	[10], [7], [6], [5], [15]

Then, the most important indicators were identified using fuzzy Delphi and fuzzy SWARA methods and were weighted in North Drilling Company.

20 out of 25 experts in the field of study participated in the present study. Details of the 20 experts are given in Tab. 2 in the Board of Experts section. Therefore, the questionnaire was distributed among them and they answered the questions carefully. In this step, the fuzzy value of each research question is calculated using the experts' opinions, and the fuzzy value of the answers to each question is obtained through triangular fuzzy numbers according to Tab. 2 too.

Table 2 Expert Panel Members & Research triangular fuzzy numbers definition

Type of activity of experts	QTY	Background and expertise in the field of physical asset management		
		5 to 7 years	7 to 10 years	More than 10 years
Deputies and senior managers and supervisors of the organization under study	20	4	7	9
Limits	Triangular fuzzy value of the i^{th} question of questionnaire			
Upper limit	maximum value allocated to the i^{th} question of questionnaire			
Intermediate limit	Geometric average of all expert opinions on to the i^{th} question of questionnaire			
Lower limit	The minimum value allocated to the i^{th} question of questionnaire			

Tab. 3 indicates the frequency of answers provided by these experts based on the 5-point Likert scale of the research questionnaire.

According to the table above, the fuzzy value of each question is considered as a triangular fuzzy number (U, M, L) so that the lower limit value of this triangular fuzzy number for each question is equal to the minimum value assigned by experts from the Likert scale (1 to 5); the middle of this fuzzy number is the calculation of the geometric mean of all expert opinions on the questions and the upper limit of this triangular fuzzy number is the maximum value assigned by experts from the Likert scale; the fuzzy value of each question is displayed in Tab. 4 below.

Table 3 Frequency of Likert scale answers to the research questionnaire

No. of question	Scale					No. of experts
	Very low (1)	Low (2)	Medium (3)	High (4)	Very high (5)	
20	11	6	2		1	1
20			5	7	8	2
20	4	14		2		3
20		1	5	10	4	4
20			2	7	11	5
20	2	13	3	1	1	6
20	12	6	2			7
20			1	6	13	8
20	1	16	2	1		9
20			5	7	8	10
20	7	10	3			11
20	10	9	1			12
20			3	3	14	13
20			1	12	7	14
20	2	14	4			15

According to the experts and the above table relating the threshold for items, where the score (defuzzified value) of each indicator is less than the average value (number 3) (red items in the above table) means that this indicator is less important and should be ignored. Seven indicators have a defuzzified value less than 3; so these indicators have been

removed and only 8 indicators have been considered by the researcher. According to Tab. 5 and the condition of consensus or agreement that 70% of the experts gave the same answer to one of the options for each question, the amount of consensus is examined, considering that the amount of consensus in the table below have not reached 70% of the consensus; so the second round of the questionnaire has started and the general results of the first questionnaire will be provided to the experts to answer the questions of the second questionnaire again according to the results of the first questionnaire.

Table 4 Fuzzy value of each question

No. of indicator	*U*	*M*	*L*
5	4.0998	1	1
3	1.6774	1	2
5	3.9024	2	3
4	1.9947	1	4
3	1.4225	1	5
5	3.5306	1	6
5	4.4433	3	7
3	1.3006	1	8
5	3.7962	2	9
3	1.6774	1	10
5	4.1422	3	11
5	4.4082	3	12
3	1.3083	1	13
3	1.6013	1	14
5	3.8615	3	15

Table 5 Evaluating the threshold of the first round questionnaire results

No. of indicator	Defuzzified value of each question	% of Consensus
55	3.5499	1
40	1.8387	2
70	3.7012	3
50	2.2470	4
55	1.7112	5
65	3.2653	6
60	4.2216	7
65	1.6503	8
80	3.6481	9
40	1.8387	10
50	4.0711	11
50	4.2041	12
70	1.6541	13
60	1.8006	14
70	3.9307	15

Based on Tab. 5, it is clear that indicators 2, 4 and 5, as well as 8, 10, 13 and 14 have not reached the consensus condition and are therefore considered as insignificant indicators.

Therefore, after removing the minor indicators and receiving expert opinions in the second step of the fuzzy Delphi method, the results of the studies are presented in Tab. 6.

According to the table above, all the fuzzy numbers of the questionnaires are all greater than the base number three for the new questions of the second round of the questionnaire, so this means that there are no minor questions in this second round of the questionnaire and on the other hand, the consensus percentage of all questions is also higher than the set value of 70%; so the consensus is accepted and there is no need to go to the third round of fuzzy Delphi.

Table 6 Assessing the threshold of the second round questionnaire results

Selected indicators	Defuzzified value of each question	% of Consensus
Annual maintenance and repair costs	70	4.5881
Equipment life cycle costs	80	3.9871
Cost of capital	70	4.0845
Accessibility and reliability levels	75	4.3305
Equipment risk taking	80	4.3412
Spare parts service level	75	4.6143
Annual logistics fee	85	3.7254
Cost of support services	70	4.3047

As it is clear, 5 of these indicators have covered the financial criteria and the other three indicators have shown the quality and performance criteria in evaluating the physical asset system in the oil and gas industry.

Second step of analysis: fuzzy SWARA

In the previous section, 8 out of the 15 identified indicators were agreed upon by experts. In other words, these 8 indicators are the most important in the field of physical asset management. Accordingly, in this step, the indicators are prioritized based on their weights. Five of the most specialized and experienced people were asked to answer the questions of the fuzzy SWARA questionnaire. The results are presented in Tab. 7.

Table 7 Analysis of fuzzy rider results

Selected indicators	w_j	q_j	k_j	b_j	*Global weight*
Annual maintenance and repair costs	0.400	(0.332, 0.461, 0.404)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)
Equipment life cycle costs	0.263	(0.237, 0.307, 0.242)	(0.714, 0.666, 0.599)	(1.4, 1.5, 1.667)	(0.4, 0.5, 0.66)
Accessibility& reliability levels	0.160	(0.192, 0.122, 0.165)	(0.580, 0.266, 0.408)	(1.23, 2.5, 1.465)	(0.23, 1.5, 0.46)
Cost of capital	0.080	(0.096, 0.061, 0.082)	(0.29, 0.133, 0.204)	(2, 2, 2)	(1, 1, 1)
Spare parts service level	0.048	(0.014, 0.003, 0.008)	(0.044, 0.008, 0.020)	(1.42, 1.373, 1.5)	(0.42, 0.37, 0.5)
Annual logistics fee	0.028	(0.062, 0.022, 0.059)	(0.189, 0.048, 0.148)	(1.53, 2.74, 1.37)	(0.53, 1.74, 0.37)
Equipment risk taking	0.013	(0.043, 0.014, 0.025)	(0.130, 0.032, 0.062)	(1.444, 1.5, 2.36)	(0.444, 0.5, 1.36)
Cost of support services	0.008	(0.020, 0.005, 0.012)	(0.063, 0.012, 0.031)	(2.04, 2.5, 2)	(1.04, 1.5, 1)

As it is clear, the annual maintenance costs with a weight of 0.400 have the highest weight or in other words, they are in the priority of the most important indicator in the management of physical assets in the study. The support services cost index with the weight of 0.008 has the lowest weight among the selected indicators.

4.1 Third Step of Analysis: Analysis the Gap between the Current and the Desired Situation

In the last step, a researcher-made questionnaire was distributed among managers, deputies, and senior experts of the company under study. From a total of 3,000 employees of the company, 341 were selected based on Morgan

sampling table at an error level of 0.05 and a questionnaire was distributed among them. Statistical Hypothesis: There is no gap between the current situation and the desired situation in the management of physical assets in the company under study. A model should be used in order to examine the research hypothesis that optimally explains the statistical hypothesis. Independent t-test is possible in a situation where a variable is examined in two statistical populations, in addition to the fact that one of the variables must be categorical (Momeni and Qayumi, 2008, pp. 71-72). However, the test used in this research is Paired sample T test. This is because this test compares two variables related to a community so that both populations must be quantitative, in addition to being a very suitable method for analysing the gap between variables and statistical hypothesis (Ibid., P. 77).

Table 8 Gap analysis with t test

Components and factors	Average opinions in the current situation	Average opinions in desired condition	Mean difference	Sig
Annual Maintenance and Repair Costs	0.000	–1.04	4.05	3.01
Equipment life cycle costs	0.000	–0.69	3.81	3.12
Spare parts service level	0.000	–0.5	3.62	3.12
Accessibility and reliability levels	0.000	0.98	3.80	4.78
Cost of Support Services	0.331	1.5	3.34	4.84
Procurement Costs	0.096	–0.18	3.89	3.71
Equipment Risk Taking	0.000	–1.06	3.71	2.65
Cost of Capital	0.201	0.6	3.67	4.27

According to the table above, 3 out of 8 components have a sig value greater than 0.05, which means that the claim about them is accepted. However, in other cases, the claim is rejected and there is a gap between the current and the desired situation. In the following, the physical assets of the studied company (North Drilling Company) were reviewed and evaluated in 2018 (before the implementation of physical asset management) and 2019 (after the implementation of physical asset management) using these indicators.

5 CONCLUSIONS

As an item, object, or entity that has potential or real value to the organization, the value of the asset varies between different organizations and their stakeholders and may be tangible or intangible, financial or non-financial, and may change during the life of the asset.

Through reviewing and improving processes, procedures and performance of assets, improving financial performance, risk management, improving services and products, improving customer satisfaction, increasing equipment safety and assisting managers in informed investment decisions on assets, physical asset management system significantly contributes to the effectiveness, efficiency and productivity, as well as improving the achievement of organizations' objective goals. The present study aimed to investigate and evaluate the physical asset management system in oil and gas equipment industries emphasizing the drilling industry. For a case study, the North Drilling Company has been selected as one of the upstream companies in the oil industry. Eight indicators have been selected as important indicators for evaluating the physical asset system in oil and gas equipment industries. Fig. 2 shows the graph of expert opinions using the fuzzy Delphi method.

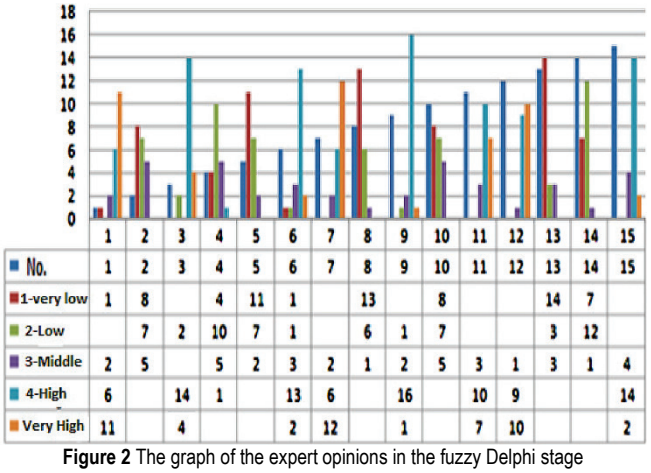

Figure 2 The graph of the expert opinions in the fuzzy Delphi stage

According to the Tab. 5 and the fact that the condition of consensus or agreement was that 70% of the experts gave the same answer to one of the options for each question, the amount of consensus was examined; considering that the amount of consensus in the table below is some questions, the questionnaire did not reach the 70% consensus level, so the second round of the questionnaire started and the general results of the first questionnaire were presented to the experts and again, according to the results of the first questionnaire, they answered the questions of the second questionnaire.

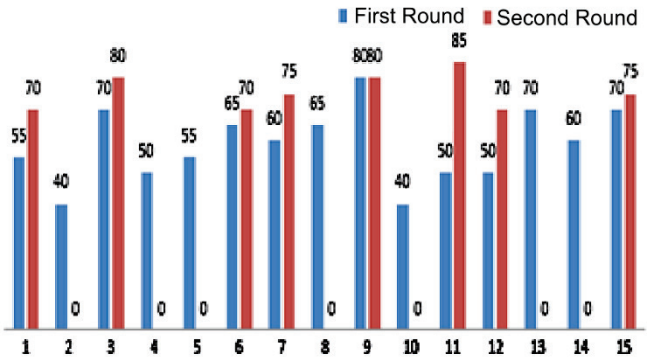

Figure 3 Comparison of opinion consensus and threshold in two fuzzy Delphi

The indicators whose threshold is less than 0.70 in the first round have been removed from the second round and their value is considered zero. Annual maintenance costs, equipment life cycle costs, capital sleep costs, monthly access and reliability levels, equipment risk, annual logistics costs, support service costs and spare parts service levels are eight indicators agreed upon by experts. Second, the fuzzy SWARA method was used to weigh the indices and

determine the importance of each index. The weight obtained was determined based on the following graph.

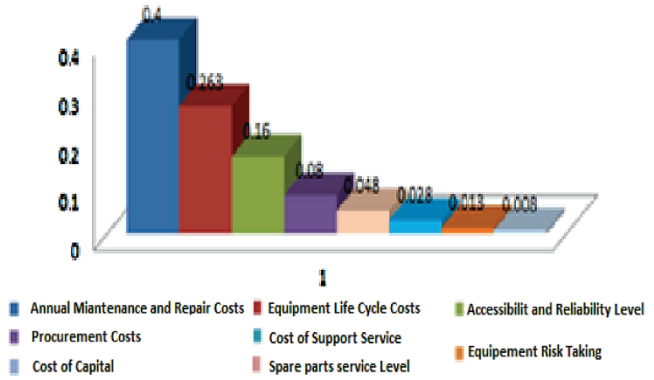

Figure 4 Weight of indicators in the second stage

Annual maintenance and repair costs with a weight of 0.400 have the highest weight or in other words in priority the most important indicator in the management of physical assets in the study area. The cost of support services index with a weight of 0.008 has the lowest weight among the selected indicators. Finally, in the third step, the gap between the current and desired situation was analysed based on the selected indicators in the studied company. At this stage, analyses were performed based on the population and the selected statistical sample and sample t-test. From the eight selected indicators, equipment risk indicators, annual procurement cost, and spare parts service level with the significance of 0.331, 0.096, and 0.201, respectively, have no gap between them. However, about other indicators, there is a gap between the current and the desired situation. In order to better study and compare its future results with this research, the following subjects are suggested to the researchers:

- Explaining the performance evaluation model utilizing other models of physical assets in the oil and gas industry
- Evaluating and prioritizing physical asset development indicators with approaches other than resource-based view and utilizing fuzzy SWARA, fuzzy EDAS and other methods.
- Investigating and explaining the control of costs related to drilling services in order to improve the physical asset management system

6 REFERENCES

[1] PAS 55-1:2008. (2008). *Asset Management*, Part 1: Specification for the optimized management of physical assets, Institute of Asset Management (IAW), ICS code: 03.100.01

[2] … (2019). Strategic document for the management of physical assets of the Ministry of Oil.

[3] … (2019). General policy document and requirements of the physical assets management system of the Ministry of Oil - approved by the High Official of the Ministry.

[4] The book "TPM" by Nasser Mohammadi Jalali and Dr. Mehpikar of the National Library of Iran, TS-678-2 92

[5] PAS 55-2:2008, Asset Management. (2008). ICS code: 03.100.01 No Copying without BSI Permission except as Permitted by Copyright Law Part 2: Guidelines for the application of PAS 55-1

[6] Asset Management Consulting Limited (AMCL). (2013). A report for the Office of Rail Regulation and Network Rail from: 350 Pages

[7] Gupta, R. K. (2013). Process Based Business Excellence Model. *Asian Journal of Research in Business Economics and Management, 3*(5), 132-149.

[8] … (2014). *The Asset Management Landscape*, second edition, English version, Global Forum on Maintenance and Asset Management (GFMAM), https://gfmam.org/sites/default/files/2019-05/GFMAMLandscape_SecondEdition_English.pdf

[9] Campbell, J. D., Jardine, A. K. S., & McGlynn, J. (2015). *Asset Management Excellence: Optimizing Equipment Life-Cycle Decisions*, third edition, 470 pages.

[10] … (2017). Asset Management & Performance Metrics Collaborative, IPL, Cause No. 44602/44576, 1-173. https://www.in.gov/iurc/files/2017-03-31,-044576_IPL_Compliance-Filing-Asset-Management-And-Performance-Metrics-Collaborative.pdf

[11] Creamer, J. (2020). Integrated Upstream Asset Management. Empowering Pumps & Equipment Staff. https://empoweringpumps.com/schneider-electric-integrated-upstream-asset-management/

[12] Klabnik, S. (2012). Asset Life Cycle Management Optimizes Performance, Exclusive Story.

[13] Vahedia M. & Movahedi, M. M. (2018). Evaluating and Prioritizing Asset Management Excellence Model Based on Critical Criteria Using the Combination of DEMATEL and ANP Techniques. *PBR (Petroleum, Business, Review), 2*(3), 56-65.

[14] Asurdzic, N. (2019). Physical Asset Management of Complex Infrastructures: Strategies, methodologies and tools for Effective Service Management. http://summerschool-aidi.it/edition-2015/images/paper2012/2.5.pdf

[15] Campbell, J. D. (1999). Uptime: Strategies for Excellence in Maintenance Management. Eisenhardt, M. K. (1989). Agency theory: An assessment and review. *Academy of Management Review, 14*(1), 57.

[16] Forza, C. (2002). Survey research in operations management: a process-based perspective. Università di Padova, Vincenca, Italy, International *Journal of Operations & Production Management, 22*(2). 152-194.

[17] Fulmer, J. (2009). What in the world is infrastructure? *Guest article investment strategy, PEI Infrastructure Investor*, 30-32.

[18] ... (2006). Engineering Asset Management. *Proceedings of the 1st World Congress on Engineering Asset Management (WCEAM)*, 11-14 July 2006, Editors: Mathew, J., Kennedy, J., Ma, L., Tan, A., & Anderson, D. Springer, 163-168.

[19] Miller, D. & Friesen, P. H. (1982). Innovation in Conservative and Entrepreneurial Firms: Two Models of Strategic Momentum. *Strategic Management Journal*, 3, 1-25.

[20] Mollentze, F. J. (2005). *Asset Management Auditing – The Roadmap to Asset Management Excellence*, Department of Engineering and Technology Management, University of Pretoria, South Africa.

[21] Jabiri, N. Z., Jaafari, A., Platfoot, R., & Gunaratram, D. (2005). Promoting Asset Management Policies by Considering OEE in Products' TLCC Estimation. *Proceedings. 2005 IEEE International Engineering Management Conference, Vol. 2*, 480-484. https://doi.org/10.1109/IEMC.2005.1559194

[22] Emmanouilidis, C. & Komonen, K. (2013) Physical Asset Management Practices in Industry: Comparisons between Greece and Other EU Countries. In: Prabhu V., Taisch M., Kiritsis D. (eds) Advances in Production Management

Systems. Sustainable Production and Service Supply Chains. APMS 2013. IFIP Advances in Information and Communication Technology, vol. 415. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-41263-9_63

[23] Vahedi, M. & Movahedi, M. M. (2018). Evaluating and Prioritizing Asset Management Excellence Model Based on Critical Criteria Using the Combination of DEMATEL and ANP Techniques. *PBR (Petroleum, Business, Review), 2*(3), 56-65. http://pbr.put.ac.ir/article_93429_c4e7b6a331c704c55b0b710ad12c8a27.pdf

[24] Kagiso Le Tswelelopele. (2019). Volume 6: *Movable Asset Management*. Accessed: http://www.nwpg.gov.za/treasury/procurement2/documents/SCM%20PRACTITIONER%20AREA/SCM%20Policy%20Management/Blue%20print%20system/VOLUME%206.pdf

[25] Lee, W.-B., et al. (2004). System Oriented Plant Maintenance, KHNP. https://doi.org/10.4028/www.scientific.net/KEM.297-300.2693

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Original scientific paper

The Capacitated Multiple Allocation Hub Location Problem under Demand Uncertainty and Excess Capacity with Possibilistic Programing Approach

Mohammad Reza Shahraki*, Shima Shirvani

Abstract: Facility location is a factor of competitiveness and demand satisfaction. Using a hub on the network can facilitate communication across the network and reduce costs. In the current study, with regards to demand uncertainty, operational costs of the hub, and building extra capacity in the hub it has been aimed to develop a mathematical programing model for the middle hub location problem with a certain capacity,. Due to the presence of the uncertainty in the problem's parameters, the possibilistic programing approach which is a subset of fuzzy programing has been used. The proposed model has been investigated via GAMS software and the CPLX solver. Finally, the proposed model has been validated by the dataset obtained from Iran Aviation Dataset (IAD) for a round-trip, and the proper locations for facilities in each level and allocation of the customers to the facilities, were determined by the obtained Pareto analysis answer.

Keywords: capacity**;** constraint; hub location; possibilistic programing; uncertainty

1 INTRODUCTION

The hubs are specific facilities that serve as the centers for transfer, coordination, and integration in the distribution systems. The research on locating and designing the hub network has been significantly improved during the last two decades. In the complex systems of transportation, communication, and computer systems, there are many points as the origin and destination among which the flow is exchanged. The hub is doing for such purpose [1]. Each of the network nodes is connected to one or several hubs and the hubs, by the use of these links as well as the links, which exist between them, can transfer the flow of information or goods. There is a very large set of points in the hub networks and the use of hubs has led the link between them to be established with a very low number of the links [2].

During recent years, the research on the hub points location has found an important position in the discussion of the location. It has been the result of the increasing use of hub points network in the modern systems of transportation and communication. Such systems try to meet the trip demands or connect the origin and destination in a way that large-scale economization is feasible. The use of the hub enables a higher number of origins and destinations to connect with fewer links. On the other hand, using fewer links in the network leads to the concentration of flow and makes the proper-scale economization viable [3]. The hub location problem was first introduced in the communication and transportation industries in which existed several transmitters and receivers. The system efficiency in transportation is increased by the use of hub points in which the products are collected from the origins and distributed in the destinations. Regarding the vast usages of the hub points networks as well as the product costs index in the competitive market, the study of hub points location is of great importance [4].

In the second section, the research on hub points location has been addressed and in the third section, a certain and uncertain model of hub location would be addressed. The analysis of the results based on the proposed model under the fuzzy conditions has been done in the fourth section. The conclusion and suggestions are provided in the fifth section.

1.1 Review of the Related Literature

The hubs are special facilities used as the exchange, transfer, and classification points in a large number of distribution systems. The hub facilities, instead of serving between each origin-destination pair, concentrate the flows to use economizations generated by it. The flows are combined with a hub from the same origin with different destinations on their paths, and then, they are combined with the flows with different origins and same destination. In the hub location problems, the flows between the origins and destinations are indicative of the demand and the hubs act as the connection or integration points [5]. Many researchers have studied and compared the issues related to the hub location such as the different strategies of direct transfer or transfer by different terminals as well as the problems related to the route design [6]. Hekmatfar and Pishvaee [7] have dealt with the Hub Location Problems (HLP). The focus of the articles has been initially on the modeling and then its optimization under different conditions [8].

The research conducted on the hub location can be classified into three general categories of the simplification of the mathematical model and provision of a new model with new variables and constraints, provision of new solving methods, and changing the model and making it functional. The existing literature about the hub location problem indicates that the researchers' approach dealing with this subject has been a quantitative one and the qualitative discussions in this field have been rarely addressed. Different types of the problems investigated in the articles are categorized under three categories of problems as middle hub location (with the fixed costs of establishment and without them), the central hub, and the covering hub [7]. Among the features of these problems, the problem space (continuous, discrete, and combinational) and the type of the problem's certainty (certain, probable, and fuzzy) can be mentioned.

The hypotheses which are the main distinctions between most of the articles include the building and establishment costs (constant or variable), number of the hubs (definite or indefinite), the nodes and arcs capacity (limited or unlimited capacity), and the type of allocation of the non-hub to hub nodes (single-allocation or multiple0allocation). The type of the objective function also, based on the problem modeling, can be single or multi-objective and the minimization (cost or time) and maximization (service or reliability) have been considered. After the establishment of the mathematical model, the used solving methods (accurate, innovative, meta-innovative) can create another classification for the problems [9].

Chen [10] proposed a linear whole number model for a single-allocation middle hub location with limited capacity and an indefinite number of hubs with a constant cost of expression hub establishment. He also provided an innovative solution for IT 5. De Sá et al. [11] proposed a linear whole number model for the location of a single-allocation p-middle hub with limited capacity. Taghipourian et al. [12] dealt with the investigation of hub location problems approach by the use of linear whole number programming. Mohammadi et al. [13] dealt with the investigation of the hub location problems by the use of the colonial competitive algorithm. Yang et al. [14] modeled the p-hub by the use of a genetic algorithm which included local search. Masaeli et al. [4] dealt with transportation programing in hub location problems. Paul et al. [15] investigated a multi-objective problem with the maximum covered problems to the hierarchical location change. Golestani et al. [33] presented a multi-objective green hub location problem with several different temperatures for perishable products.

Mokhtar et al. [2] proposed a model for solving the hub location problems. Eghbali-Zarch et al. [16] investigated the problem of locating the hub by considering the M/G/C queue system. Considering congestion in hubs under uncertainty, they presented a new mixed-integer linear programming model for an HLP with a ring-structured hub network. Wasner and Zäpfel [17] dealt with the programing and optimization of a hub routing model for post-service vehicles. Fernández and Sgalambro [34] examined hub location problem by considering several telecommunications companies.

Mohammadi et al. [18] dealt with the hub location problems by the use of game theory and fuzzy numbers. Zhalehchian et al. [19] dealt with the hub location investigation by the use of an evolutionary algorithm. Ernardes Real et al. [20] dealt with the hub location problems in the aerial networks. Wu et al. [35] selected the market to examine the hub location problem.

Gelareh et al. [21] dealt with the investigation of the hub location problems in transportation. Sadeghi et al. [22], using an artificial bee colony algorithm, investigated the problem of p-hub coverage with reliable travel time. Mohammadi et al. [1] dealt with hub location problems using a metaheuristic hybrid.

Regarding the mentioned research in the field of middle hub location, the objective function has been the minimization of the transportation and hub establishment costs. In the current study, in addition to these costs, the costs for building extra capacity and the operational costs inside the hub have been also considered, and the demand parameters, operational costs, and costs for creating extra capacity inside the hub in the uncertainty and fuzzy conditions have been investigated. In the current study, a mathematical programing model for middle hub location problem with the definite capacity and uncertainty in demand, operational costs of the hub, and costs for building extra capacity have been developed. To encounter the problem uncertainty, a possibilistic programing approach which is a subset of fuzzy programing has been used.

2 METHODOLOGY

In terms of the type of allocation, the hub location minimization problems can be divided into single-allocation and multi-allocation hub locations. These two models have approximately the same objective with different constraints. In the current study, the development of a fuzzy model for multi-allocation middle hub location problems with limited capacity has been investigated. The model proposed in this section is developed from the Skorin-Kapov et al. [23] reference model.

Sets and indices
Nset of nodes
nset of hub type
inode number index Nt∈
jnode number index NJ∈
khub number indexNK∈
lhub number indexNI∈

Decision-making variables:

W_{ij} The demand rate with the flow between the i and j groups
C_{ijkl} The cost of good transfer from group i to group j by hubs k and l
F_{kn} The constant cost of hub establishment from the n-type in node k
g_{kn} The variable cost of establishment of each unit of hub capacity from the n-type in node k
$\bar{Q}_{kn}$ The maximum annual capacity of goods crossing in the hub from the type n in node k
$\underline{Q}_{kn}$ The minimum annual capacity of goods crossing in the hub from the type n in node k
Cp_{kn} The operational cost including the separation and preparation costs in the hub from the type n in the k^{th}
Y_{kn} If in the k node, an n-type hub is established, the value will be 1 and if not, the value will be 0.
X_{ijkl} The shortage from the sent flow from i to j which is transferred by k and l hubs.
Q_{kn} The quantity of existing goods from the n-type in the k hub

Parameter

2.1 The Certain Model of the Problem

The allocation in the current study is multi-type and any non-hub point can be linked to more than one hub. The number of hubs is not predetermined and the direct link between the hubs is not allowable, and the hub network is complete. The problem space is discrete. The objective function is minimization and single-objective and the arcs capacity is infinite.

The costs for building extra capacity as well as the operational costs inside the hub have been also considered. The parameters and variables added to the basic model are as follows:

- There is a different operational cost in each hub.
- There is a different extra capacity building cost in each hub.
- The operational and extra hub capacity building costs, as well as the demand costs, have been considered as uncertain.
- There are several hub type options for building the hub in a location.

The decision-making variables and indices are initially introduced for mathematical modeling of the problem under study. The objective function is the minimization of total costs including the transportation, hub establishment, extra hub capacity, and operational costs inside the hub. The constraint (2) guarantees that all W_{ij} demand would be supplied. Constraint (3) means that in each site, a maximum of one type of hub can be established. Constraints (4) and (5) indicate that X_{ijkl} would have a value when it is developed in nodes k and l. Constraint (6) is indicative of the quantity of hubs in the hub k. The first part is the total number of goods input to the hub and the second part is the total number of goods output from it. Constraint (7) is a lower limit and suggests a maximum limit for the number of the goods inside hub k. Constraints (8) indicate the non-negative and without shortage flow and the quantity of the existing goods in the hub. Constraint (10) also shows the binary state of the hub building variable.

$$\text{Min } z = \sum_{i\in N}\sum_{j\in N}\sum_{k\in N}\sum_{l\in N} W_{ij}C_{ijkl}X_{ijkl} + \sum_{n}\sum_{k\in N} F_{kn}Y_{kn} + \\ + \sum_{n}\sum_{k\in N} F_{kn}Y_{kn} + \sum_{n}\sum_{k\in N} g_{kn}Q_{kn} + \sum_{n}\sum_{k\in N} Cp_{kn}Q_{kn} \quad (1)$$

$$\sum_{k\in N}\sum_{l\in N} X_{ijkl} = 1 \qquad \forall i, j \qquad (2)$$

$$\sum_{n} Y_{kn} \le 1 \qquad \forall k \qquad (3)$$

$$\sum_{l\in N} X_{ijkl} \le \sum_{n} Y_{kn} \qquad \forall i, j, k \qquad (4)$$

$$\sum_{k\in N} X_{ijkl} \le \sum_{n} Y_{ln} \qquad \forall i, j, k \qquad (5)$$

$$\sum_{i\in N}\sum_{j\in N}\sum_{l\in N} (W_{ij}X_{ijkl} + W_{ji}X_{jikl}) \le \sum_{n} Q_{kn} \qquad \forall k, n \qquad (6)$$

$$\underline{Q}_{kn}Y_{kn} \le Q_{kn} \le \overline{Q}_{kn}Y_{kn} \qquad \forall k, n \qquad (7)$$

$$\underline{Q}_{kn} \ge 0 \qquad \forall k, n \qquad (8)$$

$$X_{ijkl} \ge 0 \qquad \forall i, j, k, l \qquad (9)$$

$$Y_{kn} \in \{0, 1\} \qquad \forall k, n \qquad (10)$$

2.2 The Uncertain Model of the Problem

There are several methods to encounter uncertainties including the mathematical optimization methods, AI-based methods, simulation-based methods, and combined methods [24].

In the current study, the mathematical optimization approach has been used for the application of the uncertain conditions of the parameters. This method of encountering the uncertainty has been developed by the researchers [25].

The possibilistic programing method is used when there is not enough knowledge about the exact values of the input data or parameters due to a lack of access to the needed data or their inadequacy.

In this regard, proper possibilistic distributions based on the existing objective data and the subjective preferences of the decision-maker are introduced for modeling the vague data in the form of fuzzy numbers. These possibilistic distributions are indicative of the possibility of occurrence of different values of parameters based on the existing historical data or the experts' opinions, or both. The possibility distribution is indicative of the possibility rate of possible values occurrence for each parameter in the uncertain state. It is usually determined based on experts' opinions and the existing data on the intended parameter [26].

Fig. 1 shows a trapezoidal possibility distribution in the form of ε_1, ε_2, ε_3 and ε_4. The points ε_1 and ε_4 are indicative of the most pessimistic and most optimistic possible values, respectively. The points ε_2 and ε_3, and their distance, are indicative of the most possible values which are determined by the decision-makers and the experts based on the existing data and personal knowledge. In the current study and based on the type of the problem being investigated, a trapezoidal fuzzy number has been used for modeling the parameters with uncertainty.

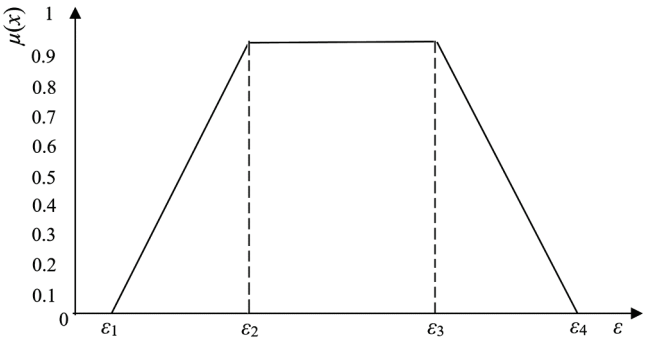

Figure 1 Trapezoidal possibility distribution of uncertain parameter $\tilde{\varepsilon}$

In the possibilistic programing problems, there is one possibilistic distribution function considered for each of the uncertain parameters. In the literature related to the fuzzy models, several methods have been presented to encounter

the fuzzy models with uncertain coefficients in constraints and objective functions. The method proposed by Liu has been used in the current study to change the proposed models into their definite counterparts.

Generally, the credit-based chance-constrained programming method is one of the sufficient possibilistic programing methods which has the following advantages [27]:

1) It is based on credible mathematical concepts such as the expected distances and mathematical expectation of the fuzzy numbers. Therefore, it has a strong mathematical ground.
2) It is designed based on the general rating method proposed by Liu [27] and can be applied to uncertain parameters with different fuzzy membership functions such as the triangular and trapezoidal functions. It can be also applied to non-linear membership functions in both symmetric and asymmetric states.
3) It enables the decision-maker to adjust the confidence level of constraints satisfaction and helps him to satisfy some chance constraints in the minimum confidence level.
4) The most significant advantage of this method is the use of credit measure which, opposed to the location and necessity measure that lacks the self-duality feature, is a self-dual measure [28]. In other words, when the credit measure is equal to 1, the decision-maker believes that the fuzzy event would occur. In addition, when the credit measure is equal to 0, he would believe that the fuzzy event will not occur (theoretically). However, when the fuzzy event possibility is equal to 1, there is still the possibility that the event won't occur. Besides, when the necessary measure of a fuzzy event is equal to 0, theoretically, there is no guarantee that the event will not occur.

Assume that $\bar{\varepsilon}$ is a fuzzy variable with the membership function of $\mu(x)$, and r is a real number, the credit measure is defined as Eq. (11) [29].

$$C_r\{\bar{\varepsilon} \le r\} = \frac{1}{2}\left[\underset{x \le r}{sup}\,\mu(x) + 1 - \underset{x > r}{sup}\,\mu(x)\right] \tag{11}$$

Since the possibility measure is equal to $pos\{\bar{\varepsilon} \le r\} = sup\,\mu(x),\ x \le r$ and necessity measure is equal to $Nec\{\bar{\varepsilon} \le r\} = 1 - sup\,\mu(x),\ ,\ x > r$, the credit measure can be defined as Eq. (12):

$$C_r\{\bar{\varepsilon} \le r\} = \frac{1}{2}\left[pos\{\bar{\varepsilon} \le r\} + Nec\{\bar{\varepsilon} \le r\}\right]. \tag{12}$$

Eq. (12) indicates that the credit measure is, in fact, the mean of the possibility and necessity measures. In addition, concerning the proposed definitions, Eq. (13) expresses the mathematical expectation of variable $\bar{\varepsilon}$.

$$E[\bar{\varepsilon}] = \int_0^{\infty} C_r\frac{1}{2}\{\bar{\varepsilon} \le r\}\,dr - \int_{-\infty}^{0} C_r\frac{1}{2}\{\bar{\varepsilon} \le r\}\,dr \tag{13}$$

Now assume that $\bar{\varepsilon}$ is a trapezoidal fuzzy number as $\bar{\varepsilon} = (\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4)$, then based on the Eqs. (12) and (13), the mathematical expectation of this fuzzy number is $(\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4)/4$ and its credit measure is in the form of Eqs. (14) and (15).

$$C_r\{\bar{\varepsilon} \le r\} = \begin{cases} 1 & r \in (-\infty, \varepsilon_3) \\ \dfrac{r-\varepsilon_1}{2(\varepsilon_2-\varepsilon_1)} & r \in (\varepsilon_1, \varepsilon_2] \\ \dfrac{1}{2} & r \in (\varepsilon_2, \varepsilon_3] \\ \dfrac{r-2\varepsilon_3+\varepsilon_4}{2(\varepsilon_4-\varepsilon_3)} & r \in (\varepsilon_3, \varepsilon_4] \\ 1 & r \in (\varepsilon_4, \infty] \end{cases} \tag{14}$$

$$C_r\{\bar{\varepsilon} \le r\} = \begin{cases} 1 & r \in (-\infty, \varepsilon_3) \\ \dfrac{2\varepsilon_2-\varepsilon_1-r}{2(\varepsilon_2-\varepsilon_1)} & r \in (\varepsilon_1, \varepsilon_2] \\ \dfrac{1}{2} & r \in (\varepsilon_2, \varepsilon_3] \\ \dfrac{\varepsilon_4-r}{2(\varepsilon_4-\varepsilon_3)} & r \in (\varepsilon_3, \varepsilon_4] \\ 0 & r \in (\varepsilon_4, \infty] \end{cases} \tag{15}$$

Based on the Eqs. (14) and (15), for each $0.5 > \alpha$, the following expressions are provable [30]:

$$C_r\{\bar{\varepsilon} \le r\} \ge \alpha \leftrightarrow r \ge (2-2\alpha)\varepsilon_3 + (2\alpha-1)\varepsilon_4 \tag{16}$$

$$C_r\{\bar{\varepsilon} \ge r\} \ge \alpha \leftrightarrow r \ge (2\alpha-1)\varepsilon_1 + (2-2\alpha)\varepsilon_2 \tag{17}$$

$$C_r\{\bar{\varepsilon} = r\} \ge \alpha \leftrightarrow r \ge \left[2\left(\frac{\alpha}{2}\right)-1\right]\varepsilon_1 + \left[2-2\left(\frac{\alpha}{2}\right)\right]\varepsilon_2 \tag{18}$$

$$C_r\{\bar{\varepsilon} = r\} \ge \alpha \leftrightarrow r \ge \left[2-2\left(\frac{\alpha}{2}\right)\right]\varepsilon_2 + \left[1-2\left(\frac{\alpha}{2}\right)\right]\varepsilon_3 \tag{19}$$

The Eqs. (16) and (17) can be directly used for changing the fuzzy chance constraints into their definite counterparts. It should be noted that Liu [27] has also proposed expressions like what was mentioned under the title of α critical values for changing the fuzzy chance constraints into their definite counterparts.

The uncertainty parameters in the model include the followings:

W_{ij} is the demand rate or the sent flow between the groups i and j. The following parameters are indicative of the trapezoidal fuzzy numbers of the demand rate:

$\left(W_{ij}^1, W_{ij}^2, W_{ij}^3, W_{ij}^4\right)$

Cp_{kn} is the operational cost. The following parameters are indicative of the trapezoidal fuzzy numbers for operational as follows:

$\left(Cp_{kn}^1, Cp_{kn}^2, Cp_{kn}^3, Cp_{kn}^4\right)$

g_{kn} is the variable cost of building each extra unit of capacity in the hub from the type n in node k. The following parameters are indicative of trapezoidal fuzzy numbers of costs of building each extra unit of capacity in the hub:

$\left(g_{kn}^1, g_{kn}^2, g_{kn}^3, g_{kn}^4\right)$

In the current study, a combined approach of credit-based possibilistic programing which uses the mathematical expectation for modeling the objective function and a chance programing approach for modeling the constraints have been applied. This model, unlike the chance-dependent programming approaches [31, 32], has not increased the number of the basic model's constraints and does not need extra information about the objective function (such as the confidence level or ideal value). In addition, this model lacks the disadvantages of chance programming and chance-dependent programming methods. It is also possible to use these methods' advantages in controlling the constraints [26]. Regarding the mentioned approach, the uncertain model would be as follows:

$$\text{Min } z = \sum_{i\in N}\sum_{j\in N}\sum_{k\in N}\sum_{l\in N}\left(\frac{W_{ij}^1+W_{ij}^2+W_{ij}^3+W_{ij}^4}{4}\right)C_{ijkl}X_{ijkl} + \\ +\sum_{n}\sum_{k\in N}F_{kn}Y_{kn} +\sum_{n}\sum_{k\in N}\left(\frac{g_{kn}^1+g_{kn}^2+g_{kn}^3+g_{kn}^4}{4}\right)Q_{kn} + \\ +\sum_{n}\sum_{k\in N}\left(\frac{Cp_{kn}^1+Cp_{kn}^2+Cp_{kn}^3+Cp_{kn}^4}{4}\right)Q_{kn} \quad (20)$$

$$\sum_{k\in N}\sum_{l\in N}X_{ijkl}=1 \qquad \forall i,j \qquad (21)$$

$$\sum_{n}Y_{kn}\le 1 \qquad \forall k \qquad (22)$$

$$\sum_{l\in N}X_{ijkl}\le\sum_{n}Y_{kn} \qquad \forall i,j,k \qquad (23)$$

$$\sum_{k\in N}X_{ijkl}\le\sum_{n}Y_{ln} \qquad \forall i,j,k \qquad (24)$$

$$\sum_{i\in N}\sum_{j\in N}\sum_{l\in N}\left[(2-2a_{kn})W_{ij}^3+(2a_{kn}-1)W_{ij}^4\right]x_{ijkl} + \\ +\sum_{i\in N}\sum_{j\in N}\sum_{l\in N}\left[(2-2a_{kn})W_{ij}^3+(2a_{kn}-1)W_{ij}^4\right]x_{ijkl}\le\sum_{n}Q_{kn} \quad (25)$$

$$\underline{Q}_{kn}Y_{kn}\le Q_{kn}\le\bar{Q}_{kn}Y_{kn} \qquad \forall k,n \qquad (26)$$

$$\underline{Q}_{kn}\ge 0 \qquad \forall k,n \qquad (27)$$

$$X_{ijkl}\ge 0 \qquad \forall i,j,k,l \qquad (28)$$

$$Y_{kn}\in\{0,1\} \qquad \forall k,n \qquad (29)$$

$$0.5\le\alpha\le 1 \qquad \forall k \qquad (30)$$

3 RESULTS AND DISCUSSION

In this section, the data obtained from the IAD (considering 20 nodes) have been used via the proposed model, so that the performance and efficiency of this model will be investigated. The data in the references are the data on the demands for a trip from each province to another. Therefore, for the calculation of the transfer costs between the origin and destination, the discount factor for transfers between the hubs have been generated. In the classic problems of hub point location, the costs for hub-to-hub arcs transfer are decreased with a constant discount factor generically. In this problem, the discount factor has been considered to be 0.7. With the assumption that in each center, three types of hubs with different costs and capacities can be built, the data which are not available (Tab. 1) have been generated in invariable intervals, each in three levels.

The GAMS software Ver.24.1.3 has been used on a computer with 4 gigabytes of RAM and Core i5 2.6 GHz CPU.

Table 1 The data used in the problem

Row	Data type	Data value
1	Demand flow	Available
2	Distance	Available
3	Building cost	An invariable interval [400 and 750]
4	Capacity building cost	An invariable interval [65 and 35]
5	Maximum capacity	An invariable interval [9000 and 125000]
6	Minimum capacity	An invariable interval [900 and 2100]
7	Operational cost	An invariable interval [45 and 75]

As was mentioned in section three, α is the confidence level value, which is the uncertain parameter constraint per α percent of the feasible events. On the other hand, this coefficient can take 0.5 to 1 values. The α factor is analyzed twice in the current study in a way that once it is considered as the variable to determine the value the model itself obtains, and once it has been taken as a parameter. In the latter state, different values are allocated to the parameter and the results have been analyzed. In fact, with the increase in α value, risk-taking of the decision-maker is also increased and in fact, it indicates that how much we are willing to cost and risk so that the constraint with the uncertain parameter be feasible with the higher confidence level and satisfy the decision-maker's confidence level. To respond to the research questions, the model solving results are demonstrated in tables and figures in a way that the hub points in each phase of problem-solving, and the allocated nodes, as well as the objective costs, have been investigated.

3.1 Factor α as the Variable

In this mode, the factor α is treated as a variable and the model itself would obtain its value. The results are shown in Tab. 2 and Fig. 2. The results indicate that the model since

the objective function has been minimized has obtained the minimum α value to have the lowest risk and cost.

Table 2 The obtained results with taking α as a variable

The value obtained from model solving α	Objective function value	The intended points for building the hubs	Type of hub	Model solving time (s)
0.5	2.515522×10^8	2.19	1.1	8781/352

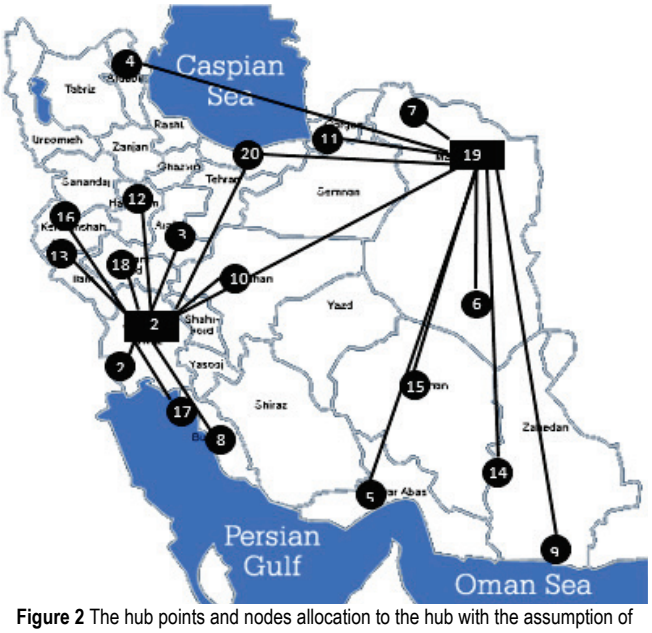

Figure 2 The hub points and nodes allocation to the hub with the assumption of variable being of factor

3.2 Factor α as the Parameter

In this mode, this factor has been taken as a parameter and different values in the allowable range have been allocated to it. The selection of this value depends on the rate of risk-taking by the decision-maker and with the increase in this rate; the intensity of constraint with the uncertain parameter is increased. The results are shown in the following, in the form of Tab. 3 and Fig. 3. In this mode, the results are the same as the mode in which the confidence level was taken as a variable (Tabs. 4-8, Figs. 4-8).

Table 3 The results for $\alpha = 0.5$

Parameter's value	Value of objective function	The points intended for hub building	Type of the hub	Solving time (s)
0.5	3.515522×10^8	2, 19	1, 1	6.521

Table 4 The results for the hub points and allocated nodes with $\alpha = 0.6$

Parameter's value	Value of objective function	The points intended for hub building	Type of the hub	Solving time (s)
0.6	3.536406×10^8	2, 19	1, 2	3.556

Table 5 The results for the hub points and allocated nodes with $\alpha = 0.7$

Parameter's value	Value of objective function	The points intended for hub building	Type of the hub	Solving time (s)
0.7	3.647931×10^8	19, 17, 3	2, 1, 3	3.453

Table 6 The results for the hub points and allocated nodes with $\alpha = 0.8$

Parameter's value	Value of objective function	The points intended for hub building	Type of the hub	Solving time (s)
0.8	3.756350×10^8	15, 17, 12	2, 2, 3	3.582

Table 7 The results for the hub points and allocated nodes with $\alpha = 0.9$

Parameter's value	Value of objective function	The points intended for hub building	Type of the hub	Solving time (s)
0.9	3.886346×10^8	20, 19, 17	2, 2, 3	3.591

Table 8 The results for the hub points and allocated nodes with $\alpha = 1$

Parameter's value	Value of objective function	The points intended for hub building	Type of the hub	Solving time (s)
1	4.212080×10^8	15, 19, 17, 12	1, 2, 2, 3	3.623

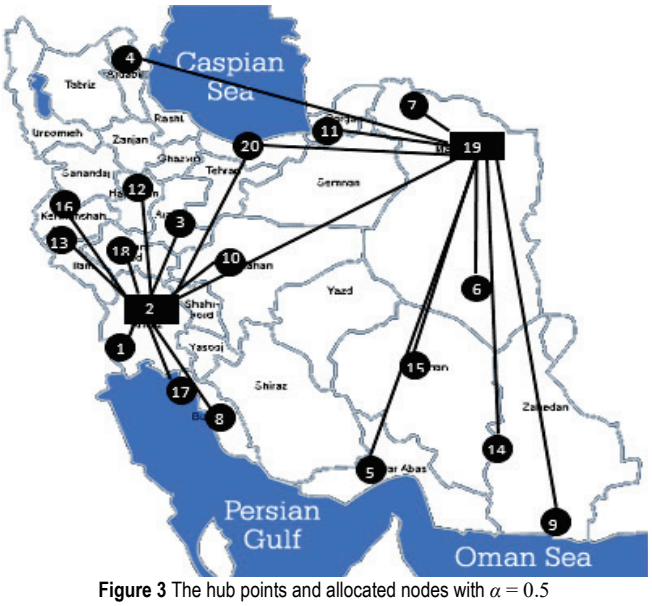

Figure 3 The hub points and allocated nodes with $\alpha = 0.5$

Figure 4 The hub points and allocated nodes with $\alpha = 0.6$

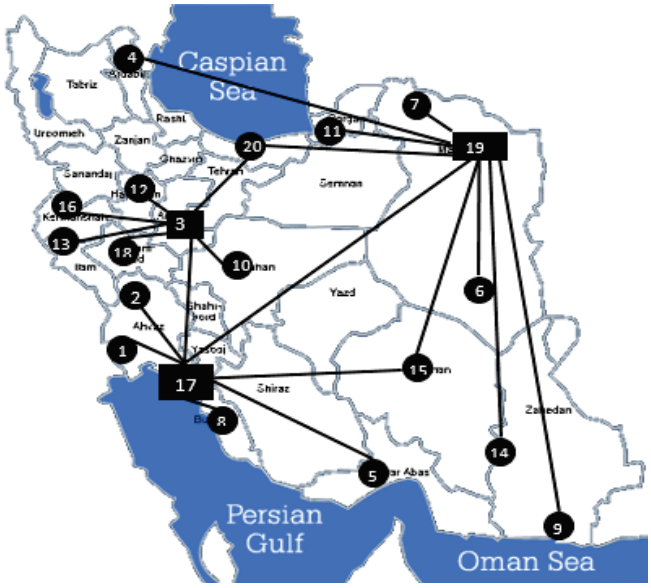

Figure 5 The hub points and allocated nodes with $\alpha = 0.7$

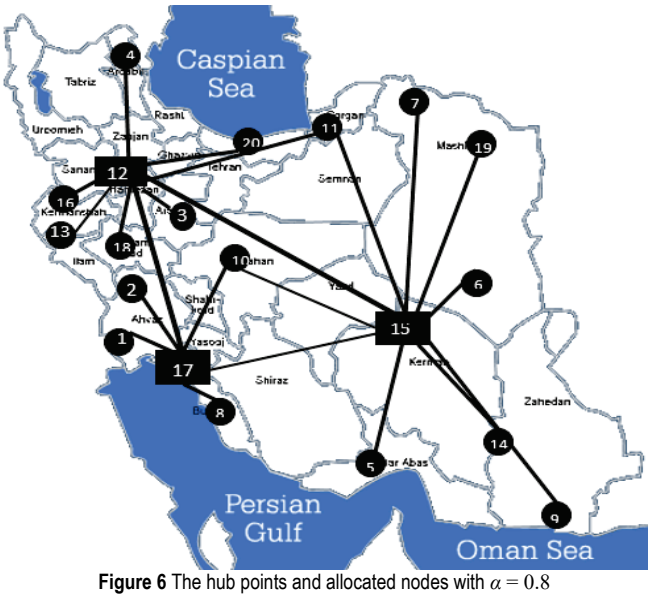

Figure 6 The hub points and allocated nodes with $\alpha = 0.8$

Table 9 The model solving results with consideration of the confidence level as a variable

The value of α obtained from model solving	Value of objective function	The points intended for hub building	Type of the hub	Solving time (s)
0.5	3.515522×10^{8}	2.19	1.1	8781.352

α is the confidence level value which is the uncertain parameter constraint per α percent of the feasible events. On the other hand, this coefficient can take 0.5 to 1 values. The α factor is analyzed twice in the current study in a way that once it is considered as the variable to determine the value the model itself obtains, and once it has been taken as a parameter. In the latter state, different values are allocated to the parameter and the results have been analyzed. According to the results obtained in Tab. 9, when we consider the confidence level of feasibility of the constraint as a variable, the model solving obtains the minimum value, which is 0.5, for the confidence level factor since the objective function is minimized and through obtaining the minimum confidence level, lower costs would be incurred.

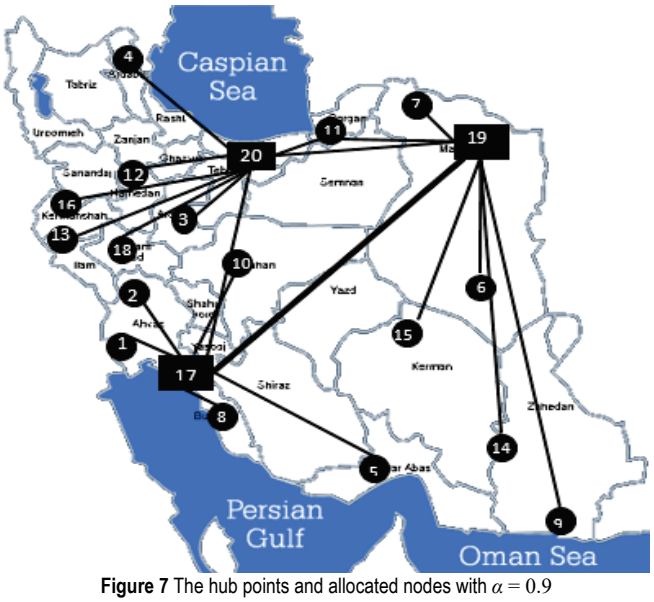

Figure 7 The hub points and allocated nodes with $\alpha = 0.9$

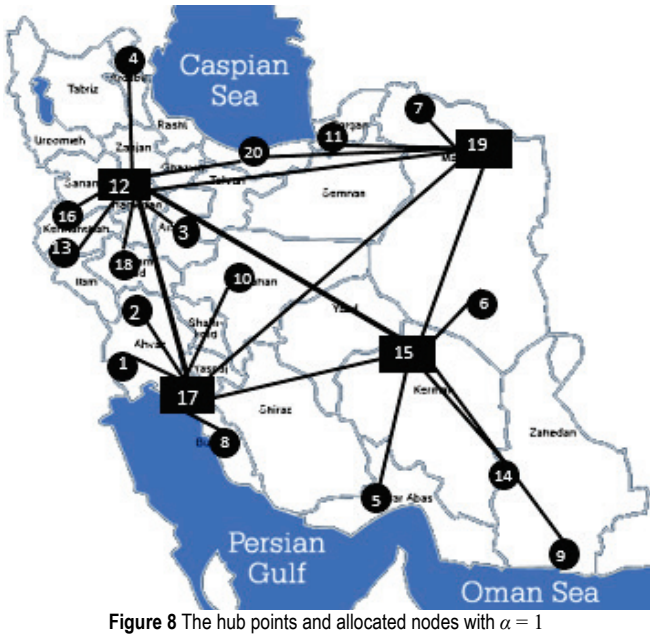

Figure 8 The hub points and allocated nodes with $\alpha = 1$

Table 10 The results obtained from the model solving with the change in confidence level parameter in the allowable range

Row	Value α	Value of objective function	The points intended for hub building	Type of the hub	Solving time (s)
1	0.5	3.515522×10^{8}	2,19	1,1	6.521
2	0.6	3.536406×10^{8}	2,19	1,2	3.556
3	0.7	3.647931×10^{8}	19,7,3	2,1,3	3.453
4	0.8	3.756350×10^{8}	15,17,12	2,2,3	3.582
5	0.9	3.886346×10^{8}	20,19,17	2,2,3	3.591
6	1	4.212082×10^{8}	20,19,17,12	1,2,2,3	3.623

Then, the confidence level factor has been taken as a parameter and different values in the allowable range have been allocated to it so that the model's behavior can be investigated. Besides, each of the change modes of this

factor, the number of hub points, and allocated nodes to the hub were determined. Tab. 10 shows a summary of the results.

Tab. 10 shows the sensitivity analysis on the values of parameter α and each case of a parameter change, the costs, problem-solving time, and the intended hub points, as well as their types, have been determined. As seen in the table, with the increase in parameter α, the objective function value has been also increased, which is shown in Fig. 9. The higher the confidence level rate, the more conservative the decision will be in a way that the number of hub points is increased and the hub type is also changed. Therefore, regarding the conducted validation, this model can be used for hub location in the presence of uncertainty through the use of experts' opinions for the determination of the range of the uncertain parameters. By this possibility, the decision-maker would be able to satisfy some chance constraints in the lowest confidence level.

The numbers in the proposed model analysis have been obtained by the GAMS software.

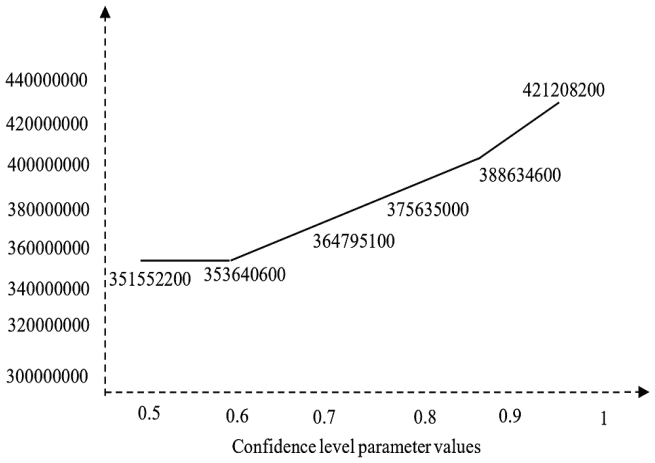

Figure 9 The graph of the changes in costs per increase in the confidence level parameter

4 CONCLUSIONS

The main objective of the hub location models is the selection of the proper hub points from the potential points and allocation of the non-hub point to selected hub points by the model. Its objective function is the minimization of the total costs of transportation between the nodes and the hub building costs. A single-objective linear model has been developed in the current study which is, in fact, a more advanced variant of hub models. In this model, in addition to the hub building costs and the transportation costs, the extra capacity building inside the hub and the operational costs have been also considered. On the other hand, regarding the fact that the objective is to apply uncertain conditions, the demand parameters, operational costs, and extra capacity building costs have been also considered to be uncertain and these uncertain parameters have been represented by trapezoidal fuzzy numbers. In the following, the introduced fuzzy programing was used and the model was rewritten in the form of a linear programing model. The proposed model was solved by standard optimization software and the hubs and the nodes allocated to them were determined. The results indicated that with the change in the feasibility confidence level of the constraint with the uncertain parameter, the costs are also increased and the number of the type of hubs is changed as well. It is also tangible in the real world since we incur additional costs as decisions become more stringent, so it can be mentioned that the more the uncertainty, the higher the costs. Therefore, with consideration for the experts' opinions about the range of uncertain parameters this model can be used for middle hub location problems under uncertainty. Through this model, the decision-maker, with the lowest confidence level, would be able to satisfy some constraints with uncertain parameters. It is suggested that future studies use an innovative or meta-innovative approach for solving the problem at larger scales. Also, proportionate to the increase in hub capacity, the operational costs can be increased step-by-step.

5 REFERENCES

[1] Mohammadi, M., Jula, P., & Tavakkoli-Moghaddam, R. (2019). Reliable single-allocation hub location problem with disruptions. *Transportation Research Part E: Logistics and Transportation Review*, *123*, 90-120. https://doi.org/10.1016/j.tre.2019.01.008

[2] Mokhtar, H., Krishnamoorthy, M., & Ernst, A. T. (2019). The 2-allocation p-hub median problem and a modified Benders decomposition method for solving hub location problems. *Computers & Operations Research*, *104*, 375-393. https://doi.org/10.1016/j.cor.2018.09.006

[3] Alumur, S. A., Nickel, S., & Saldanha-da-Gama, F. (2012). Hub location under uncertainty. *Transportation Research Part B: Methodological*, *46*(4), 529-543. https://doi.org/10.1016/j.trb.2011.11.006

[4] Masaeli, M., Alumur, S. A., & Bookbinder, J. H. (2018). Shipment scheduling in hub location problems. *Transportation Research Part B: Methodological*, *115*, 126-142. https://doi.org/10.1016/j.trb.2018.07.003

[5] Campbell, J. F., Ernst, A. T., & Krishnamoorthy, M. (2002). Hub Location Problems. Facility Location: *Applications and Theory*, Heidelberg, Germany, 373-408. Available at: http://works.bepress.com/james-campbell/54/

[6] Campbell, J. F., Ernst, A. T., & Krishnamoorthy, M. (2005). Hub arc location problems: part I—introduction and results. *Management Science*, *51*(10), 1540-1555. https://doi.org/10.1287/mnsc.1050.0406

[7] Hekmatfar, M., & Pishvaee, M. (2009). Hub location problem. In *Facility Location* (pp. 243-270). Physica, Heidelberg. https://doi.org/10.1007/978-3-7908-2151-2_11

[8] Skalna, I., Rębiasz, B., Gaweł, B., Basiura, B., Duda, J., Opiła, J., & Pełech-Pilichowski, T. (2015). Advances in fuzzy decision making. *Studies in Fuzziness and Soft Computing*, *333*. https://doi.org/10.1007/978-3-319-26494-3

[9] Sarvari, P. A., Yeni, F. B., & Çevikcan, E. (2018). Hub Location Allocation Problems and Solution Algorithms. In *Handbook of Research on Applied Optimization Methodologies in Manufacturing Systems* (pp. 77-106). IGI Global. https://doi.org/10.4018/978-1-5225-2944-6.ch005

[10] Chen, J. F. (2007). A hybrid heuristic for the uncapacitated single allocation hub location problem. *Omega*, *35*(2), 211-220. https://doi.org/10.1016/j.omega.2005.05.004

[11] de Sá, E. M., de Camargo, R. S., & de Miranda, G. (2013). An improved Benders decomposition algorithm for the tree of hubs location problem. *European Journal of Operational Research*, *226*(2), 185-202. https://doi.org/10.1016/j.ejor.2012.10.051

[12] Taghipourian, F., Mahdavi, I., Mahdavi-Amiri, N., & Makui, A. (2012). A fuzzy programming approach for dynamic virtual hub location problem. *Applied Mathematical Modelling*, *36*(7), 3257-3270. https://doi.org/10.1016/j.apm.2011.10.016

[13] Mohammadi, M., Jolai, F., & Tavakkoli-Moghaddam, R. (2013). Solving a new stochastic multi-mode p-hub covering location problem considering risk by a novel multi-objective algorithm. *Applied Mathematical Modelling*, *37*(24), 10053-10073. https://doi.org/10.1016/j.apm.2013.05.063

[14] Yang, K., Liu, Y. K., & Yang, G. Q. (2013). Solving fuzzy p-hub center problem by genetic algorithm incorporating local search. *Applied Soft Computing*, *13*(5), 2624-2632. https://doi.org/10.1016/j.asoc.2012.11.024

[15] Paul, N. R., Lunday, B. J., & Nurre, S. G. (2017). A multiobjective, maximal conditional covering location problem applied to the relocation of hierarchical emergency response facilities. *Omega*, *66*, 147-158. https://doi.org/10.1016/j.omega.2016.02.006

[16] Eghbali-Zarch, M., Tavakkoli-Moghaddam, R., & Jolai, F. (2019). A Robust-Possibilistic Programming Approach for a Hub Location Problem with a Ring-Structured Hub Network under Congestion: An M/G/C Queue System. *International Journal of Industrial Engineering, 26*(3), 273-300

[17] Wasner, M., & Zäpfel, G. (2004). An integrated multi-depot hub-location vehicle routing model for network planning of parcel service. *International journal of production economics*, *90*(3), 403-419. https://doi.org/10.1016/j.ijpe.2003.12.002

[18] Mohammadi, M., Tavakkoli-Moghaddam, R., Siadat, A., & Rahimi, Y. (2016). A game-based meta-heuristic for a fuzzy bi-objective reliable hub location problem. *Engineering Applications of Artificial Intelligence*, *50*, 1-19. https://doi.org/10.1016/j.engappai.2015.12.009

[19] Zhalechian, M., Tavakkoli-Moghaddam, R., & Rahimi, Y. (2017). A self-adaptive evolutionary algorithm for a fuzzy multi-objective hub location problem: An integration of responsiveness and social responsibility. *Engineering Applications of Artificial Intelligence*, *62*, 1-16. https://doi.org/10.1016/j.engappai.2017.03.006

[20] Real, L. B., O'Kelly, M., de Miranda, G., & de Camargo, R. S. (2018). The gateway hub location problem. *Journal of Air Transport Management*, *73*, 95-112. https://doi.org/10.1016/j.jairtraman.2018.08.006

[21] Gelareh, S., Monemi, R. N., & Nickel, S. (2015). Multi-period hub location problems in transportation. *Transportation Research Part E: Logistics and Transportation Review*, *75*, 67-94. https://doi.org/10.1016/j.tre.2014.12.016

[22] Sadeghi, M., Tavakkoli-Moghaddam, R., & Babazadeh, R. (2018). An Efficient Artificial Bee Colony Algorithm for a P-Hub Covering Location Problem with Travel Time Reliability. *International Journal of Industrial Engineering, 25*(1).

[23] Skorin-Kapov, D., Skorin-Kapov, J., & O'Kelly, M. (1996). Tight linear programming relaxations of uncapacitated p-hub median problems. *European journal of operational research*, *94*(3), 582-593. https://doi.org/10.1016/0377-2217(95)00100-X

[24] Peidro, D., Mula, J., Poler, R., & Lario, F. C. (2009). Quantitative models for supply chain planning under uncertainty: a review. *The International Journal of Advanced Manufacturing Technology*, *43*(3-4), 400-420. https://doi.org/10.1007/s00170-008-1715-y

[25] Klibi, W., Martel, A., & Guitouni, A. (2010). The design of robust value-creating supply chain networks: a critical review. *European Journal of Operational Research*, *203*(2), 283-293. https://doi.org/10.1016/j.ejor.2009.06.011

[26] Pishvaee, M. S., Razmi, J., & Torabi, S. A. (2012). Robust possibilistic programming for socially responsible supply chain network design: A new approach. *Fuzzy sets and systems*, *206*, 1-20. https://doi.org/10.1016/j.fss.2012.04.010

[27] Liu, B. (2004). An Introduction to its Axiomatic Foundations Uncertainty Theory.

[28] Li, X., & Liu, B. (2006). A sufficient and necessary condition for credibility measures. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, *14*(05), 527-535. https://doi.org/10.1142/S0218488506004175

[29] Liu, B., & Liu, Y. K. (2002). Expected value of fuzzy variable and fuzzy expected value models. *IEEE transactions on Fuzzy Systems*, *10*(4), 445-450. https://doi.org/10.1109/TFUZZ.2002.800692

[30] Zhu, H., & Zhang, J. (2009, November). A credibility-based fuzzy programming model for APP problem. In *2009 International Conference on Artificial Intelligence and Computational Intelligence* (Vol. 1, pp. 455-459). IEEE. https://doi.org/10.1109/AICI.2009.204

[31] Huang, X. (2007). Chance-constrained programming models for capital budgeting with NPV as fuzzy parameters. *Journal of Computational and Applied Mathematics*, *198*(1), 149-159. https://doi.org/10.1016/j.cam.2005.11.026

[32] Yang, L. & Liu, L. (2007). Fuzzy fixed charge solid transportation problem and algorithm. *Applied soft computing*, *7*(3), 879-889. https://doi.org/10.1016/j.asoc.2005.11.011

[33] Golestani, M., Moosavirad, S. H., Asadi, Y., & Biglari, S. (2021). A Multi-Objective Green Hub Location Problem with Multi Item-Multi Temperature Joint Distribution for Perishable Products in Cold Supply Chain. *Sustainable Production and Consumption*. https://doi.org/10.1016/j.spc.2021.02.026

[34] Fernández, E. & Sgalambro, A. (2020). On carriers collaboration in hub location problems. *European Journal of Operational Research, 283*(2), 476-490. https://doi.org/10.1016/j.ejor.2019.11.038

[35] Wu, T., Shi, Z., & Zhang, C. (2021). The hub location problem with market selection. *Computers & Operations Research, 127*, 105136. https://doi.org/10.1016/j.cor.2020.105136

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Original scientific paper

Structural and Chemical Controllers of the North and Northwest of Torud Based on Involved Fluid Studies, Structural and Geochemical Analyses

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Abstract: Chah Mura mining area in Semnan province is located 30 km southwest of Shahroud and 20 km north of Torud village with an area of 35 km^2 and includes a part of 1:250,000 Torud plate. Structurally, this area is located in the northeastern part of Central Iran and in the center of the volcanic-intrusive arc of Torud-Chah Shirin. Rock units of the area are volcanic and pyroclastic, depending on the Eocene age. Exposed assemblages in the Chah Mura area, based on field and laboratory studies, can be divided into basalt, andesite, andesite-basalt, trachyandesite, trachyandesibasalt and small outcrops of pyroclastic units in the form of agglomerates and sediments of sandstone and conglomerate. Volcanic rocks are influenced by sub-volcanic masses younger than Eocene with an intermediate to basic composition, and their predominant textures are granular, porphyroid with microcrystalline to microintragranular background. Finally, the units are cut by dikes. In this area, mineralization is mainly in the control of sub-faults and subvolcanic massifs. Mineralization is in the form of vein-veinlet, filling empty and scattered space in the oxidation-supergen stage. Mineral sequences include pyrite, chalcopyrite, chalcocite, digenite and covellite, cuprite, tenorite, natural copper, malachite, azurite, and iron oxides and hydroxides. Geochemical studies indicate that copper does not correlate well with any of the base metals and depositing elements. Copper shows only a relative correlation with silver. Micrometric studies of fluid inclusions in samples from this area indicate dilution as a result of mixing hydrothermal solutions with atmospheric fluids in formation of this reserve.

Keywords: Calc-Alkaline; Chah Mura; isotopic analysis; mineralization; subvolcanic

1 INTRODUCTION

Paying attention to the mining sector and related industries is one of the economic priorities of developing countries. Therefore, recognizing the mineral potentials and exploration of mines has a very important role in large investments in industry and mining. Iran, with its various mineral potentials of base and precious metals, can be a suitable platform for exploration of such mines. Development of mining activities contributes significantly to production of wealth, job creation and eradication of poverty from deprived areas of the country. It should be noted that in Iran, a large part of the mineral reserves is still unknown, and in this regard, research on known reserves can help us understand the conditions of deposit formation and be a key to explore unknown mineral reserves in similar formation conditions. Geochemistry is a science that deals with distribution and migration of geochemical elements within the earth [1]. One of the most important aspects that is usually considered in geochemical studies is how different elements are distributed and dispersed in rock units of each region and relationship of these elements with each other. Using these relationships, it is possible to understand to some extent the characteristics of formation environment and effective processes in formation of deposits [2]. Geochemistry is discussed in two parts: geochemistry of mineral rocks (in terms of main and secondary elements) and geochemistry of element or deposit elements in the mineralization zone. Understanding the conditions and formation of deposits is one of the main topics of economic geology and study of fluids involved can provide us with comprehensive and complete information in these areas. Each inclusion is the result of trapping a small volume of mineralizing fluid within the crystal and may be composed of magmatic, atmospheric, or compressed gas fluids. These inclusions are unique signs that, because they do not change over geological times, can indicate temperature, fluid salinity, chemical composition, and ambient pressure. Although other methods, such as studying the paragenesis of minerals and studying their texture, can be used to determine the temperature and composition of the solution and the mineralizer, the study of the fluids involved is superior to other methods in terms of accuracy and speed.

2 GEOGRAPHICAL LOCATION AND ACCESS ROADS

The studied area is in the north and northwest of Torud (between the geographical coordinates 54°58'15" east longitude and 35°34'20" north latitude up to 55°00'14" east longitude and 35°34'20" north latitude) and includes the mineral area of Chah Mura copper in Semnan province and is located 130 km southwest of Shahroud and 100 km southeast of Damghan with the geographical coordinates 54°58'14" to 55°01'20" east longitude and 35°36'00" to 35°37'21" north latitude and is located 20 km north of Torud. The studied area is located in the north of Torud, Shahroud. The access road to the area is through Shahroud-Torud road and with a distance of about 100 km from Shahroud to Torud and different parts of the area can be accessed by using side roads in the area.

2.1 Position of the Studied Area in Structural Geology of Iran

The studied area is located in the center of the Torud Mountains in northeastern Iran, is bounded on the north by the Alborz Mountains, and is separated from the Great Desert on the south by the Doruneh Fault. The Torud Mountains located in the structural zones of Iran is part of the Central Iran zone [3] and in the northern part of the Central Iran zone [4] (Fig. 1). According to Alavi [5], this area is located in the magmatic complex of eastern Iran and in the Sabzevar zone. In classification of Nogol Sadat and Almasian [6], this area

is located in the tectonic-sedimentary unit of Central Iran, its northern half and below the central magmatic section. According to Shamanian et al. [7], this arc is considered to be part of the Alborz magmatic arc. Houshmandzadeh [8] consider this mountain range as a part of the Urmia-Dokhtar magmatic arc, from which it has been separated due to an inter-arc tension in the late Eocene. The arc is bounded on the north by the Anjilo fault and on the south by the Torud fault, and the mountain ranges and faults have an approximate trend of N70°E; on the northern edge, there is the fall of the Great Desert.

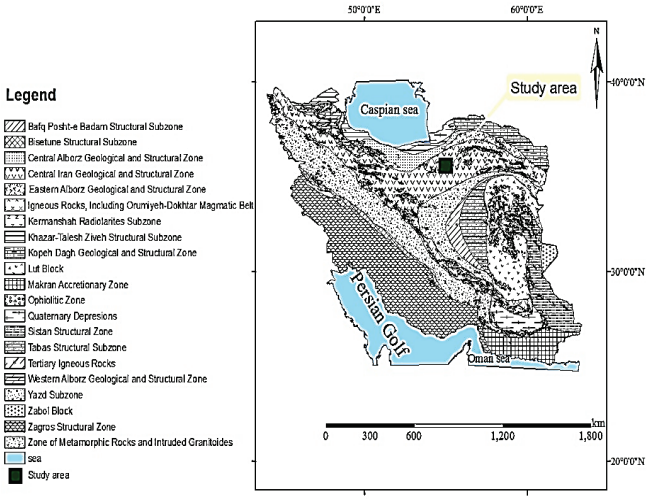

Figure 1 Location of the studied area in the map of structural-sedimentary zones in Iran

2.2 General Stratigraphy of Torud Area

The oldest rocks in the area are precambrian gneisses, amphibolites and micaschists. From Cambrian to Devonian, the metamorphic equivalents of niur formation, Padha, Sibzar and Bahram can be seen. Paleozoic rock units are less widespread in the area and include limestone, dolomite limestone, dolomite, gneiss, amphibolite, and schist, which have also undergone low-grade compressive-thermal metamorphism (up to green schist facies). These rocks have recrystallized and at least one metamorphic foliation has occurred in them. The oldest exposed rocks are metamorphic rocks which are given Paleozoic age in Kalateh Rashm based on stratigraphic sequences. These rocks, which are mostly crushed and cut, have been affected by Eocene-Oligocene magmatic masses and their hydrothermal fluids. Therefore, there are signs of concentration of metal ores, especially iron oxides in the joints and cavities of their carbonate rocks.

Mesozoic deposits in the studied area include only Late Cretaceous limestone-shale and sandstone units that have formed in a marine sedimentary environment and have been exposed in the northwestern to western parts of the plate (Figs. 2-3). Cenozoic deposits begin mainly with Lower Eocene volcanic activities and have produced large volumes of igneous-sedimentary materials during the Paleogene. These materials have appeared in the form of various stone units. Cenozoic deposits are characterized by the highest magmatic activity in the area and have left a large volume of igneous rocks during the Early Tertiary (Eocene-Oligocene). Post-Pleistocene deposits are mostly seen as old terraces. Neogene deposits are not visible below the Torud-Chah Shirin zone, and non-hardened destructive and foothill deposits can be seen only at the end of the Neogene and at the beginning of the Quaternary. However, under the Jandagh zone, a large amount of very low-depth marl deposits and gypsum sandstones have been deposited during the Neogene period. In the Torud area, Quaternary deposits are limited to the deeper parts of the desert. Flood rivers in these parts are relatively thin, covered with mud and sand, and in some places the evaporation of these waters has left pure salt. Quaternary deposits are generally thin and the basins are not very shallow. These deposits include old and young alluvial terraces and alluvial fans, mudflats, sand dunes and deserts (clay and saline sediments).

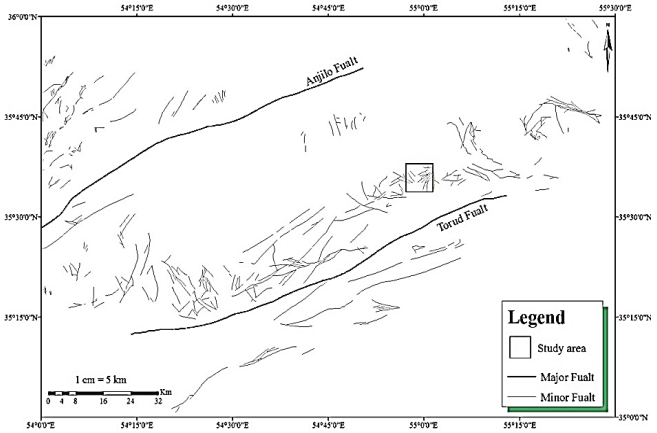

Figure 2 Map of major and minor faults in Torud area and location of the mineral area on it

2.3 Magmatism

Iran, as part of the central-western regions of the Alpine-Himalayan orogenic system, has undergone extensive magmatic (volcanic and intrusive) activity, especially during the Cenozoic period, due to special tectonic structure of the convergence zones [5, 9-12]. Geological and magmatic maps [13] of Iran have well reflected the severity and importance of this event and also show that the widespread Cenozoic magmatism is irregularly distributed throughout Iran, so that numerous volcanic-intrusive chains can be imagined throughout Iran. The Torud area has witnessed magmatic activity since the earliest geological times. These activities started in the first and second periods due to small tectonic events and peak in Tertiary. Magmatic activity in the area begins during the Silurian period, which is accompanied by the release of andesitic lavas. Hooshmandzadeh et al. [8] consider this activity to be related to early Silurian Epirogenic movements. The magmatic activities of the second period are not widespread in the area of Torud. Tertiary is a period of extensive magmatic activity of which products (tuff, lava, and intrusive masses) cover the entire area.

2.4 Tectonics

Hooshmandzadeh et al. [8] divided tectonic movements in Torud area into three periods:

2.4.1 Tectonic Movements of the First Period

The movements of this period mostly show the state of epeirogenic movement; the first movements in the late Ordovician caused the Silurian sea floor to rise, and continued to rise regularly until the late Devonian. During the Middle Devonian period, the sea receded again which continued until the end of the Devonian. In the early Carboniferous period, the Torud area suddenly emerged from the water and in the Permian the sea advanced again, but at the end of this period some parts emerged from the water.

2.4.2 Tectonic Movements of the Second Period

The most important movements of this period can be divided into four phases:

A) The phase between Middle Triassic-Late Triassic (Early Kimmerian): This phase is mostly epeirogenic movment in the area where piezolite horizons, iron oxides and alumina on permutriassic dolomites can be the result of the operation of this phase [5].
B) The phase between Lias-Dogger: The result of the operation of this phase in the area is eprieogenic movements with short and insignificant amplitudes; conglomerate of the Middle Jurassic base and andesitic lavas in the north of Sahl, Mit and Andes village indicate the operation of this phase.
C) The phase between Late Jurassic-Early Cretaceous (Late cambrian): This phase is the most important phase in terms of folding. In the volcanoplotonic belt of Torud, folding along with dynamothermal metamorphism is the result of the operation of this phase.
D) Cretaceous phases: The Cretaceous movement in the Torud area includes the following:

- The sea precedes in the lower Cretaceous.
- The sea recedes from the middle Albian and the area emerges from the water in the Cenomanian area.
- In Turonian, the sea is advancing again.
- From Coniacian, the sea recedes and in Maastrichtian this area emerges from the water.

2.4.3 Tertiary Tectonic Movements

Tertiary dynamic activity is studied in two parts:

A) Movements after Cretaceous and before Eocene (Laramide phase)
B) Middle tertiary movements-posterior tertiary

2.5 Dynamic Components

2.5.1 Faults

In the north of Torud, a group of main faults have affected the Torud area. The most important of these faults are Torud fault and the other is Anjilo fault which is located in the north of Torud fault. The trend of these faults is N-60-70 E and they have a slope of about 80 degrees to the south [3]. Because these faults have been active for long periods of time and many times, it is not possible to determine their exact movement. Although the trend of these faults is Caledonian trend, Hooshmandzadeh et al. [8] believe that these faults, at least from the Cambrian onwards, have affected the area. Torud fault is in fact a fault with northeast-southwest trend that in Sabzevar region has caused the separation of Sabzevar melange ophiolites from the desert zone. The mechanism of this fault is left-handed landslide. This fault has caused severe deformation in the region and is one of the oldest faults in Iran. This fault has changed many sedimentary facies in the distance between Kavir and Sabzevar. Due to scratches seen on the fault planes, these faults have two directions [14]. The Torud earthquake was associated with moving along the fault along the east, northeast (reactivation of the Torud fault). One of the plates obtained from solution of the focal mechanism by Shirokova [15] corresponds well with the rupture caused by earthquake and shows a sloping fault to the south, the southern block of which is pushed upwards and has a right-handed small horizontal component [16]. Anjilo fault with an almost northeast-southwest trend is seen in the south of the structural zone of the eastern Semnan. Khademi et al. [17] introduced this fault as parallel and similar to Torud fault and introduced it as left-slip landside. In the south of this fault, there is Torud fault with left slip landside, which has been active in terms of seismicity.

2.6 Mineral Potentials of Torud

The mineral rang in question is part of the field metallurgy gold-polymetallic of Torud. This area is in fact a volcanic-intrusive magmatic arc of the Tertiary (Eocene, Oligocene, Mio-Pliocene), which is present on the Precambrian and Paleozoic metamorphic belt in a band extending approximately east-west in the northern margin of the Great Desert, which is one of the potential axes in terms of mineralization and metal and non-metal mines in which mining activities have long flourished. The presence of abundant metal deposits such as lead and zinc, copper, iron, gold and turquoise and non-metallic deposits such as bentonite, feldspar, fireclay and industrial soils confirm the high potential of mineralization. This complex, which consists of volcanic rocks with a predominant andesitic composition and granodiorite masses with a predominantly diorite composition, hosts numerous vein deposits of base metals and gold [18, 19]. So far, no evidence of porphyry copper mineralization has been seen in this arc and it is the predominant form of vein metal deposits [20]. In the report of Iranian copper reserves, copper deposits of the area are vein type deposits [21]. Among the important copper deposits, one can mention Chah Musa mine, Chah Gale and lead and zinc deposits of Khanjar, Abolhassani, Cheshmeh Hafez and Gandi gold deposits, Darestan index, etc. (Fig. 3).

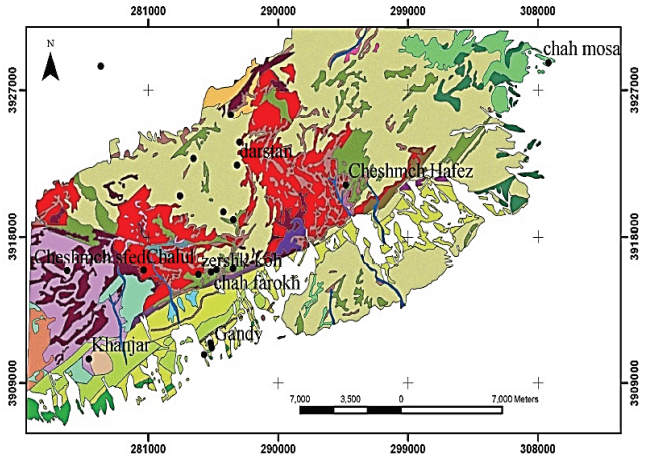

Figure 3 Photomap and guide of the location of some copper-lead and zinc-gold deposits in volcanic-intrusive arc of Torud-Chah Shirin

3 GEOCHEMICAL PROPERTIES OF ROCKS

In order to carry out geochemical studies, including designation, determination of magmatic series, tectonic site and spider diagrams for trace elements, 15 samples of mineralization-related rocks in Chah Mura area with minimal alteration were prepared for XRF analysis and sent to the wet chemistry laboratory of the Geological Survey and Mineral Explorations of Iran.

3.1 Classification and Designation of Volcanic Rocks

A) TAS classification (total alkali versus silica)

Oxide-oxide two-variable diagrams of main elements are probably the most direct way to classify igneous rocks. Today, however, this method is more suitable for volcanic rocks. One of these diagrams is in total alkali diagram ($Na_2O + K_2O$) in SiO_2. Rare elements are also used versus SiO_2. The results show that volcanic rocks fall into the combined domain of basalt-hawaiite-mugearite-trachyandesite-basalt andesite-andesite and composition of the rocks is between the basic to the intermediate. Volcanic rocks fall into the combined domain of basalt-trachyandesite-trachyandesite basalt-andesite basalt-andesite. Since mineralogical and chemical alternations are higher in endogenous igneous rocks due to the possibility of alternation in volcanic rocks, they can be designated using elements that are less mobile. The most important of these elements are Nb, Y, Zr/TiO_2 and Ga [22].

B) Chemical classification based on trace element

In these diagrams, the vertical axis of which is based on silica and the horizontal axis of which is based on logarithmic ratio Zr/TiO_2, the results showed that volcanic rocks fall into hybrid domain of andesite-andesite basalt-latite to latite andesite-mugearite and dikes into mugeandesite domain. The results showed that most of the samples are on the trachyandesite-alkali basalt boundary. The samples show more traction towards the trachyandesite and can confirm the separation process from a mafic parent magma.

3.2 Determination of Magmatic Series

In a given volcanic region, lavas have pieces of similar chemical properties that are assigned to the same region. The study of magmatic series effectively contributes to understanding the magmatic and lithological developments of a region. The gradual evolution of chemical and mineralogical composition from one lava to another is a sign of the kinship of the lavas and their origin from a common source. According to Kuno [23] theory, a magmatic series is a collection of different igneous rocks that have different chemical compositions and are obtained by subtraction from an early basic magma. However, it has recently become clear that in addition to partial crystallization, the melting mechanism of magma mother rock can also lead to igneous rock diversity. Diagrams were used to determine the magmatic series (Fig. 4).

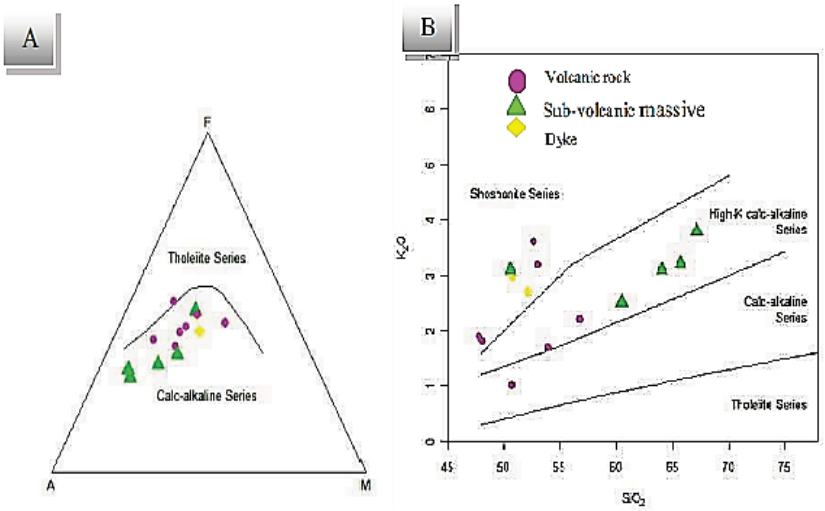

Figure 4 Diagrams of magmatic series determination

AFM diagram

According to these diagrams, location of subvolcanic rocks and volcanic rocks in the area are within the range of calc-alkaline series.

K_2O *vs.* SiO_2 *diagram*

According to these diagrams, location of subvolcanic and volcanic rocks in the region range from calc-alkaline series to potassium-rich shoshonitic.

Th *vs.* CO *diagram*

This diagram is introduced for areas affected by alteration in order to reduce the alteration effects in petrological studies, in which CO substituting $ThSiO_2$ replaces K_2O and the mentioned ratios replace AFM. According to these diagrams, the sub-volcanic rocks and volcanic rocks of the area range from calc-alkaline series to potassium-rich shoshonite.

4 TECTONIC SITE OF ROCK

Geochemical detection diagrams were widely used in the late 1970s and early 1980s to identify tectonic sites of igneous rocks. Obviously, these diagrams can never be used to prove the presence of a tectonic environment, but these diagrams only show the possibility of a tectonic environment [24]. Trace elements and major elements are used by many researchers to detect tectonic environments. Among them, Y, Tb, Nb Th/Yb, Ta/Yb elements are very important due to their low mobility during magmatic rock formation processes such as subduction phenomenon [25-27] (Fig. 5).

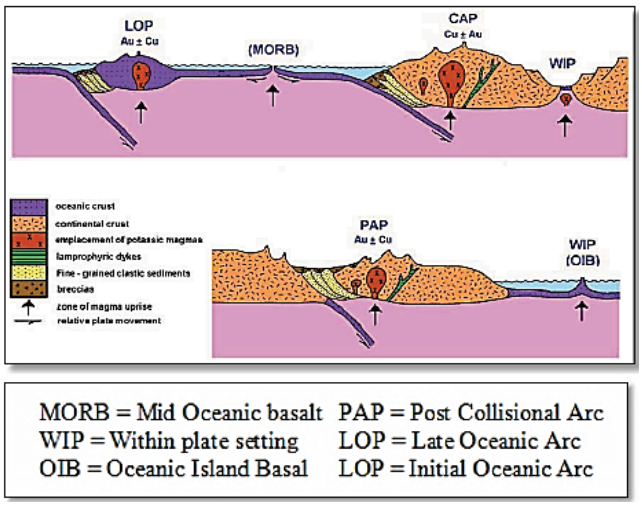

Figure 5 View of some important tectonic sites in formation of igneous rocks and associated deposits (Mitchell & Garson)

4.1 Study of Geochemical Properties of Copper Element in the Area of Chah Mura

Copper is a chalcophile element, its average value in the Earth's crust is 55 ppm. It is a metal in the group of intermediate elements. In monovalent state, this metal is similar to precious elements such as gold and silver, and in divalent state, it is similar to other metals of the first group of intermediate elements such as Ni, Co and Fe. Because copper is a chalcophile element, it rarely produces silicate minerals, although alteration of primary sulfides results in formation of secondary minerals such as oxides, carbonates, and silicates.

4.2 Distribution and Abundance of Elements Related to Mineralization

Examining the abundance and distribution of major, minor and trace elements in rock mass to investigate the behavior of one element and its relationship with other elements can be useful for development of exploration methods for similar deposits. In order to know the distribution and abundance of elements, especially copper, and determine their correlation coefficient with associated mineralizing elements, 20 lithogeochemical samples were taken from units related to mineralization for ICP-OES analysis and sent to chemical laboratory in the Geological Survey and Mineral Explorations of Iran. Finally, according to the results of analysis and petrography and field observations, the following units are described in terms of the importance of copper mineralization. SPSS and Excel software were used to process and analyze the data.

4.3 Distribution and Abundance of Elements in the Andesitic Unit (EAN)

In order to understand distribution and abundance of copper, 5 samples of mineralized and non-mineralized rocks were taken from this unit and studied and the results are given in Tab. 1. Due to the faulting as well as injection of subvolcanic masses, small fractures were created in the mineralized zones and the main factor for concentration of copper in the fractures was in the form of vein-veinlet and sulfide type spray. Alterations such as silicification, carbonation, oxidation and argillization have been implicated in copper deposit. In this unit, maximum amount of copper is equal to 21760 ppm which was measured in sample EB-5 and its minimum amount is equal to 65 ppm in the non-mineralized part. The presence of metal minerals such as chalcopyrite and chalcocite, etc. in this unit shows the importance of mineralization. Maximum amounts of sulfur and barium are 1176 ppm and 742 ppm, respectively. The amount of other base metals (lead and zinc) in this unit is relatively low. The low levels of these elements should be attributed to mobility of these elements during hydrothermal alteration [28] or the difference in their transport by hydrothermal fluids [29]. Maximum levels of silver (Ag) and arsenic (As) are 4 ppm and 3 ppm.

4.4 Distribution and Abundance of Elements in Tracyandesitic Unit (Eta)

In order to understand distribution and abundance of copper, 7 samples were taken from this unit and studied and the results.

There are many sub-faults and fractures in this unit, which are the main factor for operation of hydrothermal

fluids and ultimately cause alteration in the unit rocks. Based on field, microscopic, and XRD observations, alterations such as chlorination, carbonation, iron oxide and hydroxides, predominant argillization, and low silicification are present. In the tracyandesitic unit, the element copper has a value of 13408 ppm, which was measured in the sample EB-23, and sulfur has a maximum value of 322 ppm and minimum amount of copper in this unit is equal to 76 ppm in the altered part of the sample EB-41. The element barium in this unit has a maximum value of 1030 ppm, which was measured in sample EB-29, and its minimum value is equal to 248 ppm in sample EB-33. Other elements, such as lead and zinc, are not abundant. In the study of polished sections of these samples, copper minerals such as chalcocite, malachite, atacamite, tenorite along with hematite and goethite were observed that the presence of these minerals is consistent with the results of analysis. The maximum levels of silver (Ag) and arsenic (As) are 1.3 ppm and 8 ppm.

Table 1 Statistical parameters of Cu, Mo, Pb, Zn, Ba, S, Ag elements in the andesitic unit

Statistic										
		CU	Mn	Pb	Zn	Ag	As	Mo	S	Ba
N	Valid	5	5	5	5	5	5	5	5	5
	Missing	0	0	0	0	0	0	0	0	0
Mean		4522	1039	35	81	.1	2	2	595	522
Median		170	851	37	79	.1	2.5	2	517	499
Mode		65	793	22	67	.1	1	2	188	371
Minimum		65	793	22	67	.1	1	2	188	371
Maximum		21760	1696	50	90	4	3	8	1176	742
A Multiple modes exist The smallest value is shown										

Table 2 Statistical parameters of Cu, Mo, Pb, Zn, Ba, S, Ag elements in subvolcanic masses

Statistic										
		CU	Mn	Pb	Zn	Ag	As	Mo	S	Ba
N	Valid	8	8	8	8	8	8	8	8	8
	Missing	0	0	0	0	0	0	0	0	0
Mean		211	865	35	80	.1	3	2	377	869
Median		171	812	34	83	.1	3	3	347	622
Mode		81a	264a	23a	37a	.1	1a	3	214a	453a
Minimum		81	264	23	37	.1	1	1	214	453
Maximum		707	1713	45	111	.5	7	4	144	2743
Sum		1688	6923	282	646	1	27	23	3019	6958
A Multiple modes exist The smallest value is shown										

Table 3 Results of fluid inclusion microthermometric data in the Chah Mura area

	Mineral	Position	Type	Origin	Size	*n*	Th Total (0c)	Tm Ice (0c)	Salinity Aqwt%Nacl
KB-20	Qtz	Cc-bearing Qtz vein	L+V	p	14×5	1	160	–0.8	1.89
KB-29	Cal	Cc-Mal-bearing Qtz vein	L+V	p	10×6 to 48×16	15	165 to 299	–4.20 to –0.8	1.37 to 6.39
KB-24	Qtz	Cc-Mal-bearing Qtz vein	L+V	p	9×3 to 48×10	15	165 to 317	–4 to 5.8	0.99 to 7.07
KB-25	Cal	Cc-bearing Cal vein	L+V	p	11×9 to 80×35	8	221 to 330	–4.2 to 5.6	3.39 to 7.07
KB-38	Cal	Mal-bearing Cal vein	L+V	p	10×4 to 25×24	5	143 to 170	–2.6 to 4.9	0.97 to 3.98

4.5 Distribution and Abundance of Elements in Subvolcanic Masses

In order to understand the distribution and frequency of copper and the role of subvolcanic masses as one of the controllers of mineralization, 8 samples were taken and examined and the results are presented in Fig. 6 and Tabs. 2 and 3. Composition of the masses changes from intermediate to acidic. Its injection into volcanic units has caused many fractures in the area. Common alterations in them are: chlorite, silicification, carbonation clay and sericitization and are similar to mineralization host units. Copper minerals were not observed in this unit and only minerals such as pyrite, calcite, granular quartz, magnetite and hematite were seen in microscopic studies. The maximum amount of copper is equal to 707 ppm which was measured in sample EB-4 from gabbro-porphyry diorite and the minimum amount of copper is equal to 81 ppm from micro gabbro mass. In addition, the amount of barium and sulfur elements are 2743 ppm and 544 ppm, respectively. The presence of a high field of copper in subvolcanic masses can highlight their role in relation to potential source of copper; moreover, high amounts of sulfur and the presence of pyrite in these masses can be identified according to the results.

5 FLUID INCLUSIONS

5.1 Petrography of Fluid Inclusions

To study the fluids involved in Chah Mura area, 5 samples of quartz and calcite minerals in copper mineral veins that contained minerals were used. In order to determine the temperature, depth, pressure of the mineral fluid was selected. Considering the thin sections of the rock, it contains porphyry andesite. A number of the studied fluids involved in quartz and calcite are associated with minerals. Once the double polish sections were prepared, they were given to the relevant laboratory of fluid studies of the Geological Survey and Mineral Explorations of Iran in order to perform petrographic and thermometric studies (cooling and heating). PVTX Modeling for Fluid Inclusion V2.6

software was used to determine the percentage of salinity and density of fluids and to draw diagrams.

Figure 6 A and B: View of the fluid involved in the quartz mineral; C: View of the fluid involved in the mineral calcite

5.2 Classification of Fluids Involved Based on Time and Origin of Formation

In this classification, formation time of the involved fluids is measured relative to formation time of the crystal. In fact, this classification is a kind of classification based on the origin of the fluids involved. The classification proposed by Yermakov [30] and Shepherd [31] includes three types of fluids involved:

5.3 Primary Inclusion

This group of fluids is formed during crystal growth. These fluids are trapped by processes such as dendritic growth of crystal plates, spiral growth, semi-parallel growth, or partial dissolution of crystalline surfaces within these plates.

5.4 Secondary Inclusion

This group of involved fluids is formed after the crystallization is complete. One of the processes involved in formation of secondary fluids is the trapping of fluid at the fracture sites that occur after mineral formation [32].

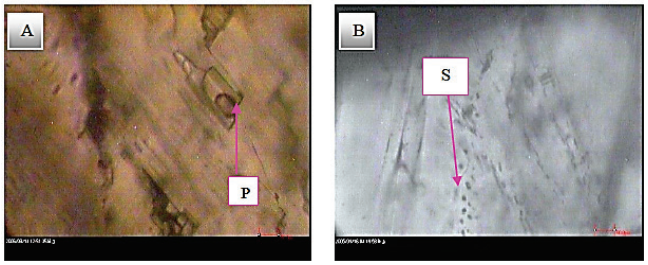

Figure 7 A view of primary fluid involved, indicated by P

5.5 Pseudosecondary Inclusion

These fluids are formed during the crystallization of the mineral containing them, but some of their properties are similar to those of the secondary fluids involved. If the crystal cracks during crystal growth due to phenomena such as tectonic stress, the mineralizing fluids can concentrate at the crack site and give rise to pseudosecondary fluids (Fig. 7).

6 THERMOMETRY

The thermometry studies, which are performed in order to determine the homogeneity temperature of inclusions and determine the chemical composition, particularly fluid salinity, is based on destructive and non-destructive methods. In non-destructive methods, the inclusions are heated in order to determine the degree of homogeneity without damaging the internal content of the inclusions, and they are frozen in order to determine the salinity of the fluids [33]. Thermobarometric measurements were performed on two different types of A-B. It was not possible to measure in single-phase fluids involved.

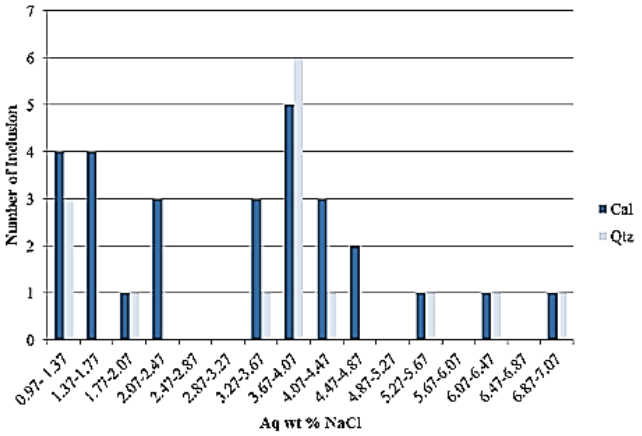

Figure 8 Bar chart measuring salinity changes (% Wt NaCl versus frequency

7 FREEZING

By measuring changes in freezing degree, salinity and density can be measured in the fluids involved. The first temperature recorded was during the formation of the first melting drop (T_e) or eutectic point temperature. The eutectic temperature, T_e, is lower than –20 °C in some of the studied samples, which indicates the presence of salts other than NaCl in the mineralizing fluid, the ice melts gradually until the last ice crystal disappears. The last temperature recorded during melting is called T_m temperature. Using T_m, the fluid salinity can be determined. In the studied samples, salinity WtNaCl% and density were calculated by PVTX modeling software, Linkam. The information is presented in the form of tables and histogram models. The last ice crystals in these inclusions are melted at +6 to –4.20 °C and the highest number of samples in this temperature range is related to the samples that are in the temperature group of –1.6 to –2 °C.

According to studies performed on the samples, salinity of the fluids involved varies from 0.97 to more than 7% Wt NaCl. The diagrams of the studied samples show the highest frequency of salinity percentage in the numerical range of 0.97-1.37 as well as 3.67-4.07 in NaCl Wt% (Fig. 8).

8 HEATING

The results showed that vapor rich fluids involved are not a good indicator for measuring microthermometry of other fluids, so that repeated measurements several times on this type of fluids have completely different results. This is most likely due to the non-closure of the thermodynamic system of this type of fluid involved (Roedder & Bodnar). Based on stratigraphic reconstruction of the area, if it is determined that pressure and temperature were not high at the time of crystal formation, this temperature will be mineralization temperature. However, if it is found that the crystal has undergone compression at the time of formation, pressure corrections will be applied after determining salinity and using special diagrams [30].

In the studied samples, homogenization temperature of the two-phase fluids involved was measured by converting vapor to liquid, and in samples containing high vapor, conversion of liquid to vapor was measured. Histogram of homogenization temperature varies from 143 to 330 °C. The highest frequency of homogenization temperature of the studied samples is shown in the temperature range of about 200 to 220 °C (Fig. 9).

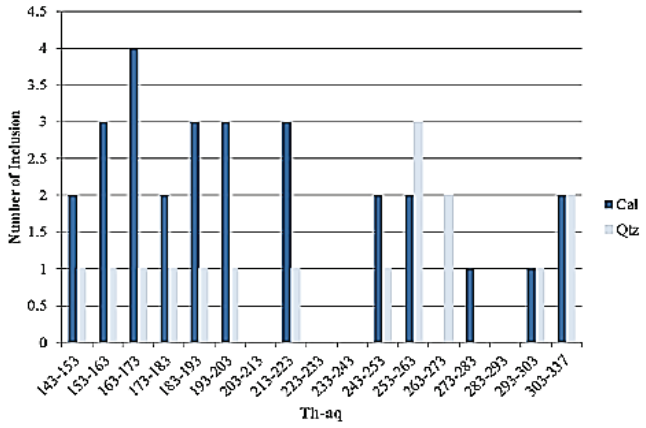

Figure 9 Bar chart measuring variations in homogenization temperature (Th) versus frequency

9 PRESSURE, DENSITY AND DEPTH OF FLUIDS INVOLVED

Homogenization temperature data, together with fluid Salinity data, determine fluid density approximately at the time of fluid entrapment. Density changes are especially important with respect to fluid flow mechanisms and evolution of specific changes in fluid density, especially in systems that can interrupt the fluid flow process. Data on salinity and homogenization temperature of the studied samples were matched with the diagram adapted from Bodnar and the result is presented as a diagram. According to this diagram, density of fluids is less than 0.6 g/cm^3 to more than 0.9 g/cm^3. The most populous group of fluid inclusions studied are in the density range of 0.87 g/cm^3 to more than 0.90 g/cm^3. According to homogenization temperature and density, depth and pressure of fluid formation can be determined. After matching the temperature-density data of the inclusions with Fig. 10, the process of fluid formation shows a pressure of about 20-200 bar to the ground.

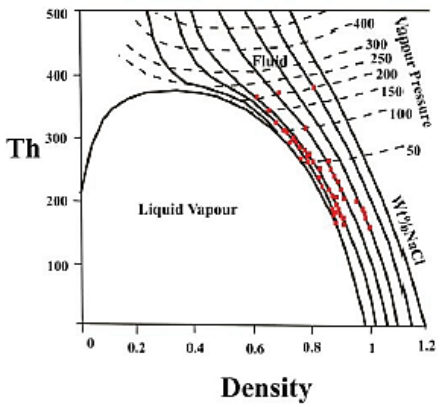

Figure 10 Temperature-density diagram to determine the amount of pressure with respect to salinity

9.1 Determination of Mineralization Type

Homogenization temperature and salinity are two main parameters in thermometric studies. Although properties of reserves are not a function of temperature and fluid salinity, the relationship between mineral and natural changes of these two parameters have led to most interpretations based on them. The main classes of mineral deposits occupy ranges in the homogenization temperature-salinity space, which indicates the basic properties of the fluids involved in their formation and are confined entirely between the halite saturation curve and critical curve for pure solution [34]. In Wilkinson [34] diagram, information on Th and salinity of different types of reserves are combined. After matching the Th dispersion-salinity diagram of fluid inclusions in the region with this diagram, most of the samples are in the range of epithermal reserves (Fig. 11).

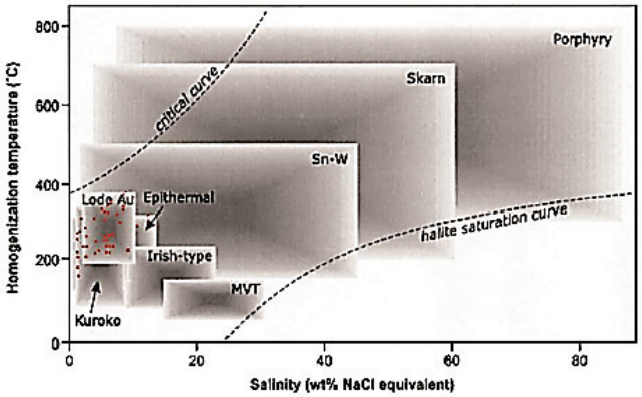

Figure 11 Position of fluids involved on homogenization temperature-salinity diagram of various mineral reserves

10 GENERATIVE MODEL

In order to compare and determine the type of mineralization and generative model of Chah Mura copper deposit, the deposits formed in volcanic rocks were studied and compared.

10.1 Michigan Copper Deposits

Keweenaw-type copper deposits, also known as Michigan copper deposits, are found on the keweenaw Peninsula (northern Michigan). In these deposits, natural copper is the main mineral and calcocite and digenite are present, both of which have high metal to sulfur ratios. Natural copper in these deposits is associated with silver, which also confirms the low partial pressure of sulfur. Mineralization has taken place within basaltic rocks with amygdaloidal-tholeiitic nature as well as in the context of interlayer conglomerate layers. Manto andesitic copper deposits such as Peru and Chile and Arizona may be associated with Michigan copper ores found in basalts and conglomerates. The Calumet-Hecla copper ores on the keweenaw Peninsula in northern Michigan are examples of low-temperature hydrothermal ores that have been transferred to their current location through impermeable conglomerates and fragmented areas of low-slope lava flows. Butler and Burbank [35] point out that basalts are of Precambrian and continental tholeiitic type and have also received conglomerate sediments in areas with volcanic activity.

Due to abundance of open space filler texture compared to open space filler texture compared to substitution texture and lack of alteration, it shows very low pressures and low temperatures. The idea behind generation of the Michigan-type mineralization is the epigenetic theory of such reserves. Stoiber and Davidson [36], in their field and laboratory studies, concluded that transformation of lavas at depth caused the alteration of basalt into pompoleite-perhonite-chlorite and the release of copper and other chemical structures.

10.2 Andesitic Copper Deposits

Veins, veinlets, and bubbles of species resulting from accommodation of cavities and sprays of free copper and silver, chalcocite, and Bornite, and to a lesser extent chalcopyrite, are also found in Middle Mesozoic to Pliocene calc-alkaline volcanic rocks in the American Cordillera. Economic accumulations of this type of ore have been seen so far in Chile and Bolivia (Kuroko taype deposit). These copper manto deposits are generally tens of meters thick and extend up to several kilometers along their direction (in fact, the copper manto deposits were considered to be called andesitic copper deposits). Surface areas of andesitic, dacite, and latite flows, cuts, and ignembrites have been more suitable hosts. As porosity and permeability of these rocks decreases downwards, the grade of copper also decreases. Alteration manifests itself only in the form of slight silicification, carbonation and sometimes pyritization.

Mineralogical, textural characteristics and mineralization host rock in Chah Mura copper deposit, which occurs in volcanic rocks with a combination of basalt andesite and trachyandesic basalt. Its geochemical characteristic, that is, high levels of copper-silver and, in general, a review of these properties, immediately recalls the reserves of the Michigan-type keweenaw Peninsula, USA; by studying more, we will find the differences between the two. Lack of sulfur in formation of copper reserves is unusual. Most copper deposits contain natural copper, but copper deposits are found only in the oxidized zone. It is usually associated with cuprite, tenorite and other secondary copper minerals such as malachite, chrysocolla, azurite, etc. However, natural copper is the main mineral in the Michigan Type deposit. In this deposit, the size of amygdala and veinlets filled with natural copper sometimes reaches 10 cm. In the Michigan type, natural copper ranks first in mineral paragenesis. Other minerals are oxide minerals, including cuprite, tenorite, and chrysocolla. In the group of copper minerals in the Michigan type, no sulfide mineral is found, while in the Chah Mura, the identified copper minerals are copper sulfide minerals and natural copper mineral is present in small amounts along with copper oxide minerals (cuprite-tenorite). Perhaps this is the obvious difference between the Chah Mura and Michigan copper generation. There is another obvious difference between the two deposits. The difference is in the host rock of the Michigan deposit and mineralization of the Chah Mura. In the Michigan deposit, the host rock has been altered to the extent of the prehnite-pompoleite facies, while no trace of alternation is seen in mineralization of Chah Mura copper. This difference may not seem significant at first glance, but when we look deeper into this, we notice a difference in the genetic model of the two reserves. In the Michigan deposit of the keweenaw Peninsula, USA, host rock alternation has led to the formation of the deposit fluid, which has deposited natural copper ores in a sulfur-free environment. Regarding the origin of Chah Mura mineralization, it seems that mass-dependent hydrothermal solutions play a role by leaching copper from host units and enrichment.

10.3 Volcanic Redbed Deposits

This type of copper mineralization has typically occurred from Proterozoic to Tertiary. Mineralization host rocks include mafic to felsic lavas, especially tuff, cut lavas, and associated sedimentary rocks such as amygdaloidal basalts, conglomerates, sandstones, and so on. In terms of composition, volcanic rocks cover a range from basalt to rhyolite. Some deposits have a flat structure, some are stratabound zones, and others are controlled by intersecting structures and stratigraphy.

The by-product of copper in this type of reserves is silver. The main minerals of copper are chalcocite, bornite and natural copper. Mineralization has occurred sporadically, in veins, amygdaloidal fillers and fractures. These deposits are typically found at tectonic sites of intracontinental rifts with superficial flood basalt sequences (in contact with open air) and near the plateau along with islands and continental

arc volcanoes. Low to medium latitude continental to low-depth marine volcanic sites and arid to semi-arid environments are typical of such reserves.

10.4 Manto Copper Deposits

These deposits are the result of hydrothermal replacement process in andesites and sometimes rhyolites. Manto deposits are a group of deposits that are usually stratigraphic and consistent with stratification and within layers or lavas. The main minerals are copper, chalcocite and bornite. Mineralization in this group usually occurs in volcanic layers that are accompanied by dikes, intrusive rocks and sill with gabbrodiorite composition, and unlike other types of deposits, the absence or lack of hydrothermal phenomena of the host rock is one of their obvious features. Manto copper deposits occur mainly near subvolcanic masses with basaltic intermediate composition, but intrusions are often non-mineralized and some have delayed copper minerals. According to age measurement data, it is believed that mineralization is primary sulfide; however, due to stratigraphy, volcanic rocks appear to have formed epigenetically after the deposition and are associated with diorite-type intrusions.

The presence of infertile andesitic dikes injected after mineralization has been reported in the Manto copper deposits, including ... and other Manto deposits in Chile. In Manto copper deposits, the most important alterations are chlorination, epidotization, albitization, silicification, calcification, sphenification, and zeolitization. The presence of negative Eu in the trace element process is common as in most Manto copper deposits.The mineralization of Chah Mura copper is similar to Manto copper deposits due to paragenetic sequence, texture, construction and alteration and the presence of diorite subvolcanic masses and sterile andesitic dikes in the mineral range as well as the host rock.

11 CONCLUSIONS

According to the results, the pattern of rare and trace earth elements that are enriched of LILE and LREE and depleted from HFSE and HREE indicate the characteristics of volcanic arc rocks associated with subduction zone and calc-alkaline magmas. Among the elements, only the amount of copper in the field of E^{ta} and E^{an} rocks and subvolcanic masses was higher than normal and other base metals were low. It should be noted that the element copper does not correlate with any of the base metal groups such as lead and zinc, indicating that they do not accompany copper in mineralization, which helps us to obtain the mineralization type. It should be noted that the correlation matrix of copper with silver, arsenic and sulfur is good and this shows that these elements can also accompany the mineralization of copper. The presence of copper sulfide minerals reveals its genetic link with sulfur in mineralogical examination. No specific minerals were found for the presence of silver and arsenic in the study of microscopic sections. It should be noted that elements such as silver and arsenic may be present in the network of other minerals, such as chalcopyrite or chalcocite, and it is best to have a microprop electron analyze to ensure. X-ray diffraction results show the presence of arsenic element next to copper in the structure of an arsenic-containing copper mineral with the chemical formula (Cu_3AsSe_4).

In the samples of Chah Mura area, based on the constituent phases, 4 types of fluids are involved and based on the origin, two types of primary (P) and secondary (S) can be distinguished. The homogenization temperature is 143 to 330 °C and the fluid density in these studies is less than 0.6-0.9. Examination of fluid inclusions shows that their salinity varies from 1 to more than 7% by weight of NaCl, which can indicate the presence of fluids with different salinity. The maximum salinity range is 0.97-1.37 and 3.67- 4.07. Based on the diagram of pressure and depth changes against temperature-salinity and the presence of carbonate minerals such as malachite, azurite and calcite, which indicate the presence of CO^{3-} or HCO^{-3} anion in fluids, is evidence of the role of atmospheric fluids in copper mineralization as a result of dilution caused by mixing magmatic-hydrothermal fluids with atmospheric waters. Based on data of homogenization temperature and salinity as well as petrographic results, the fluids involved in the area are in the epithermal category.

12 REFERENCES

[1] Mason, B. & Moor, C. B. (1982). *Principles of geochemistry*, Jonh Wiles & Sons Inc.

[2] Barnes, H. J. (1979). Solubilities of ore minerals. *Geochemistry of hydrothermal ore deposits*, 404-460.

[3] Agha Nabati, A. (2004). *Geology of Iran.* Geological Survey & Mineral Explorations of Iran.

[4] Nabavi, M. H. (1976). An introduction to the geology of Iran, Geological Survey of Iran.

[5] Alavi, M. (1991). Sedimentary and structural characteristics of the Paleo-Tethys remnants in northeastern Iran. *Geological Society of America Bulletin*, *103*(8), 983-992. https://doi.org/10.1130/0016-7606(1991)103<0983:SASCOT>2.3.CO;2

[6] Nogole-Sadat, M. A. & Almasian, M. (1993). Tectonic map of Iran in 1: 1000, 000 scale. *Geological survey of Iran*.

[7] Shamanian, G. H., Hedenquist, J. W., Hattori, K. H., & Hassanzadeh, J. (2004). The Gandy and Abolhassani epithermal prospects in the Alborz magmatic arc, Semnan province, Northern Iran. *Economic Geology*, *99*(4), 691-712. https://doi.org/10.2113/gsecongeo.99.4.691

[8] Houshmandzadeh, A. (1979). *Evolution of the geological phenomena of Torud (Precambrian to the present day).* Geological Survey & Mineral Explorations of Iran.

[9] Takin, M. (1972). Iranian geology and continental drift in the Middle East. *Nature*, *235*(5334), 147-150. https://doi.org/10.1038/235147a0

[10] Mohajjel, M., Fergusson, C. L., & Sahandi, M. R. (2003). Cretaceous–Tertiary convergence and continental collision, Sanandaj–Sirjan zone, western Iran. *Journal of Asian Earth Sciences*, *21*(4), 397-412. https://doi.org/10.1016/S1367-9120(02)00035-4

[11] Ghasemi, A. & Talbot, C. J. (2006). A new tectonic scenario for the Sanandaj–Sirjan Zone (Iran). *Journal of Asian Earth Sciences*, *26*(6), 683-693. https://doi.org/10.1016/j.jseaes.2005.01.003

[12] Shahabpour, J. (2007). Island-arc affinity of the central Iranian volcanic belt. *Journal of Asian Earth Sciences*, *30*(5-6), 652-665. https://doi.org/10.1016/j.jseaes.2007.02.004
[13] Emami, M. H. (2001). *Magmatism in Iran.* Geological Survey & Mineral Explorations of Iran.
[14] Abdalian, S. (1953). Le tremblement de terre de Toroude en Iran. *La Nature*, *81*(3222), 314-319.
[15] Shirokova, E. I. (1962). Stresses effective in earthquake foci in the Caucasus and adjacent districts. *Izv. Akad. Nauk. USSR, Ser. Geophiz*, *10*, 809-815.
[16] Berberian, M. (1979). Discussion of the paper AA Nowroozi, 1976 "Seismotectonic provinces of Iran". *Bulletin of the Seismological Society of America*, *69*(1), 293-297.
[17] Khademi, M. (1990). *Structural features and tectonic status of Torud region (south of Damghan).* PhD Thesis, Shahid Beheshti University, Department of Earth Sciences.
[18] Rashidnejad, A. (1993). *Investigation of lithological developments and its relationship with gold mineralization in Baghu region (south-southeast of Damghan)*. MA report, Tarbiat Moallem University, Department of Science.
[19] Borna, B., & Eshgh Abadi, M. (1998). *Evaluation and exploration of lead and zinc deposits and indices in Semnan province.* Prganization of Industry, Mining and Trade of Semnan Province.
[20] Araghi, A., Martinez, C. J., Adamowski, J., & Olesen, J. E. (2019). Associations between large-scale climate oscillations and land surface phenology in Iran. *Agricultural and Forest Meteorology, 278*, 107682. https://doi.org/10.1016/j.agrformet.2019.107682
[21] Bazin, D. & Hubner, H. (1969). Copper deposits in Iran: Report No. 13. *Geological Survey of Iran*, *190*.
[22] Adabi, M. H. (2006). *Comprehensive designation and classification of sedimentary, igneous and metamorphic rocks.* Ferdosi University of Mashhad.
[23] Kuno, H. (1968). Origin of andesite and its bearing on the island arc structure. *Bulletin Volcanologique*, *32*(1), 141-176. https://doi.org/10.1007/BF02596589
[24] Rollinson, H. R. (2014). Using geochemical data: evaluation, presentation, interpretation. Routledge. https://doi.org/10.4324/9781315845548
[25] Zarasvandi, A., Liaghat, S., & Zentilli, M. (2005). Geology of the Darreh-Zerreshk and Ali-Abad porphyry copper deposits, central Iran. *International Geology Review*, *47*(6), 620-646. https://doi.org/10.2747/0020-6814.47.6.620
[26] Zhang, H., Shi, X., Li, C., Yan, Q., Yang, Y., Zhu, Z., ... & Zhao, R. (2020). Petrology and geochemistry of South Mid-Atlantic Ridge (19° S) lava flows: Implications for magmatic processes and possible plume-ridge interactions. *Geoscience Frontiers, 11*(6), 1953-1973. https://doi.org/10.1016/j.gsf.2020.06.007
[27] Maanijou, M., Aliani, F., Miri, M., & Lentz, D. R. (2013). Geochemistry and petrology of igneous assemblage in the south of Qorveh area, west Iran. *Geochemistry*, *73*(2), 181-196. https://doi.org/10.1016/j.chemer.2013.04.001
[28] Seewald, J. S. & Seyfried Jr, W. E. (1990). The effect of temperature on metal mobility in subseafloor hydrothermal systems: constraints from basalt alteration experiments. *Earth and Planetary Science Letters*, *101*(2-4), 388-403. https://doi.org/10.1016/0012-821X(90)90168-W
[29] McCuaig, T. C. & Kerrich, R. (1998). P—T—t—deformation—fluid characteristics of lode gold deposits: evidence from alteration systematics. *Ore Geology Reviews*, *12*(6), 381-453. https://doi.org/10.1016/S0169-1368(98)80002-4
[30] Ermakov, N. P. & Roedder, E. W. (Eds.). (1965). *Research on the nature of mineral-forming solutions: with special reference to data from fluid inclusions* (Vol. 22). Pergamon.
[31] Shepherd, T. J., Rankin, A. H., & Alderton, D. H. (1985). *A practical guide to fluid inclusion studies*. Blackie.
[32] Pirajno, F. (2008). *Hydrothermal processes and mineral systems*. Springer Science & Business Media. https://doi.org/10.1007/978-1-4020-8613-7
[33] Haj Alilo, M. (2000). *Geothermometry of fluid inclusions.* Tehran: Payam Nour University.
[34] Wilkinson, J. J. (2001). Fluid inclusions in hydrothermal ore deposits. *Lithos*, *55*(1-4), 229-272. https://doi.org/10.1016/S0024-4937(00)00047-5
[35] Butler, B. S. & Burbank, W. S. (1929). *The copper deposits of Michigan* (Vol. 144). US Government Printing Office. https://doi.org/10.3133/pp144
[36] Stoiber, R. E. & Davidson, E. S. (1959). Amygdule mineral zoning in the Portage Lake Lava series, Michigan copper district; Part 1. *Economic Geology*, *54*(7), 1250-1277. https://doi.org/10.2113/gsecongeo.54.7.1250

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Original scientific paper

How Web Shops Impact Consumer Behavior?

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Abstract: The behavior of e-customers is quite unpredictable, which raises additional questions about this topic. The purpose of the paper is to conduct research on e-customers, understand the impact of marketing actions on e-customer behavior and understand the unpredictability of e-customers. Research was conducted on the Mlinar web shop that sells cakes. 284 respondents/buyers had the opportunity to solve questionnaires about behavior after purchase and consumption of product. Different methods have been used in the analysis - descriptive statistics, multivariate analysis (reliability analysis, correlation analysis and linear regression) and analysis of variance (ANOVA). The results showed that most examinees were satisfied with online shopping on the Mlinar web shop and that they are impulsive when online shopping. Saving time is the main reason to buy on a web shop. Research proved that variables such as firm reputation/perceived value, e-satisfaction and online services positively affect the creation of e-loyalty in their users.

Keywords: customer behavior; e-customer; marketing; purchasing habits; web shop

1 INTRODUCTION

With a rapid development of technology and application in all spheres of business, there is a growing stress being put on consumer behavior in an online environment. Contemporary consumers, in the majority of cases, use the information available on various internet destinations when shopping for a product (pre-shopping, shopping, and post-shopping phase), like applications, social profiles, reviews, blogs, vlogs, website information etc. The usage of the aforementioned technologies for economic purposes has become the primary matter in the everyday life of the majority of business subjects, independent of the industry they are in. The majority of business subjects is turning to selling their products online, because buyers, after doing research online, arrive at the virtual store (web shop) in order to conclude their purchase. E-trade and digital markets brought about fundamental changes and movements in all forms of trade. E-trade primarily consists of distribution, transferring information, purchase, sales, marketing, and servicing products and services using the internet or some other electronic systems. Business subjects today strive for the digitalization of their products and services in order not to fall behind the competition in the market, in order to be able to do business globally and come closer to consumers, be available 24/7. Shopping in virtual stores (web shops) developed a stiff competition and the advanced usage of technological innovation with the aim of keeping existing buyers and getting new ones. If we observe the aforementioned activities from a marketing standpoint, web shops enable direct communication with consumers, easier and faster responses to inquiries and comments of users and connecting after purchase through other platforms. It is because of this reason that it is necessary to ask the question just how much of an influence do web shops have on the end consumer i.e. what are the attitudes of a consumer towards this type of shopping.

The aim of this paper is to research the preferences of the consumer on the web shop of the business subject Mlinar. Mlinar, in its portfolio, has a wide array of products, but has specialized for a certain group of products on its web shop. In order to narrow down this research, the authors chose the aforementioned business subject because it only sells torts and pastries on its web shop. That way, only the consumers who purchase the aforementioned group of products were targeted. Based on the primary research, the aim is to explore the trust of consumers towards e-trade, how often they visit certain web shops, and how they perceive the marketing activities of specific business subjects i.e., a specific industry. Given that the majority of business subjects is beginning to offer an e-trade service, the traditional way of buying is changing, and consumers have more of a choice, more flexibility in the place, time, and way of shopping. Precisely because of this, online consumers are different than the traditional ones by their approach to shopping, as well as their reactions to marketing activities, which is the aim of research of this paper.

Considering the aforementioned, this paper sets three hypotheses, in the following order:

H1 - Firm reputation and perceived value have a positive impact on e-loyalty

H2 - E-satisfaction has a positive impact on e-loyalty

H3 - Online services have a positive impact on e-loyalty

2 CONSUMER BEHAVIOR IN ONLINE SHOPPING - PRELIMINARIES AND RELATED WORKS

Consumer behavior is not just about the action and the result of the purchase, but much more than that. For that reason, it can not only be perceived, but must also be studied, in order to reach (and understand) those activities that take place in the mind of the consumer during the purchase process. Therefore, it is not only about marketing, but also about economics and behavioral science in general. According to [1] the term consumer behavior can be defined as behavior that involves "all activities associated with the purchase, use and disposal of goods and services, including the consumer's emotional, mental and behavioral responses that precede or follow these activities." [2] Explained consumer behavior "as the study of individuals, groups, process and organizations they use to secure, select, and arrange of experience, products, services, experiences, or ideas to satisfy the consumer and society". That area of marketing has been researched dynamically and curiously

since the 1950s and 1960s [3] and, since then, the definition of consumer behavior has remained the same, but everything else is changing - from shopping habits to products and technology.

Alluding to technology, the World Wide Web, invented by Berners-Lee, was developed in 1990, and since then, the mass consumption of the Internet has begun [4]. As the popularity and use of the Internet grows, new technologies are emerging, and one of them are web shops. Furthermore, the development of web shops has influenced the change in customer behavior [5] because those (web shops) are so prevalent nowadays that it is impossible to observe consumer behavior without considering a way of shopping in which physical presence is not required at all. However, with the development of Internet technology, online marketing is also evolving, which brings major changes in marketing practices and changes some of the basic principles of marketing [6]. In addition, the behavior of e-customers is quite unpredictable [7], which raises additional questions about this topic. There is a lot of research on the topic of online shopping [8-11], but [12] states that, until 2002, only 9% of the papers include e-customers topics.

Before discussing the behavior of online consumers in shopping, it is a good idea to mention a study that examined what influences the intention for online shopping. Research [13] has shown that intent is influenced by usefulness, ease of use and enjoyment. Usefulness can be explained as the individual's perception that using the new technology will enhance or improve performance [14, 15]. Ease of use is defined as the individual's perception that using the new technology will be free of effort. Enjoyment is explained as intrinsic motivation. Furthermore, [16] in their paper, present a model in which consumers' attitudes to e-commerce is influenced by convenience, website design, security, and time saving. And what do e-consumers want from web shops? According to [17], e-consumers "seek for clear information about product and service. Time saving, connivance, wide variety and better price on time are all important factor for online shopping".

In their research about consumer behavior in online shopping, [18] concluded that there is a strong bond between consumer behavior and online selling of products and their marketing strategies. [19] have identified several factors that influence e-shopper behavior, and the same factors have been used to build a research model of this paper. The factors that have an effect on online consumer behavior mentioned by these authors are: e-satisfaction, trust and online risk, e-loyalty, online services, perceived value, firm reputation, privacy and functionality. A study conducted among students by [6] showed that some of these factors have more and some less impact on this target group. Therefore, those factors which influence the behavior of online customers more are functionality, privacy, firm reputation, perceived value and trust. In order to build the model for this research, the parameters used are: perceived value and firm reputation (relates to the perceived value that the consumer expects from the purchase and the process itself, and the trust in the brand, its reputation), e-satisfaction (refers to the satisfaction of the customer in terms of satisfying the needs, feel of respect and the cost/price of the product [20], online services (related to the professionalism of the service, consumers should be aware of it, notice it and feel it) and e-loyalty. E-loyalty, as well as loyalty in physical shopping, refers to the link between the brand and the consumer, which causes the consumer to repeat the purchase with the same brand because of a good previous experience with the service, products or the whole process [6, 21].

[22], on the other hand, show other factors that influence online consumer behavior. They mention the relationship among demoFigureics, personal characteristics, and attitudes towards online shopping. Also, they mentioned that those who have a "wired" lifestyle are more willing to shop online. The same is true for those who are more limited over time. This is certainly true, but the question is how many more people today have that kind of lifestyle. Many more! This is one of the reasons why e-commerce is developing at a high speed. According to [24] "they suggested that customized information should be provided to the online shoppers who buy standard or repeat items, which can lead to shoppers gaining a feeling of increased convenience, and which in turn will allow them to make quick purchase decisions."

As in the offline shopping form, online shopping also has different types of consumer personality that affect the purchase itself. "Some online consumers are an adventurous explorer, fun seeker, shopping lover, and some are technology muddler, hate waiting for the product to ship" [25]. To better understand the behavior of e-consumers, [23] come to interesting conclusions and facts about the behavior of e-consumers:

- Online shopping is getting popular among the young generation as they feel it is more comfortable, time saving and convenient,
- Customers compare prices from different brands more and more in online shopping than in physical shopping,
- Security has been recognized as a major barrier to online shopping,
- Online shopping is an emerging trend among the 18-33 age group
- Most online shoppers are employed
- Online shoppers are more motivated to buy online as payment is easier (and it is time-saving)
- Online shopping helps when comparing products from different online shopping websites.

3 RESEARCH METHODS

E-consumer behavior was observed with the Mlinar web shop. Mlinar is the largest bakery industry in the region, with headquarters in Croatia. It has a network of over 200 stores, which makes this brand nationally recognizable. As such, Mlinar's web shop is the only one in Croatia to own a national web shop for cakes and small cakes. The web shop started its operation in June 2019 and, thanks to strong marketing efforts, it is now recognized nationwide.

3.1 Sample and Research Design

Research was done in the period from November 1st 2019 to February 1st 2020 on a sample of 284 examinees who visited the Mlinar web shop and bought something there. The research i.e. preparing the questionnaire, as well as its

processing, was done in accordance with the several aims set previously:

- Identifying characteristics and preferences of Mlinar's online shoppers
- Identifying the perceived value of Mlinar's reputation with online shopping
- The satisfaction with buying on Mlinar's web shop
- The satisfaction with services on Mlinar's web shop
- The intent/recommendation of future shopping on Mlinar's web shop with the aim of creating loyalty.

The examinees were familiarized with the aim of research. The first part of the questionnaire was about examining the purchasing habits of examinees. The second part of the questionnaire was based on the satisfaction with shopping, and the third one was created so that there would be answers to the questions related to the intentions of shopping by the examinees so far and in the future. The last part of the questionnaire was about the socio-demoFigureic characteristics of the examinees. Research was conducted by using a highly structured questionnaire. Majority of the questions were closed, using a five-point Likert scale, where 1 indicated the lowest and 5 the highest level of satisfaction.

Detailed sample description is given in Tab. 1.

Table 1 Sample description

		N	%
Years of age*	20 – 30	21	7,4
	31 – 40	118	41,5
	41 - 50	68	23,9
	Over 51	72	25,4
Gender**	Woman	240	84,5
	Men	42	14,8
Employment status***	Unemployed	22	7,7
	Employed	237	83,5
	Student	16	5,6
	Retired	7	2,5
Level of education****	High school	92	32,4
	Baccalaureus	53	18,7
	Magister	104	36,6
	Magister of science	23	8,1
	PhD	8	2,8
Monthly household income*****	< 400 €	8	2,8
	401 – 800 €	28	9,9
	801 – 1200 €	75	26,4
	1201 – 1600 €	58	20,4
	> 1601 €	95	33,5

*Missing 5 (1,8%), ** Missing 2 (0,7%), *** Missing 2 (0,7%), **** Missing 4 (1,4%), ***** Missing 20 (7%)

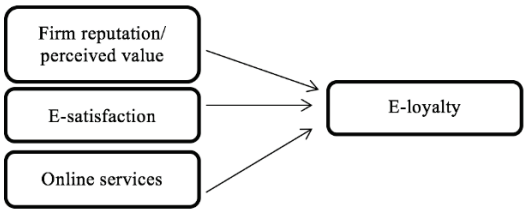

Figure 1 Conceptual model

As was previously stated in the paper, the authors created a model where they want to show how the independent variables (firm reputation/perceived value, e-satisfaction and online services) affect the dependent one (e-loyalty – Fig. 1). The authors adopted measurement scales from [26] for the firm reputation/perceived value, e-satisfaction and online services and from [27] for the e-loyalty value.

The research results were obtained using the statistical package SPSS 23.0. Descriptive statistics, multivariate analysis (reliability analysis, correlation analysis and linear regression), and analysis of variance (ANOVA) were used for data analysis.

3.2 Research Results

The first part of research was about examining the habits of shopping i.e. whether the examinees rather shopped in Mlinar stores or the web shop. The results showed that 75,4% of examinees tried torts/cakes by Mlinar prior to their first online purchase, while 61,6% of examinees bought a tort/cake earlier in one of Mlinar's stores. The majority of examinees (72,5%) first bought a tort/cake by Mlinar on the web shop. The other part of examinees (27,5%) shopped for torts/cakes on Mlinar's web shop prior to that (1× 4,7%, 2× 13,7%, 3× 4,6%, 4 and more times 4,5%). A very good piece of information for Mlinar is the fact that 63% of examinees agree they would decide to shop for Mlinar's torts/cakes even if they didn't have a web shop, which proves their recognizability and the quality of their products and services.

When identifying the intent to buy on a web shop, the results showed that 40,5% of examinees, prior to arriving at Mlinar's web shop already knew what they will buy and did so. An interesting piece of information is that 39,4% of examinees did not know which article they will buy prior to arriving at Mlinar's web shop, but they bought something anyway. 6,7% of examinees knew what they wanted to buy before arriving at the web shop, but they ended up deciding for another article, and 13,4% of examinees bought another article, along with their planned one.

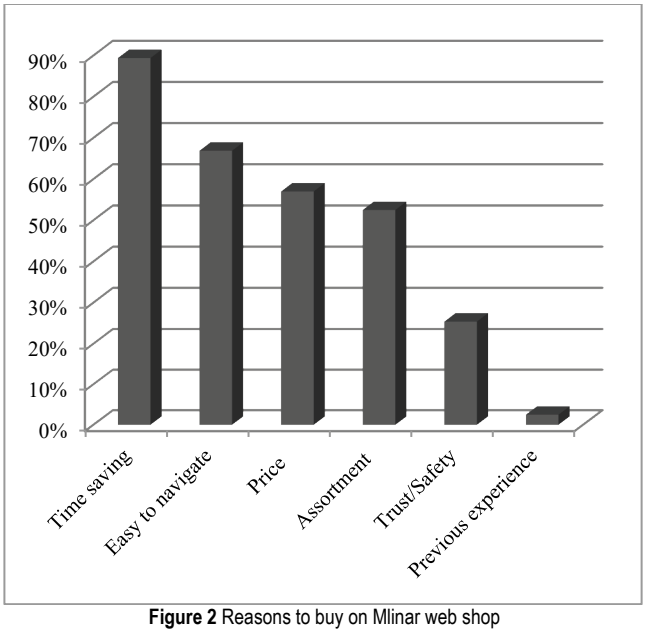

Figure 2 Reasons to buy on Mlinar web shop

The Fig. 2 shows which are the most frequent reasons of buying on Mlinar's web shop. As can be seen, saving time is the biggest reason for buying on a web shop (89,4% of examinees). Apart from the reasons shown on the figure, the remaining reasons are sales, not knowing about other web shops, recommendations, and getting the tort from the "neighborhood" Mlinar store. The majority of examinees (58,6%) stated that the cause of ordering torts/cakes were birthdays, and less than 10% said that it was anniversaries, holidays, parties etc.

Furthermore, results showed that 38% of exam Mlinar's web shop on Mlinar's website, then using Facebook (30,3%), and via recommendation by a friend or a family member (19,7%). The most frequent channels using which they arrived at Mlinar's web shop are the direct input into the search engine (50,7%) and using Mlinar's website (30,6%). Social networks, as a channel using which examinees arrived at the web shop, were represented, but not to the extent as the previously stated channels (11,6% using Facebook posts or ads, 3,9% using Instagram posts or ads).

As was stated earlier in the paper, a conceptual model was set using which it was attempted to find out the influence of certain variables on the dependent variable. Therefore, the research wanted to examine the way in which firm reputation/perceived value, e-satisfaction and online services affect e-loyalty (Fig. 1).

Prior to doing a correlation analysis and regression, a descriptive analysis will show the mean values of certain variables within a determined construct. Fig. 3 shows that the attitudes of examinees are positive for the firm reputation/perceived value i.e. the majority of examinees completely agrees that online shopping on Mlinar's web shops makes them happy (65,1%), consider that the shop is customer-oriented (59,2%), and that they partially or completely agree that they will look to them first when buying torts/cakes online (49,6%).

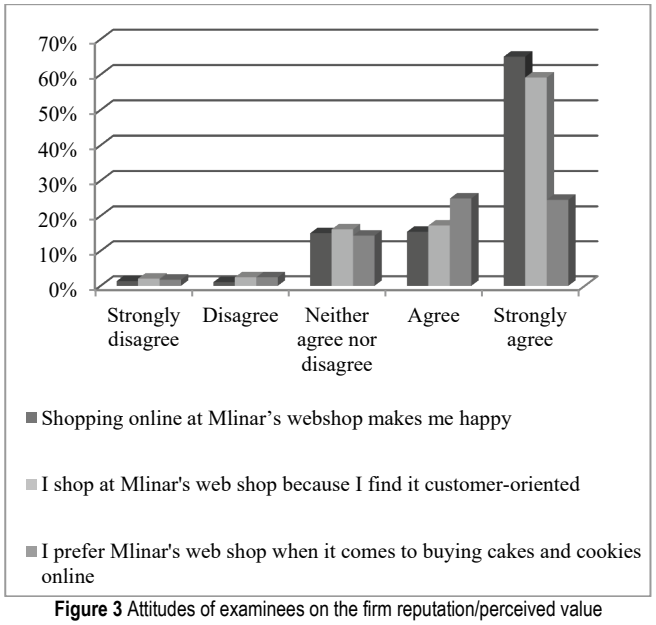

Figure 3 Attitudes of examinees on the firm reputation/perceived value

When the attitudes of examinees on e-satisfaction are observed, the results show that examinees are satisfied with all the variables observed i.e. they are completely satisfied with the prices (52,8%), with their expectations (66,9%), with the price/quality ratio (58,1%), and the range of products (48,6%) (Fig. 4).

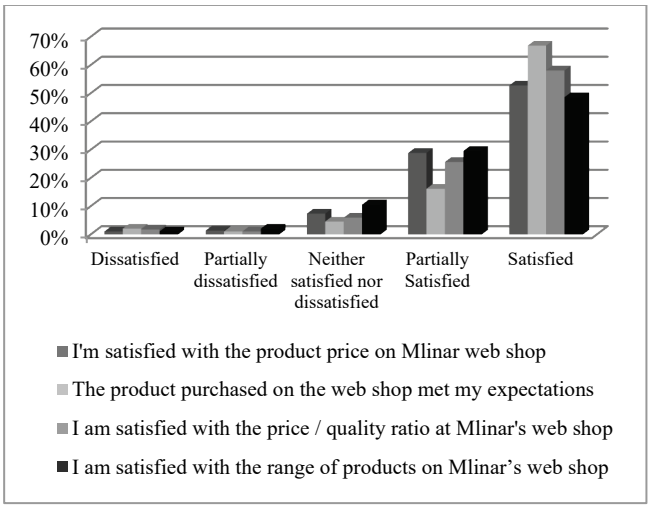

Figure 4 Attitudes of examinees on e-satisfaction

If we look at the attitudes concerning online services, the examinees are completely satisfied with the quality of information on Mlinar's web shop (57,7%), the quality of the purchase process (73,9%), and customer support (52,5%). The question about the security of the transaction was to be expected (25,5% of examinees were partially or completely satisfied) (Fig. 5).

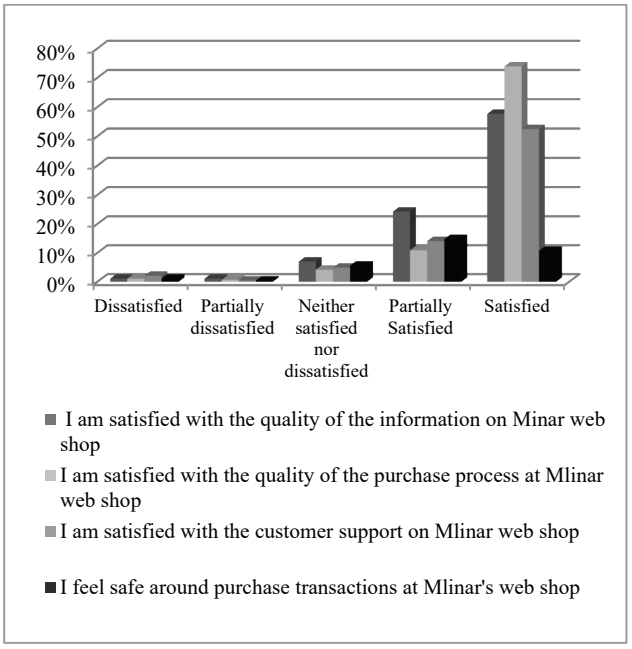

Figure 5 Attitudes of examinees on online services

The following figure shows the attitudes of examinees on e-loyalty, which was observed as a dependent variable in the conceptual model. Namely, 69,7% of examinees

completely agree that they will keep following the news on the web shop (sales), 78,2% of them intend on buying again on the web shop, 84,2% will say positive things about the web shop, and 86,3% of examinees would recommend online shopping of torts and/or cakes on Mlinar's web shop to their friends or family (Fig. 6).

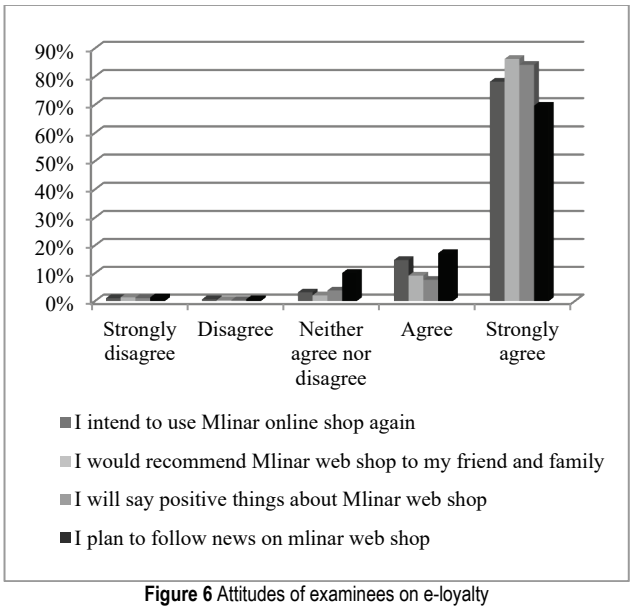

Figure 6 Attitudes of examinees on e-loyalty

Before examining the mutual correlation and performing the regression analysis, it is necessary to examine the Cronbach alpha coefficients of all observed variables. The following is an interpretation of the items used (Cronbach alpha):

- Firm reputation/perceived value (α = 0,741)
- E-satisfaction (α = 0,870)
- Online services (α = 0,899)
- E-loyalty/Intention (α = 0,885)

The Cronbach alpha coefficient is between 0,741 and 0,899. All variables have an acceptable and good consistency, which confirms good reliability and stability of the measurement instrument [28][1] (Fig. 7).

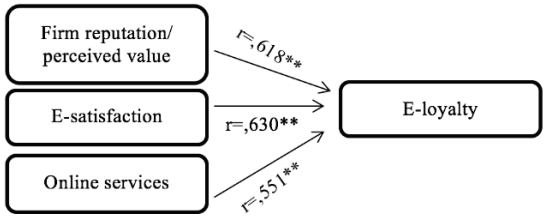

Figure 7 Correlation analysis
**Correlation is significant at the 0,01 level

Regression analysis is used in order to determine the correlation between the observed variables, i.e. the effect of the dependent variables on the independent variable. The influence of individual predictors on consumers' e-loyalty on the web shop was determined by regression (Tab. 2). The model explains the total of 58% of the variance.

Table 2 Linear regression model

Predictor variables	βeta	*t*-value	Significance (*p*)	Model summary
Firm reputation/ perceived value	,377	7,245	,000	R = 0,720 R^2 = 0,581 F = 93,883
E-satisfaction	,364	5,746	,000	
Online services	,097	1,552	,122	

Dependent variable: consumers' e-loyalty on web shop

4 DISCUSSION OF RESULTS

Electronic trade for business subjects enables doing business on a global market, offering various benefits for shopping along the way. Even though electronic trade undoubtedly provides advantages, the problems that shoppers face are objectively larger than the problem of traders. The electronic market brings a dose of risk in regards to the classic market because the buyer cannot feel, smell, start, drive, weigh the service/merchandise etc. before shopping for the first time. Therefore, investing into e-loyalty is necessary for the majority of business subjects. The dangers for online shoppers are also the phenomena which cannot be considered fraud, but it can increase the expenses for customers and/or harm them. Research showed that customers appreciate the reputation of a certain web shop because, that way, they can ensure there will be no fraud and they can realize electronic trade so that they extract the maximum benefit and satisfaction from it. Guided by the problems set, this paper had the aim of examining the preferences of customers of specific products. Reasons to buy on Mlinar web shop shows the most significant variables that business subjects can relatively quickly accept and implement into their business. The customers are used to the option of finding information they are interested in at that on the internet. Namely, examinees stated that online shopping enables them to save time and, therefore, business subjects should invest in technology/web shops which simplify purchasing and state this as a competitive advantage. The majority of examinees already shopped online and consider the advantage of e-trade to be quicker and easier shopping, as well as comparing prices. Generally speaking, in order to use the full potential of the advantages and opportunities of e-trade, the observed business subject should develop and accept certain electronic strategies in business. Such an e-strategy must be appropriate for the industry, be constantly innovated, and create competitive advantages and new values, which is presented in the model – the variables firm reputation/perceived value, e-satisfaction and online services affect the web shop and create e-loyalty in their users. Research proved that focusing attention on controlling the relations with consumers/clients, and primarily doing so through tracking user satisfaction and investing in technology i.e. additional services on the web shop and

[1] _ > .9 – Excellent, _ > .8 – Good, _ > .7 – Acceptable, _ > .6 – Questionable, _ > .5 – Poor, and _ < .5 – Unacceptable

maintaining credibility can actually create a partner relationship. Results showed that, by building a relationship with the consumers within the observed industry, it is possible to create web shop user loyalty which is presented through the intent of future shopping and recommendations to other customers. The trend which is rapidly growing is the growth in the mobile dimension i.e. buying using mobile devices. Taking the aforementioned into account, the recommendation is to expand the model using additional variables which will include mobility i.e. location marketing where every visit to Mlinar will result in sending information to the mobile device. Research confirmed that, in the context of global economy and a large presence of various products and services which are almost universally available, consumers want a product and/or service which are appropriate for them or suit them completely – mass production is now replaced by mass personalization. The next step is to personalize the profiles of users who buy online and track their consumer habits, especially with wide application products such as torts and cakes, which were the object of this research. We can conclude that there is a proportionate relationship between the successfulness of a web shop and user satisfaction because it enables user communication, which is key for keeping them as consumers by increasing the quality of service for consumers and their overall shopping satisfaction, which is defined by the research results. In accordance to research results and the statistical analysis done, we can confirm the hypotheses set i.e. that firm reputation/perceived value, e-satisfaction and online services have a positive impact on e-loyalty.

5 CONCLUSION

The authors of the paper wanted to examine which marketing activities can business subjects use to affect the user satisfaction, through tracking the examinees' shopping habits, shopping satisfaction and answering the questions connected to their intents of shopping so far and in the future on the observed and specific business subject. The aim of the research was to see whether there is a connection between the efficiency of a web shop and the influence on consumer behavior. Electronic trade service users have the option of comparing online shops and can, in a short time, change the shop where they wish to buy a product. Because of that, it is of the utmost importance for the business success of a web shop to define a business strategy which will remove the risks and losses in doing business caused by a drop in loyalty of a consumer of e-trade products and services. In order to examine this, the authors performed a research in which they wanted to see what is important for buyers during online shopping i.e. which elements can business subjects implement into their strategy in order to exert influence on consumer behavior. Generally speaking, e-loyalty presents the basic aim to which business subjects, who deal in both online and offline business, strive. Contemporary business demands business subjects to interact directly with the consumers so that, based on the information gathered, they can influence the offer of their products and services, but also marketing activities in general. Unlike the classical offline transaction modes which focused only on sales, today there is a trend of developing and nurturing a relationship with the consumers through the communication process which goes on prior to shopping and after it. The paper sets a conceptual model which attempted to understand in what way do firm reputation/perceived value, e-satisfaction and online services affect e-loyalty. The research was done on examinees who bought a product on the Mlinar web shop. In accordance with the research results, we can conclude that the observed variables can influence the development of e-loyalty towards the subject observed (Mlinar) and its consumers. Even though the observed business subject primarily achieves sale through offline channels, the concept of traditional trade is losing ground to the new, contemporary way of electronic business so it is, therefore, necessary to build a clear strategy of acting in the electronic market. The limitations of the paper are the fact that only one business subject selling specific products was observed. This definitely limited research results, given that the offer of such products is limited. Also, in a logistical sense, the buyer must physically get the product, meaning that in the post-shopping activities there is also the experience they had in the store. A limitation can also be the fact that the observed business subject only recently started using the web shop as a sales and distribution channel for their products and is insufficiently familiarized with their consumers in order to be able to get to know their habits, given the fact that there isn't a large number of consumers who made several purchases. Also, this paper observed a business subject who introduced a relative innovation in the sale of the aforementioned products by way of internet, given that there isn't a similar model (when the observed product group is concerned). This is precisely the recommendation of the authors for further research – to expand it to other industries dealing in the similar model where the product needs to be ordered online but taken by the customer themselves. Given that the authors only examined those people who bought the product online, the aim of the authors is also to survey the customers who do not buy their products online and those who have the intent to do so but give up at a certain point. That way, there could be a more detailed insight into the pre-purchase activities and reasons why some customers give up during the act of shopping. The result is in the fact that tracking consumer habits is necessary in order for business subjects to be able to define key variables which can serve as specific measures to advance web shops, with the aim of influencing consumer behavior and their travel before and after shopping.

6 REFERENCES

[1] Kardes, F., Cronley, M., & Cline, T. (2011). *Consumer Behavior.* Mason, OH, South-Western Cengage.

[2] Kuester, S. (2012). *MKT 301: Strategic Marketing & Marketing in Specific Industry Contexts*, University of Mannheim.

[3] Kassarjian, H. H. (1971). Personality and consumer behavior: A review. *Journal of marketing Research*, *8*(4), 409-418. https://doi.org/10.2307/3150229

[4] Berners-Lee, T. & Fischetti, M. (2001). *Weaving the Web: The original design and ultimate destiny of the World Wide Web by its inventor.* DIANE Publishing Company.
[5] Hernández, B., Jiménez, J., & Martín, M. J. (2010). Customer behavior in electronic commerce: The moderating effect of e-purchasing experience. *Journal of business research,* 63(9-10), 964-971. https://doi.org/10.1016/j.jbusres.2009.01.019
[6] Mohammed, R. A., Fisher, R. J., Jaworshi, B. J. & Cahill, A. M. (2002). *Internet Marketing-Building Advantage in a Network Economy.* International edition, McGraw-Hill, Irwin Marketspace.
[7] Kwan, I. S., Fong, J., & Wong, H. K. (2005). An e-customer behavior model with online analytical mining for internet marketing planning. *Decision Support Systems*, 41(1), pp. 189-204. https://doi.org/10.1016/j.dss.2004.11.012
[8] Aldridge, A., White, M., & Forcht, K. (1997). Security considerations of doing business via the Internet: cautions to be considered, *Internet Research,* 7 (1), 9-15. https://doi.org/10.1108/10662249710159809
[9] Barnard, L. & Solms, R. (1998). The evaluation and certification of information security against BS 7799. I*nformation Management & Computer Security,* 6 (2), 72–77. https://doi.org/10.1108/09685229810209397
[10] Feindt, S., Jeffcoate, J., & Chappell, C. (2002). Identifying success factors for rapid growth in SME e-commerce. *Small business economics*, 19(1), 51-62. https://doi.org/10.1023/A:1016165825476
[11] Hoffman, D. L., Novak, T. P., & Peralta, M. (1999). Building consumer trust online. *Communications of the ACM*, 42(4), 80-85. https://doi.org/10.1145/299157.299175
[12] Ngai, E. W. T. & Wat, F. K. T. (2002). A literature review and classification of electronic commerce research. *Information and Management,* 39, 415-429. https://doi.org/10.1016/S0378-7206(01)00107-0
[13] Monsuwé, T. P., Dellaert, B. G., & De Ruyter, K. (2004). What drives consumers to shop online? A literature review. *International journal of service industry management*. 15(1), 102-121. https://doi.org/10.1108/09564230410523358
[14] Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology, *MIS Quarterly*, 13(3), 319-40. https://doi.org/10.2307/249008
[15] Davis, F. D. (1993). User acceptance of information technology: system characteristics, user perceptions and behavioral impacts, I*nternational Journal of Man-Machine Studies*, 38(3), 475-87. https://doi.org/10.1006/imms.1993.1022
[16] Sultan, M. U. & Uddin, N. (2011). Consumers' attitude towards online shopping. *MBA Thesis*. Business Administration. Uppsala University. Visby.
[17] Kavitha, T. (2017). Consumer buying behavior of online shopping-A study. *International Journal of Research in Management & Business Studies*, *4*(3), 38-41.
[18] Nazir, S., Tayyab, A., Sajid, A., Rashid, H., & Javed, I. (2012). How online shopping is affecting consumers buying behavior in Pakistan? *International Journal of Computer Science Issues*, 9(3), pp.486-495.
[19] Kotler, P. & Armstrong, G. (2010), *Principles of Marketing,* (13th edition). New Jersey: Pearson Education.
[20] Lin, C. C. (2003). A critical appraisal of customer satisfaction and e commerce. *Managerial Auditing Journal*, 18(3), 202-212. https://doi.org/10.1108/02686900310469952
[21] Gommans, M., Krishman, K. S., & Scheffold, K. B. (2001). From brand loyalty to e-loyalty: A conceptual framework. *Journal of Economic & Social Research*, *3*(1).
[22] Bellman, S., Lohse, G., & Johnson, E. (1999). Predictors of online buying behavior. *Communications of the ACM*, 42(12), 32-38. https://doi.org/10.1145/322796.322805
[23] Amit, K. S. & Sailo, M. (2013). Consumer Behavior in Online Shopping: A Study of Aizawl. *International Journal of Business & Management Research*, 45-39.
[24] Baba M.M. & Siddiqi M. A. (2016). *Attitude of Consumers towards Online Shopping.* Chapter 11, Marketing in Emerging Economies, Manakin Publishers.
[25] Rahman, M. A., Islam, M. A., Esha, B. H. & Sultana, N., Chakravorty, S. (2018). Consumer buying behavior towards online shopping: An empirical study on Dhaka city, Bangladesh. *Cogent Business & Management*, *5*(1), 1514940. https://doi.org/10.1080/23311975.2018.1514940
[26] Farah, G. A., Ahmad, M., Muqarrab, H., Turi, J. A., & Bashir, S. (2018). Online Shopping Behaviors among University Students: Case Study of Must University. *Advances in social Sciences Research Journal*, 5(4), 228-242. https://doi.org/10.14738/assrj.54.4429
[27] Cater, T. & Cater, B. (2010). Product and relationship quality influence on customer commitment and loyalty in B2B manufacturing relationships. *Industrial Marketing Management*, 39(8), 1321-1333. https://doi.org/10.1016/j.indmarman.2010.02.006
[28] George, D. & Mallery, P. (2003) *SPSS for Windows step by step: A simple guide and reference*. 11.0 update (4th ed.), Boston: Allyn & Bacon.

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Original scientific paper

Prioritization of Brand Equity Components Using an Integrated Structural Equation Modelling and Fuzzy AHP

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Abstract: Brand equity of health tourism is the set of assets (or liabilities) of the brand in relation to the name and symbol of the tourism destination that cause changes in the value of services and experiences that are determined there. Considering the characteristics and cultural, social and economic capacities of Iranian tourism destinations, this study tends to develop a model for brand equity in health tourism, derived from the Acker model, according to Iran's conditions and studies conducted. First, previous studies in this regard were carefully reviewed by meta-synthesis. Then the mixed method including qualitative and quantitative methods was applied. The data were analyzed using grounded theory and MAXQDA18 software and then using structural equation method and fuzzy Analytic Hierarchy Process (Fuzzy AHP). Statistical population included experts including professors in the field of marketing and health tourism specialists for qualitative part, and foreign users of health tourism services of Iran for quantitative part. The results showed that hospital brand equity is directly affected by brand awareness, brand association, perceived quality, brand loyalty, social responsibility, firm value and customer value. As a result, at the national level, investing in this sector and branding and paying attention to brand equity of health tourism can make Iran one of the best health tourism destinations in the world.

Keywords: Analytic Hierarchy Process (AHP); brand equity; fuzzy; grounded theory; structural equations

1 INTRODUCTION

A brand without awareness is just a word on the product. The goal of investing in advertising is to reveal the meaning of the brand and spread it as much as possible so that people can try the products offered. Aaker [1] defined brand awareness as the ability of potential buyers for recognition or recall of a brand of a particular product category. Brand awareness refers to the power of brand memory, that is, how easy it is for consumer to remember the brand. Brand recall is the most common method of evaluating brand awareness [2]. Keller [2] believes that brand awareness can increase tendency towards the brand as a part, a chosen form, and even a set of interest. Recognition refers to correct differentiation of a brand from other brands by customers and recall refers to ability to recover brand from memory when accompanied by a guide. There are a wide range of various brands on the market; on one hand, there are famous brands for consumers and, on the other hand, there are brands of which customers are less aware [3]. Customer-based brand equity occurs when the customer has a high level of awareness and closeness with the brand and keeps strong and unique brand associations in his mind [3]. Tourism industry, as one of the most diverse and largest industries in the world, is the most important source of income and job opportunities for many countries in the world. This industry is important in two main ways: first, it provides nations with familiarity with other cultures, races, ethnicities, lands, dialects, etc., and second, it is economically the source of income and currency. Development of tourism industry, in addition to having broad economic dimensions such as job creation, income generation, poverty reduction and increased welfare in society, also affects the expression of national identity and social security and expansion of social justice in society [4]. According to definition of the World Tourism Organization, one of the goals that encourages tourists to travel is to gain health. Currently, tourism has become so important in socio-economic development of countries that economists have called it invisible exports. Tourism, as the third largest industry in the world, is very important. One of the potentials of tourism is travel for the purpose of treatment. Health and healthcare tourism has grown dramatically in recent years. Increased demand for health services due to aging population in developed countries, availability of quality and affordable medical services in developing countries compared to developed countries, long waiting lists for surgery in developed countries, and lack of health insurance are the most common factors for medical travel. Among the various fields of tourism, health tourism and its sub-sectors due to their competitive capabilities and advantages have received double attention and show rapid growth among the types of tourism [5]. The World Tourism Organization defines health tourism as the use of services that improve or enhance one's health and morale (by using mineral water, weather, or medical interventions) in a place outside one's residence and last more than 24 hours [5]. Health tourism includes people and groups who travel to take advantage of climate change (for medical and therapeutic purposes), to use mineral water, to recover, to undergo treatment, and so on. Many patients also go to important and reputable medical centers in developed countries or capitals of countries that benefit from health facilities for treatment. This type of tourism is very prestigious and popular. At the macro level, governments are interested in taking advantage of economic benefits of this industry. Currently, increasing competition has begun between different countries, especially developing Asian countries, to attract health tourists. On the other hand, health tourism has also flourished in developing countries. Globalization and liberalization of trade in the field of health services became the basis for rapid growth of this type of tourism. According to the studies conducted in the field of health tourism, this industry can be divided into three types: A) health tourism: travel to health villages and areas with mineral springs and hot water, to get rid of stresses of daily life and rejuvenate without medical intervention and supervision; B) medical tourism (rehabilitation): travel to use

natural healing resources (such as mineral water, salt and sludge) to treat some diseases or to recover under medical supervision and intervention; C) medical tourism: travel to treat physical illnesses or perform a variety of surgical procedures under the supervision of physicians in hospitals and medical centers. In a study conducted by the United Nations, factors such as advanced facilities, high quality and low cost of treatment have been cited as the most important factors in attracting patients in the field of medical tourism.

According to Shabani and Taleghani [6], every tourist who enters the country creates jobs for three people; in medical tourism, doctors, nurses, etc. will be added to these three people. Every health tourist imports currency three times as much as an ordinary tourist. In the field of medical tourism, not only the tourist attraction is considered, but also medical tourism strengthens the position of the country in terms of science, politics, society and region. If health tourism is considered a priority, Iran can potentially prevent the outflow of currency and manpower to other countries. Iran has capabilities in this field such as recombinant drugs, stem cells, ophthalmic and cancers treatments, as well as low medical costs compared to European and American countries, low cost of accommodation compared to the Persian Gulf region, religious commonalities, proximity to the Arab market, similarity of culture and dialect with some neighboring countries and natural potentials such as climatic diversity as a four-season country, sludge therapy, sand therapy, mud volcanoes and hydrotherapy and existence of more than a thousand mineral springs and other natural attractions that have the necessary potential in the field of health tourism and particularly medical tourism. On the other hand, the benefits of health tourism can lead to economic development in our country, which is heavily dependent on oil revenues. In the perspective of the contemporary tourism industry, destination brand development has become a strategic tool worldwide due to the increasing competition of tourism destinations. A successful tourism brand can be very effective in increasing the competitive advantage of the destination, attracting tourists and as a result increasing the revenues from the tourism industry and prosperity of the national economy. The tourist destination brand can be used as a way to communicate the unique identity of the tourist destination by differences of that destination with its other competitors. In marketing, a brand is widely used for products and services. A tourist destination can also be considered as a product or a brand that contains tangible or intangible features. Although destination brand is a new concept, many tourism destinations around the world are trying to adopt brand strategies for their destinations, as manufacturers of goods do, in order to distinguish their identity from their competitors and emphasize the uniqueness of their products. Tourist destination brand can be used as a way to communicate the unique identity of the tourist destination by differences of that destination with its other competitors. In the past decade, the concepts of brand, reputation and social policy making have been widely used in national and international communities, urban and national tourism and economic development; currently, there are approximately 300 countries and administrative regions in the world, 3400 large cities regardless of their size, current reputation, trade centers and resources have faced competitive challenges in global marketing through development and adaptation or somehow management of national and international reputation. Destination reputation plays an important role in the tourism industry. A more popular destination will be more reliable and trustworthy than lesser-known destinations. Strong reputation has a positive effect on destination image, perceived value, destination loyalty and, ultimately, satisfaction [3]. The destination brand is more complex than the product brand and firm brand; because it is involved with a larger number of stakeholders in products, services, resources and even different sectors of the economy. Countries, cities or regions should express the benefits of traveling to that region and create a good image of it in the minds of tourists, rather than creating tourism infrastructure and offering the right products and services. They should also strive to improve the brand equity [7].

2 THEORETICAL FOUNDATIONS

As Clare believes, there are different definitions of brand equity that are generally considered from different perspectives. Brand equity can be discussed from the perspective of the manufacturer, retailer or customer. While manufacturers and retailers tend to engage in strategic brand equity functions, investors are increasingly interested in the defined financial concept. Advocates of the financial view define brand equity as total value of a brand that is a separate asset when it is sold or added to the balance sheet. Other definitions that agree with this view consider brand equity as cash flows that have an upward trend over time for branded goods versus non-branded goods. Brand equity is the value that a brand adds to a product. In general, brand equity is the consumer's perception of all the advantages that one brand has over other competing brands. Consumer-based brand equity is a strategic role and an important competitive advantage that is considered in strategic management decisions and has a great impact on marketing decisions. Keller defines brand equity as distinctive effect of brand knowledge on consumer response to brand marketing [2]. In general, brand equity is the consumer perception of all the advantages and superiority that a brand has compared to other competing brands. According to Aaker [8], brand equity represents the price difference that a strong brand attracts in its sales compared to a medium brand.

2.1 Theoretical Framework for Evaluating Customer-Based Brand Equity

Boo et al. [9] defines the brand equity of a tourist destination as follows: Brand assets or liabilities in relation to the name and symbol of the tourist destination that add value to the services and experiences provided there. According to a study conducted by Wang et al. [10], brand equity output was considered by consumers' preferences to buy that product compared to its competitors. As noted in the theoretical literature of the present study, brand equity is a multifaceted and complex concept; in this study, the most important items tested empirically have been considered. Among various models for evaluating brand equity, this study adopted the model developed by Konecnik Ruzzier

[11], which has been experimentally tested. The following is a brief description of each of these factors and their associated hypotheses:

Tourist destination brand awareness: The purpose of tourist destination marketing is to increase awareness of the tourist destination by creating a unique brand. Aaker [1] considers brand awareness as the power of a potential buyer in recall and recognition that put the brand in certain categories of products. He introduced several levels of brand awareness, starting with brand recognition and ending with the dominant brand. The dominant brand is a condition in which the brand is the only name that is recalled in the mind of the consumer in that product category. In this study, brand awareness means the ability of potential tourists to recognize and recall the tourism brand of Yazd as a tourist destination.

Tourist destination brand image: By definition, brand image is "perceptions of the brand that are reflected in the mind of the consumer by brand associations." The brand image does not necessarily have to be objective or reflect reality. For example, a customer's image of the quality of restaurant food can be based on the service provided by its staff rather than an objective assessment of the taste of the food. Likewise, the sun and the waves are reminiscent of Queensland.

Perceived quality: Perceived quality is defined as "consumer perception of the overall quality or superiority of a product or service over other options" [12]. Perceived quality is a competitive necessity, and today most companies are turning to customer-based quality as a strategic weapon [3]. In fact, perceived quality is not the real quality of the product, but the customer's mental evaluation of the product [12]. Like the brand image, perceived quality provides value to customers so that they have a reason to buy by differentiating the brand from competitors.

A study of past research on development of tourist destinations shows that only a few limited studies have examined perceived quality. This seems interesting because the overall evaluation of tourists from a destination is actually a combination of products, services and experiences. In all of these examples, quality plays a vital role in influencing consumer behavior. Because the tourism product is a service product, it is used to measure the perceived quality of the quality level. Parasuraman [13], by psychometric test and examining the common traits and characteristics of service quality, introduced five broad dimensions of service quality as follows: 1) perceptible factors of physical and tangible environment; 2) reliability; 3) accountability and assistance to customers; 4) guarantee of responsibility; 5) empathy.

Tourist destination brand loyalty: Although the concept of loyalty has been extensively studied in public marketing literature, brand loyalty in the form of tourist destinations has rarely been studied. It should be noted that loyalty increases the stability of the destination and advantages of brand loyalty for destinations include lower marketing costs, increased influence of travel business and repetition of word-of-mouth advertising. In their study, Pike [14] point out five factors that lead to a return to a destination already visited: 1) reduced risk of an unsatisfactory experience; 2) awareness that they are meeting people like themselves at that destination; 3) emotional attachment; 4) an opportunity to visit aspects of the destination that they have not experienced before; 5) showing others that their previous experience has been satisfactory.

3 LITERATURE REVIEW

Imani Yazdi and Ayoobi Yazdi [15] conducted a study on effective factors on brand equity in tourism in Yazd. The results of this study show that studies of the last thirty years considered it as the most important factor in evaluating the tourism destination brand by tourists. Brand loyalty, perceived quality, and tourism destination brand awareness also have a direct impact on brand equity of Yazd and loyalty is the most important effective factor.

Kotsi et al. [16] studied customer-centric brand equity in the context of an international stop destination: Dubai, on the way to France, Australia" and investigated the destination brand equity indicators and the reasons for choosing the destination. Liu et al. [17], using customer-based brand equity of luxury hotels, examined the elements of customer-centric brand equity of luxury hotels. Sam Liu and Chou [18] studied sustainable tourism development and promotion of adaptation process of brand equity, marketing and motivation and ways to identify ways of sustainable tourism development through brand equity dimensions.

Chahal and Bala [19] studied important elements of service equity in the health sector and introduced three variables, perceived quality, brand loyalty, and image, as the most important effective factors on service brand equity and examined the relationship between these variables and their effect on service brand equity in the health sector. The data was collected from 602 native respondents in India. The findings show that brand equity in health services is strongly influenced by brand loyalty and perceived quality. In addition, the perceived quality is effective on brand image, while brand image indirectly through brand loyalty is effective on brand equity (brand loyalty is mediator). Sarker et al. [26] developed service-branding theory by theorizing and confirming a customer-oriented service brand equity in airline service industry. Guo and Zhou [27] studied the effect of brand awareness, brand association, perceived quality, and customer satisfaction on customer-based brand equity in China mobile phone industry.

4 MAIN QUESTION

How are brand equity components in health tourism prioritized?

5 MATERIALS AND METHODS

In this study, first, the qualitative research method is used to present the model and then the quantitative research method is used to test the model. This study used a mixed exploratory research design. In the first phase, the model was extracted using the model of Strauss and Corbin [20], qualitative method of grounded theory, and it was tested using quantitative tools in the next phase.

5.1 Grounded Theory

Grounded theory was first proposed in 1967 by Glaser and Strauss. Strauss and Corbin [20] define grounded theory as follows: grounded theory is what is inductively derived from the study of a phenomenon and represents that phenomenon. That is, the theory is discovered, developed, and validated through systematic collection and analysis of data. Thus, data collection, analysis, and theory are in a reciprocal, two-way relationship. The ultimate goal of grounded theory is to provide comprehensive theoretical explanations of a particular phenomenon. In general, this strategy converts data from information resources into a set of codes, common codes into categories, and then categories into theory.

5.2 Data Analysis

As grounded theory was used, qualitative data analysis and paradigm model (regular or systematic design) were used. The regular design of grounded theory emphasizes the use of data analysis steps through open coding, axial coding, and selective coding, as well as presentation of a logical paradigm or visual representation of an evolving theory. Qualitative data analysis was performed with grounded theory and with the help of MAXQDA18 software, and as a result, the final model was extracted. This model was sent back to experts for review and approval and was approved by them. Fig. 1 shows the conceptual model of the study.

Figure 1 Conceptual model

5.3 Statistical Population

In the first phase, the statistical population consists of experts to the research topic. The conditions for certification of members were a strong scientific or experimental insight into the phenomenon, i.e. brand equity in health tourism. In order to benefit from opinions of experts who have scientific insight, professors of marketing and tourism and practitioners in the field of health tourism, as well as consultants and managers in this field who have a scientific and experimental background consist the statistical population. In this part, 22 marketing professors and health tourism specialists were interviewed, which was used to reach theoretical saturation.

In quantitative part, foreign patients who have used health tourism services in our country's hospitals and medical centers consist the statistical population. The questionnaire was distributed among 400 people and the number of healthy questionnaires was 380, which were quantitatively processed.

6 DATA ANALYSIS

A questionnaire was developed based on what was obtained from the qualitative part and was given to 400 foreign patients using medical services and finally 380 questionnaires were identified as healthy and processed by structural equation method and using SmartPLS software. The results are shown in Tab. 1. As can be seen, there is a significant relationship between stages of prioritization of brand equity components in health tourism with fuzzy AHP technique [21, 22], as follows:

6.1 Obtaining Component Weight by Fuzzy Analytic Hierarchy Process

1) Build a decision hierarchy tree

The first step in analytic hierarchy process begins with developing a decision hierarchy tree.

The levels of the decision hierarchy tree are:

First level (general goal): Prioritization of brand equity components in health tourism

Second level (criteria): 1) Perceived quality, 2) Creating value for the customer, 3) Other brand assets, 4) Brand association, 5) Social responsibility, 6) Brand awareness, 7) Brand loyalty, 8) Creating value for the organization;

Third level (sub-criteria): quality of hospitals, quality of medical staff, quality of up-to-date medical equipment, number and variety of medical centers, perceived quality of the country's brand, accountability, trust in customer purchasing decisions, consumer satisfaction, stakeholder interests, customer information process, treatment and traditional medicine, interaction with international medical organizations, applying ideas and opinions, paying attention to Iran's potential, managing activities and resources, the country's brand association, word of mouth, multimedia advertising, existence of relational channels, social accountability, communication with medical staff, attention to the environment, the country brand image, urban management in Iranian cities, geographical location, brand loyalty, hospitality, philanthropy of the medical staff, continuous evaluation of patients, advice to others, effectiveness and efficiency of the marketing program, brand development, competitive advantage, prices and profit margins.

2) Pairwise comparisons and calculation of the weight of variables

In this section, we can compute the weights of pairwise comparison matrix by Chang's method [25]. Respondents are asked to evaluate the importance of each factor in pairs. In fact, people's opinions are combined with each other after

completing the questionnaires. Next, to determine consistency or inconsistency of the judgments, it is necessary to calculate the inconsistency rate of each individual's judgment matrix.

$$\tilde{t}_{ij} = (a, b, c) \tag{1}$$

Using the decision maker's judgment, a comparison matrix (Eq. (2)) is formed using triangular fuzzy numbers based on judgments of several decision makers.

In this matrix, p_{ij} is the number of people judging the priority of element i over j.

$$\tilde{\boldsymbol{A}} = \begin{bmatrix} (1,1,1) & \begin{Bmatrix} \tilde{a}_{121} \\ \tilde{a}_{122} \\ \vdots \\ \tilde{a}_{12p_{12}} \end{Bmatrix} & \cdots & \begin{Bmatrix} \tilde{a}_{1n1} \\ \tilde{a}_{1n2} \\ \vdots \\ \tilde{a}_{1np_{1n}} \end{Bmatrix} \\ \begin{Bmatrix} \tilde{a}_{211} \\ \tilde{a}_{212} \\ \vdots \\ \tilde{a}_{21p_{21}} \end{Bmatrix} & (1,1,1) & \cdots & \begin{Bmatrix} \tilde{a}_{2n1} \\ \tilde{a}_{2n2} \\ \vdots \\ \tilde{a}_{2np_{2n}} \end{Bmatrix} \\ \vdots & \vdots & \vdots & \vdots \\ \begin{Bmatrix} \tilde{a}_{n11} \\ \tilde{a}_{n12} \\ \vdots \\ \tilde{a}_{n1p_{n1}} \end{Bmatrix} & \begin{Bmatrix} \tilde{a}_{n21} \\ \tilde{a}_{n22} \\ \vdots \\ \tilde{a}_{n2p_{n2}} \end{Bmatrix} & \cdots & (1,1,1) \end{bmatrix} \tag{2}$$

Table 1 Factor loading

Variable	Factor Loading	P-Value	Criteria		Factor Loading	P-Value
Brand Equity	0.625	0.001	Perceived quality	Hospital quality	0.845	0.001
				Medical staff quality	0.542	0.001
				Up-To-Date medical equipment quality	0.538	0.001
				Number and diversity of medical centers	0.831	0.001
				Country brand perceived quality	0.832	0.001
				Accountability	0.838	0.001
	0.546	0.001	Customer value	Patient trust	0.729	0.001
				Consumer satisfaction	0.804	0.001
				Stakeholder interests	0.714	0.001
				Customer information process	0.736	0.001
	0.371	0.001	Other brand assets	Traditional treatment and medicine	0.884	0.001
				Interaction with international medical organizations	0.860	0.001
				Applying ideas and opinions	0.847	0.001
				Paying attention to Iran's potential	0.831	0.001
				Managing activities and resources	0.719	0.001
	0.469	0.001	Brand association	Country brand association	0.714	0.001
				Word-of-mouth	0.734	0.001
				Multimedia advertising	0.725	0.001
				Relational channels	0.726	0.001
	0.252	0.001	Social responsibility	Social accountability	0.806	0.001
				Communication with medical team	0.797	0.001
				Attention to environment	0.715	0.001
	0.643	0.001	Brand awareness	Country brand image	0.899	0.001
				Urban management in Iranian cities	0.880	0.001
				Geographical position	0.882	0.001
			Brand loyalty	Country brand loyalty	0.678	0.001
				Hospitality	0.733	0.001
				Philanthropy of medical team	0.739	0.001
				Continuous assessment of patients	0.661	0.001
				Advice to others	0.670	0.001
		0.001	Firm value	Effectiveness and efficiency of marketing program	0.873	0.001
				Brand development	0.719	0.001
				Competitive advantage	0.834	0.001
				Prices and profit margin	0.863	0.001

3) Arithmetic mean of judgments: Arithmetic mean of decision-makers' judgment is calculated as the following matrix:

$$\tilde{\boldsymbol{A}} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \tag{3}$$

Arithmetic mean of decision-makers' judgments

$$\tilde{a}_{ij} = \frac{\sum_{k=1}^{p_{ij}} a_{ijk}}{p_{ij}} \quad i, j = 1, 2, \ldots, n \tag{4}$$

4) Calculation of the sum of row elements: The sum of row elements is calculated:

$$\tilde{s}_i = \sum_{j=1}^{n} \tilde{a}_{ij} \quad i = 1, 2, \ldots, n \tag{5}$$

5) Normalization: The sum of rows is normalized as follows:

$$\tilde{M}_i = \tilde{s}_i \otimes \left[\sum_{i=1}^{n} \tilde{s}_i \right]^{-1} \quad i = 1, 2, ..., n \tag{6}$$

Let show $\tilde{s}_i$ as (l_i, m_i, u_i); the Eq. (7) is calculated as:

$$\tilde{M}_i = \left(\frac{l_i}{\sum_{i=1}^{n} u_i}, \frac{m_i}{\sum_{i=1}^{n} m_i}, \frac{u_i}{\sum_{i=1}^{n} l_i} \right) \tag{7}$$

6) Determining the degree of probability of being larger: We calculate the degree of probability that each μ_i is larger than the other μis and call it $d'(A_i)$.

The degree of probability that the fuzzy triangular number $\mu_2 = (l_2, m_2, u_2)$ is larger than the fuzzy triangular number $\mu_1 = (l_1, m_1, u_1)$ is equal to:

$$V(M_2 > M_1) = \mathrm{Sub}_{y \geq x} \left[\min \left(\mu_{M_1}(x), \mu_{M2}(y) \right) \right] \tag{8}$$

This relation can be synonymously expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) =$$

$$= \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{Otherwise} \end{cases} \tag{9}$$

where, d is coordinates of the highest point in the communality region and collision of two membership functions μ_{M_1} and μ_{M_2}.

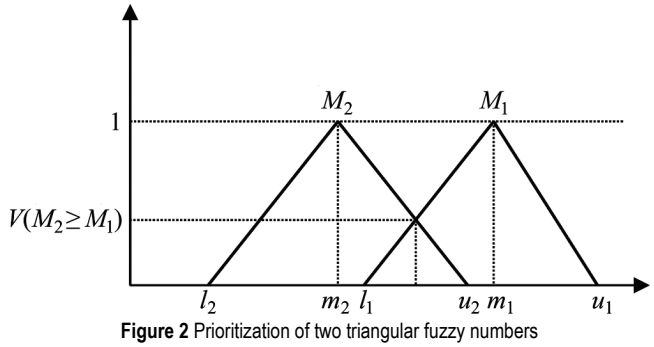

Figure 2 Prioritization of two triangular fuzzy numbers

To compare M_1 and M_2, it is necessary to calculate both $V(M_2 \geq M_1)$ and $V(M_1 \geq M_2)$ (Fig. 2). The degree of probability that a convex fuzzy number (M) is greater than another K convex fuzzy number (M_i; $i = 1, 2, \ldots, k$) is divided as follows:

$$\begin{aligned} d'(M) &= V(M \geq M_1, M_2, ..., M_k) = \\ &= V\left[(M \geq M_1), (M \geq M_2), ..., (M \geq M_k) \right] = \\ &= \min V(M \geq M_i) \end{aligned} \tag{10}$$

7) Normalization: By normalizing the weight vector, normalized weights are obtained.

$$\boldsymbol{w} = \left[\frac{d'(A_1)}{\sum_{i=1}^{n} d'(A_i)}, \frac{d'(A_2)}{\sum_{i=1}^{n} d'(A_i)}, ..., \frac{d'(A_n)}{\sum_{i=1}^{n} d'(A_n)} \right]^{\mathrm{T}} \tag{11}$$

The above weights are definite (non-fuzzy) weights. By repeating this process, the weights of all matrices are obtained.

8) Composition of weights: By combining the option weights and the criteria, the final weights are obtained.

$$\tilde{U}_i = \sum_{j=1}^{n} \tilde{w}_i \tilde{r}_{ij} \quad \forall i \tag{12}$$

In fact, after completing the questionnaires, people's judgments are combined with each other. Next, to determine consistency or inconsistency of the judgments, it was necessary to calculate the inconsistency rate of the judgment matrix of each person.

In order to achieve this goal, questionnaires of pairwise comparisons were designed and distributed among experts. According to fuzzy approach in this study, corresponding verbal expressions and evaluation of indicators and sub-indicators relative to each other (for pairwise comparisons) in Tab. 2 were used.

Table 2 Fuzzy spectrum and corresponding verbal expressions

Code	Verbal expression	Fuzzy number
1	Absolutely equal preference	(1, 1, 1)
2	Approximately equal preference	(0.5, 1, 1.5)
3	Low preference	(1, 1.5, 2)
4	High preference	(1.5, 2, 2.5)
5	Very high preference	(2, 2.5, 3)
6	Absolutely high preference	(2.5, 3, 3.5)

The scale used in this study is a 6-item fuzzy scale based on the modified method of Saaty [23].

3) Consistency of judgments

The following steps are used to calculate the inconsistency rate:

Step 1. Calculate the total weight vector: Multiply the pairwise comparison matrix (***D***) by the column "Relative Weight" (W). The new vector obtained this way is called the total weight vector.

$$\boldsymbol{WSV} = \boldsymbol{D} \times W \tag{13}$$

Step 2. Calculate the consistency vector: Divide the elements of total weight vector by relative priority vector. The resulting vector is called the consistency vector.

Step 3. Obtaining λ_{max} gives the average of λ_{max} consistency vector elements.

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{14}$$

where, n implies the number of options in the problem.

Step 4. Calculate the consistency index: The consistency index is defined as follows:

$$CI^{g} = \frac{(\lambda_{\max}^{g} - n)}{(n-1)} \tag{15}$$

Step 5. Calculate the consistency ratio: The consistency ratio is obtained by dividing the consistency index by a random index.

$$CR = \frac{CI}{CR} \tag{16}$$

Consistency ratio of 0.1 or less expresses consistency in comparisons.

6.2 Analysis of Results in Calculations of Pairwise Comparison Matrices and Inconsistency Rate

The calculations of all pairwise comparison matrices as well as inconsistency rate and analysis and results are presented in Tab. 3. Ranking of these factors are shown in Tab. 4. The order of prioritization is as Brand awareness, Firm value creation, Brand association**,** Perceived quality**,** Social responsibility**,** Customer value creation, Brand loyalty, and other brand assets.

Table 3 Fuzzy pairwise comparisons

Brand equity in health tourism	Perceived quality	Customer value creation	Other brand assets	Brand association	Social responsibility	Brand awareness	Brand loyalty	Organization value
Perceived quality	(1, 1, 1)	(0.707, 1.225, 1.732)	(1.5, 2, 2.5)	(0.667, 1, 2)	(1, 1.5, 2)	(0.333, 0.4, 0.5)	(1, 1.5, 2)	(0.5, 0.667, 1)
Customer value creation	(0.577, 0.816, 1.414)	(1, 1, 1)	(1.225, 1.732, 2.236)	(0.447, 0.577, 0.816)	(0.5, 1, 1.5)	(0.365, 0.447, 0.577)	(0.5, 1, 1.5)	(0.447, 0.707, 1)
Other brand assets	(0.4, 0.5, 0.667)	(0.447, 0.577, 0.816)	(1, 1, 1)	(0.447, 0.577, 0.816)	(0.667, 1, 2)	(0.286, 0.333, 0.4)	(1, 1, 1)	(0.333, 0.4, 0.5)
Brand association	(0.5, 1, 1.5)	(1.225, 1.732, 2.236)	(1.225, 1.732, 2.236)	(1, 1, 1)	(0.707, 1.225, 1.732)	(0.5, 0.667, 1)	(1, 1.5, 2)	(0.667, 1, 2)
Social responsibility	(0.5, 0.667, 1)	(0.667, 1, 2)	(0.5, 1, 1.5)	(0.577, 0.816, 1.414)	(1, 1, 1)	(0.447, 0.577, 0.816)	(1.225, 1.414, 1.581)	(0.516, 0.707, 1.155)
Brand awareness	(2, 2.5, 3)	(1.732, 2.236, 2.739)	(2.5, 3, 3.5)	(1, 1.5, 2)	(1.225, 1.732, 2.236)	(1, 1, 1)	(1.414, 1.936, 2.449)	(0.5, 1, 1.5)
Brand loyalty	(0.5, 0.667, 1)	(0.667, 1, 2)	(1, 1, 1)	(0.5, 0.677, 1)	(0.632, 0.707, 0.816)	(0.408, 0.516, 0.707)	(1, 1, 1)	(0.333, 0.4, 0.5)
Firm value creation	(1, 1.5, 2)	(1, 1.414, 2.236)	(2, 2.5, 3)	(0.5, 2, 1.5)	(0.866, 1.414, 1.936)	(0.667, 1, 2)	(2, 2.5, 3)	(1, 1, 1)

Table 4 Mean of pairwise comparisons to brand equity in health tourism

Criteria	Geometric mean	Final weight	Rank
Perceived quality	(0.765, 1.0491, 1.428)	0.137	4
Customer value creation	(0.581, 0.8441, 1.163)	0.11	6
Other brand assets	(0.517, 0.621, 0.806)	0.081	8
Brand association	(0.805, 1.177, 1.6391)	0.153	3
Social responsibility	(0.637, 0.865, 1.259)	0.116	5
Brand awareness	(1.286, 1.741, 2.159)	0.218	1
Brand loyalty	(0.588, 0.71, 0.934)	0.093	7
Firm value creation	(1.018, 1.442, 1.977)	0.188	2

7 DISCUSSION

In grounded theory, the process of data collection and interpretation should both be evaluated and validated as research findings. Internal validity is defined as: "Internal validity deals with the question of how do research findings match facts?" The question is whether what has been studied and found is what really exists and what researchers observe is what they think has been measured. To strengthen the internal validity of qualitative research, Merriam [24] has suggested the following:

- Pluralism: Several researchers, multiple data sources, or multiple methods are used to validate emerging data.
- Member review: Ask respondents if the results are acceptable.
- Long-term observation of research site or repetitive observations of similar phenomenon: Data is collected over a period with the aim of increasing the validity of the findings.
- Pairwise review: Ask colleagues to note on emerging findings.
- Elimination of prejudices: At the beginning of the research, the researcher should identify the assumptions, theoretical tendencies and prejudices and prevent them from interfering in the research process.

This study used triangular methods, member reviews and pairwise review for internal increase.

As observed, there is a significant relationship between brand equity and brand awareness, brand association, perceived quality, brand image, brand loyalty, firm value, customer value and social responsibility. By improving and developing these dimensions, which we examined in the analysis, we can offer a health tourism brand equity for Iran and promote it to take the best advantage of this profitable industry considering the many facilities and capacities in the

country, including natural and historical attractions, tourism facilities, medical facilities, experienced doctors and paramedics that now exist in the country. Considering that most of the neighbouring countries, which are very culturally close to us, do not have such facilities in their country, we can take the best advantage of this favorable situation and introduce our country as one of the best health tourism centers, while creating employment and bringing currency for our country and reach sustainable development of this industry so that we can become one of the best health tourism destinations in the world in the near future.

8 CONCLUSION

As it is obvious, there is a relationship between brand equity and brand awareness, brand association, brand loyalty, customer value, other firm assets, social responsibility and firm value. In the meantime, it can be seen that health tourism brand equity is most affected by dimensions of brand awareness, brand association, and other brand assets. In addition, we see that firm value itself is affected by brand development, competitive advantage, price and profit margin, and effectiveness of the marketing program. Moreover, social responsibility is related to social accountability, communication with medical staff and attention to the environment. Customer value is also related to customer information, patient trust, consumer satisfaction, and stakeholder interests. Brand awareness is also affected by brand position, country brand image and urban management. Perceived quality is also related to hospital quality, medical staff quality, medical equipment, variety of medical centers, perceived quality and accountability. Brand loyalty depends on country brand loyalty, hospitality, philanthropy of the medical staff, continuous evaluation of patients, and brand loyalty. Brand association is related to association of the country brand, word of mouth, multimedia advertising and relational channels.

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9 REFERENCES

[1] Aaker, D. A. (1991). *Managing Brand Equity: Capatilizing on the Value of a Brand Name*. Free Press, New York

[2] Keller, K. L. (1993). Conceptualizing, measuring, and managing customer-based brand equity. *Journal of Marketing*, *57*(1), 1-22. https://doi.org/10.1177/002224299305700101

[3] Atilgan, E., Aksoy, Ş., & Akinci, S. (2005). Determinants of the brand equity: A verification approach in the beverage industry in Turkey. *Marketing Intelligence & Planning, 23*(3). https://doi.org/10.1108/02634500510597283

[4] Firoozjaian, A. A., Firoozjaian, M., Hashemi petroodi, S. H., & Gholamrezazadeh, F. (2012). Using of Interpretive modeling in Tourism Studies. *Journal of Tourism Planning and Development, 6*(1), 129-159.

[5] Haghighi Kafash, M. & Jafari, Gh. (2006). Prioritize of factors in Iran medical Tourism. *Tourism Studies Journal*, *11*, 23-41.

[6] Shabani, A. & Taleghani, M. (2013). Effect of Experience and satisfaction of tourists for returning. *Journal of Geography and Environmental Studies, 2*(1), 55-64.

[7] Dehdashti, Z., Harandi, A., & Sedghiani, J. (2015). Effect of Brand Equity for hotel customers. *Tourism Management Studies Journal, 5*(71), 1-23.

[8] Aaker, D. A. (1996). Measuring brand equity across products and markets. *California Management Review, 38*(3). https://doi.org/10.2307/41165845

[9] Boo, S., Busser, J., & Baloglu, S. (2009). A model of customer-based brand equity and its application to multiple destinations. *Tourism Management*, *30*(2), 219-231. https://doi.org/10.1016/j.tourman.2008.06.003

[10] Wang, H., Wei, Y., & Yu, C. (2008). Global brand equity model: combining customer-based with product-market outcome approaches. *Journal of Product & Brand Management, 17*(5). https://doi.org/10.1108/10610420810896068

[11] Konecnik, M. (2002). The image as a possible source of competitive advantage of the destination - The case of Slovenia. *Tourism Review*. https://doi.org/10.1108/eb058373

[12] Zeithaml, V. A. (1988). Consumer perceptions of price, quality, and value: a means-end model and synthesis of evidence. *Journal of marketing, 52*(3), 2-22. https://doi.org/10.1177/002224298805200302

[13] Parasuraman, A., Berry, L. L., & Zeithaml, V. A. (1993). More on improving service quality measurement. *Journal of retailing, 69*(1), 140-147. https://doi.org/10.1016/S0022-4359(05)80007-7

[14] Pike, S. (2004). Destination brand positioning slogans-towards the development of a set of accountability criteria. *Acta Turistica, 16*(2), 102-124.

[15] Imani Yazdi, M. H. & Ayoobi Yazdi, H. (2014). Affecting factors on Brand Equity in Yazd. *Tourism Management Studies Journal, 13*, 137-113.

[16] Kotsi, F., Pike, S., & Gottlieb, U. (2018). Consumer-based brand equity (CBBE) in the context of an international stopover destination: Perceptions of Dubai in France and Australia. *Tourism Management, 69*, 297-306. https://doi.org/10.1016/j.tourman.2018.06.019

[17] Liu. M. T., Wong, I. A., Tseng, T. H., Chang, A. W., & Phau, I. (2017). Applying consumer-based brand equity in luxury hotel branding. *Journal of Business Research, 81*, 192-202. https://doi.org/10.1016/j.jbusres.2017.06.014

[18] Liu, C. H. S. & Chou, S. F. (2016). Tourism strategy development and facilitation of integrative processes among brand equity, marketing and motivation. *Tourism Management, 54*, 298-308. https://doi.org/10.1016/j.tourman.2015.11.014

[19] Chahal, H. & Bala, M. (2012). Significant components of service brand equity in healthcare sector. *International Journal of Health Care Quality Assurance, 25*(4), 343-362. https://doi.org/10.1108/09526861211221518

[20] Strauss, A. L. (1987). *Qualitative analysis for social scientists*. Cambridge University Press. https://doi.org/10.1017/CBO9780511557842

[21] Nazari-Shirkouhi, S., Mousakhani, S., Tavakoli, M., Dalvand, M. R., Šaparauskas, J., & Antuchevičienė, J. (2020). Importance-performance analysis based balanced scorecard for performance evaluation in higher education institutions: an integrated fuzzy approach. *Journal of Business Economics and Management*, *21*(3), 647-678. https://doi.org/10.3846/jbem.2020.11940

[22] Keramati, A., Samadi, H., & Nazari-Shirkouhi, S. (2013). Managing risk in information technology outsourcing: an approach for analysing and prioritising using fuzzy analytical network process. *International Journal of Business Information Systems*, *12*(2), 210-242. https://doi.org/10.1504/IJBIS.2013.052052

[23] Saaty, T. L. (2009). Applications of analytic network process in entertainment. *Iranian Journal of Operations Research, 1*(2), 41-55.

[24] Merriam, S. B. (1988). *Case study research in education: A qualitative approach*. Jossey-Bass.

[25] Chang, D. Y. (1996). Application of extend analysis method on Fuzzy AHP. *European Journal of Operational Research, 96*, 343-350.

[26] Sarker, M., Mohd-Any, A. A., & Kamarulzaman, Y. (2021). Validating a consumer-based service brand equity (CBSBE) model in the airline industry. *Journal of Retailing and Consumer Services, 59*, 102354. https://doi.org/10.1016/j.jretconser.2020.102354

[27] Guo, W., & Zhou, L. (2021). Influence factors of customer-based brand equity: A study on China mobile phone industry. *International Journal of Financial Engineering, 8*(01), 2050050.

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Preliminary communication

Correlation between Ink Thickness and "Shrink Sleeve" Flexographic Print Quality at a Stable Friction Coefficient

Igor Zjakić*, Ivana Ljevak, Albulena Bilalli

Abstract: Flexographic technology usage is increasing in recent years. Predicted growth in the technology usage intensifies the demand for improved quality. It is expected that flexographic printing will achieve greater results than ever before. Since this technique is used in the printing of shrink sleeve packaging, it is imperative to meet the technical and economic requirements of the shrink sleeve product. This is primarily to ensure gliding of the white printing material. The amount of white should be as small as possible, making the sliding of the material optimal and the quality of the print better. Therefore, the quality of the printing was measured by changing the conditions of slippage and white color. This research has established a correlation between the thickness of the white layer and the reduction of print quality over thin lines.

Keywords: flexographic printing; gliding; ink layer; print quality; shrink sleeve

1 INTRODUCTION

Flexographic printing is a fast-paced printing process that has extensive application in the packaging industry. The packaging industry produces high quality graphics on coated, unopened paper and board, and on flexible foils. Flexographic printing is a printing technique that uses flexible sheets with elevated printing elements with a direct printing principle on the substrate [1]. Flexographic printing is a highly sensitive printing technique, and the printing form is easily adapted to all print media. Precisely because of its suppleness and softness, the plate under pressure combined with low viscosity color can produce an extremely large increase in rastertone value [2]. Thanks to the elastic printing elements, this printing technique can be applied on a variety of intricate and inadequate printing presses, such as: thin films, flexible and rigid films, almost all papers, cartons of different thicknesses and grammars, packing materials of rough surfaces and similar.

A variety of parameters are influenced by the print quality. Some of the most important parameters are the shapes of the dot element, the size of the dot cell, and the pressure on the surface to which it is printed. These two characteristics define the growth of rastertone value which is essential for the study of the thickness of the line in this research [3, 4].

In flexographic printing "shrink sleeve" technology, it is necessary to apply white color that, besides visual application has a role in defining sliding material, so the amount of white color used for this need is extremely important in the overall product price [5]. Accordingly, the most important commercial part of the workflow is a flexographic process of color management that obtains predictable and repeatable prints, whether it is a color press, or to print a background white color [6]. In many cases, the price of the ink is about 4-6%, and the printing media 60-70% of the total production costs. Poor color management, especially printed white color on transparent materials, which most often makes the surface of the entire printing press, can lead to increased production costs [7]. Shrink sleeve labels are made from many types of macromolecular materials, PVC, PET, PET-G, OPS, PLA (polylactic acid) and other hybrid materials for specific applications [8].

1.1 Flexographic Technology

The research in this paper was done by printing control strips (predefined printing fields) with a borderline of high quality reproduction at different thicknesses of white layers. Flexographic technology is specific in color dosage control. It is defined by anilox line count and volume.

Proper selection of anilox rollers allows for achieving a target of Solid Ink Density (*SID*) and permissible deviations of color difference ΔE, in order to obtain a consistent and repeatable print quality [5].

Further, it is necessary to determine which volume of anilox rollers (*BCM* - billion cubic microns) meets the highest color density limit. The highest color density limit is acceptable because it leaves room for wear and less filling of the anilox roller. For example, if the 1.8 *BCM* anilox roller gives a color density of 0.95, it can be predicted that the new 2.0 *BCM* anilox roller, which gives a color density of 1.05, after a certain time of application (when it will transmit 1.8 *BCM*) and still deliver results within the tolerance limit.

1. 2 Printing Parameters

The volume of anilox rollers is calculated in billion cubic microns per inch square (10^9), so the unit of measurement for the volume of the anilox roller can be calculated by the expression [18]:

$$\frac{BCM}{\text{inch}^2} = \frac{10^9 \times 10^{-12}}{6.4516 \times 10^{-4}}. \tag{1}$$

Above expression can be transfered to cm^3/m^2 and after calculation we get:

$$\frac{BCM}{\text{inch}^2} = 1.55 \ \frac{\text{cm}^2}{\text{m}^2}, \tag{2}$$

following

$$\frac{\mathrm{cm}^2}{\mathrm{m}^2} = \frac{1}{1.55} = 0.6455\frac{BCM}{\mathrm{inch}^2}. \quad (3)$$

The volume parameter defines theoretical amount of ink held in anilox cells in a square inch or square centimeter. So the ink layer thickness calculation is obtained by:

$$Ink\ thickens = \frac{BCM}{0.65}. \quad (4)$$

Since the ink of the cells in the printed plate is transferred by about 50% due to the "contact" of the printing form and the anilox roller, and 50% due to the contact of the printing press and the printing substrate, the actual amount of ink on the printed media can be calculated as shown in Tab. 1.

Table 1 Ink layer thickness on the substrate in regards to volume of anilox roller

Volume of anilox roller		Ink layer thickness at printing form	Ink layer thickness on the substrate, μm
BCM	cm^3/m^2		
1	1.55	0.77	0.39
2	3.10	1.55	0.77
3	4.65	2.32	1.16
4	6.20	3.10	1.55
5	7.75	3.87	1.94
6	9.30	4.65	2.32
7	10.84	5.42	2.71
8	12.39	6.20	3.10
9	13.94	6.97	3.49
10	15.49	7.75	3.87

By producing pressforms for flexo printing with CtP technology it is necessary to satisfy the requirements where we have at least 256 different shades for each color which shall be printed. As the 8 bit color data provides the ability to print 16.7 million colors, it is necessary to determine the size of the dot cell and the number of gray shades that can be printed with the CtP device.

Cell size and number of gray levels are calculated according to:

$$Cell\ size = \frac{ppi}{lpi}, \quad (5)$$

$$Number\ of\ gray\ levels = \left(\frac{ppi}{lpi}\right)^2 + 1, \quad (6)$$

where: *ppi* - output resolution of a CtP device defined by the number of pixels per inch; *lpi* - the line screen is defined by the number of lines per inch.

Since demands in graphic reproduction on quality of printing are usually very high, it is important to make high quality printing plate as well. This can be done by conventional polymers and standard digital CtP polymerization processes on the polymer plate, then by UV oscillation of two-InkJetCtP technology that prints the mask on the top of the board and the LED with UV technology with the main exposure inside the CtP [10].

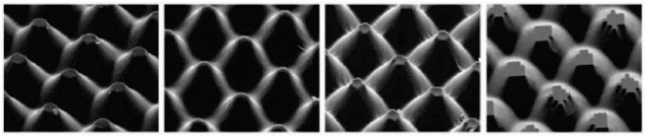

Figure 1 Influence of different lighting technologies on the geometry of the dot element [11]

The aim of each reproduction is to optimize the production chain so that the information about color remains as true to the original as possible during the transition from the original to print [12]. During the transformation of such information, from phase to phase, there is possibility of losing tones and irregular transformation is possible.

The transfer of tonal values and the reproduction quality depends on the adherence of the ink to the printing plate and the printing substrate. Theoretically defined, the screen element loses its theoretical value by imaging the printing plate and, in this way, increased or decreased adherence of the ink comes into play and consequently has an effect on quality of printing. Apart from the ink transfer onto the printing plate, the ink quantity that is transferred to the printing substrate depends on the transfer time, the strength of the pressure on the printing substrate, the rheological properties of the ink, the temperature of the ink and the properties of the printing substrate, and can be expressed by Eq. (7) [13].

$$p = \left(1 - \mathrm{e}^{-(am)x}\right)\left\{w_0\left(1 - \mathrm{e}^{\left(-\frac{m}{w_0}\right)}\right) + \alpha\left[m - w_0\left(1 - \mathrm{e}^{\left(-\frac{m}{w_0}\right)}\right)\right]\right\}, \quad (7)$$

where: p - quantity of the ink transferred onto the printing substrate (g/m^2); m - quantity of ink on the printing substrate (g/m^2); a - smoothness of the printing substrate (m^2/g); w_0 - maximal adsorption of ink (g/m^2); α - ink separation factor; x - machine factor.

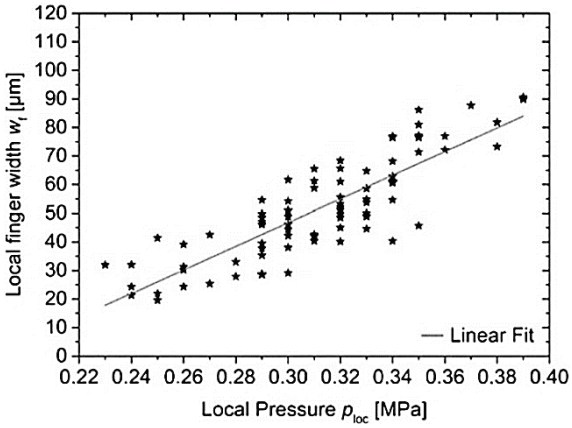

Figure 2 Relation of local pressure p_{loc} and local finger width w_f

Earlier research by A. Lorenz et al. [14] show that the dependence of the pressure and the surface size by adapting the data to the linear function as shown in Fig. 2.

2 METHODS

In this research, the polyvinyl foil (PVC) is used in the printing of shrink sleeve packaging. The prints were made by printing thin lines on the white ink layer to determine the dependency in the conditions of satisfactory print quality as showed on Fig. 3.

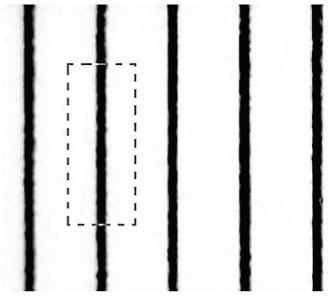

Figure 3 Printed lines and measuring area (dashed line) with magnification (200×)

The printing machine on which the foils were printed was: Nilpeter FA 4. The test line was 10 μm thin. The foil that was used for printing was transparent foil with thickness of 40.50 μm, manufacturer Bilcare. The lines were printed on 6 different volumes of ink layer, respectively on the thicknesses of the white layer as shown in the Tab. 2.

Table 2 Layer thickness on the substrate relative to the volume of anilox roller used for research

Sample No.	Volume of anilox roller		Ink layer thickness on the substrate, μm	Opacity %
	BCM	cm^3/m^2		
1	3	4.65	1.16	53
2	5	7.75	1.94	53
3	6	9.30	2.32	55
4	7	10.84	2.71	56
5	8	12.39	3.10	56
6	9	13.94	3.49	57

After printing the foil, a sliding material test was performed to determine whether gliding meets the needs of shrink sleeve technology. Material sliding test is performed on the SST3-XS, RDM.

In the last part of the experiment, the thickness of the printed lines was measured and the image was greatly enlarged by the ImageJ software, at which edge of the line was lost. After measuring the thickness of the line, the function of addiction was calculated. The measurements of measured thickness dependence of the layer thickness on the color layer thickness were chosen using two functions: linear functions and logarithmic functions with a natural number basis e. The relative coefficients of these functions are determined by the least mean squares method [15].

3 RESULTS AND DISCUSSION

After the film was printed, the sliding material testing of the material was applied to the sliding test and the following results were obtained where we can see coefficient of friction for each sample (Fig. 4).

The slippage results are compared to the actual sliding test on the machine to see if some result from satisfactory foam behavior when stretching the material. After the testing phase, it was determined that all the results met the quality condition of the actual production, meaning that all samples can be used on the slider factor.

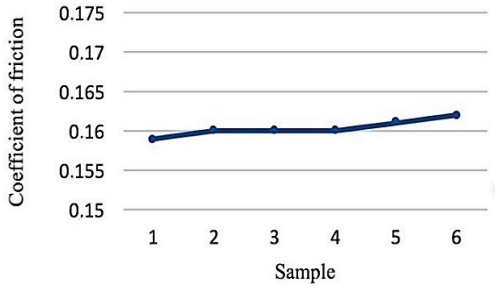

Figure 4 Coefficient of friction of the sample

Prints on different thicknesses of white layers were recorded with camera enlargement and were analyzed with the usage of ImageJ software. As the image analysis based on the establishment of different brightness on the margins of the analyzed thin lines [16], the results are shown as the brightness level on the gray level in the intro of 0-255. Since ImageJ works on the principle of reflected light, the different values of light gray for this study are not relevant given the degree of tolerance of the camera itself and the measurements.

The data on the prints is viewed at a moment when there is a significant shift of gray level since this shift implies an edge between the printed and unsealed part of the line.

The results are shown in the following figures.

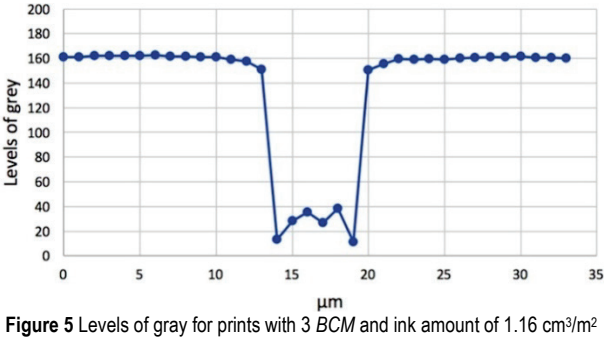

Figure 5 Levels of gray for prints with 3 *BCM* and ink amount of 1.16 cm^3/m^2

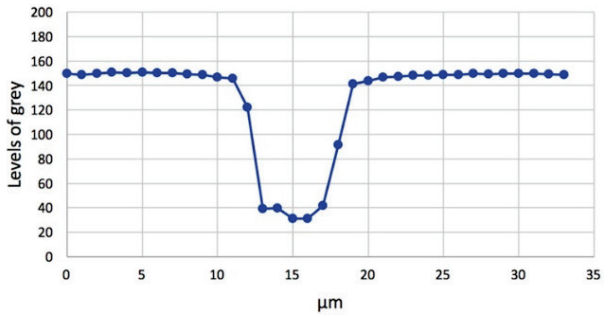

Figure 6 Levels of gray for prints with 5 *BCM* and ink amount of 1.94 cm^3/m^2

By analyzing these graphs, the points of sudden change in brightness were determined, respecting, the said method determines the actual width of the line on the prints having different thicknesses of the white layer.

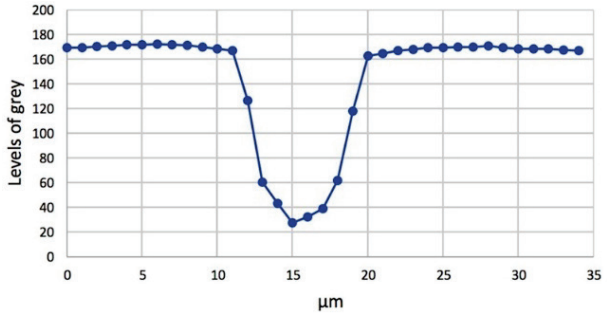

Figure 7 Levels of gray for prints with 6 *BCM* and ink amount of 2.32 cm³/m²

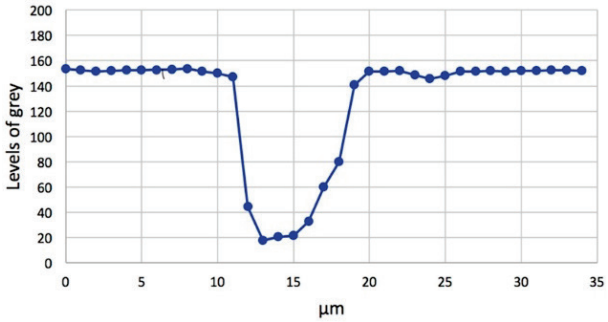

Figure 8 Levels of gray for prints with 7 *BCM* and ink amount of 2.71 cm³/m²

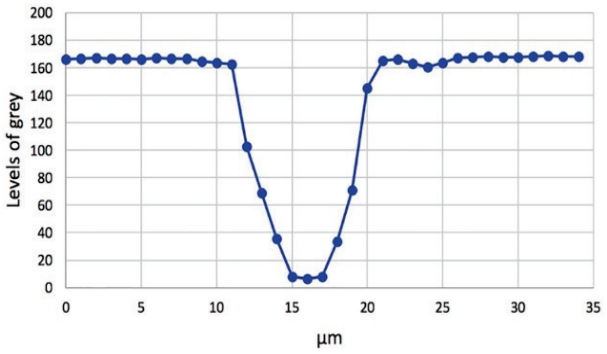

Figure 9 Levels of gray for prints with 8 *BCM* and ink amount of 3.10 cm³/m²

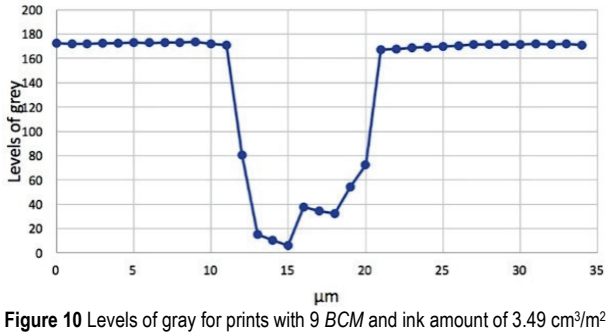

Figure 10 Levels of gray for prints with 9 *BCM* and ink amount of 3.49 cm³/m²

This difference is expected, since in thicker layers the ink of the second color (in this case the thin line) penetrates more in ink and the color discoloration and geometric and optical growth of rastertone values occur [17].

For this research, the increase in rastertone values is not calculated, just the function required to show how the size of the printed thin lines changes in the manner of increasing the ink layer.

Table 3 Measured line widths

Sample	Thickness, μm	Line width, μm
1	1.16	6.9
2	1.94	8.1
3	2.32	8.8
4	2.71	9.5
5	3.10	9.7
6	3.49	10

The least mean squares method calculates the parameters for the logarithmic function.

Table 4 Results obtained by the least mean squares method

	Linear function		Logarithmic function	
Coeff.	0.600	6,733	1.760	6,903
Std. Err.	0.087	0,340	0.059	0,074
R2, sey	0.922	0,365	0.995	0,088
F, df	47,250	4,000	877,214	4,000
ssreg, ssresid	6.300	0,533	6.802	0,031

With the least mean squares method we can see the relation between logarithmic and linear functions and the thickness of the ink layer on the print.

These generated functions are represented by Fig. 11.

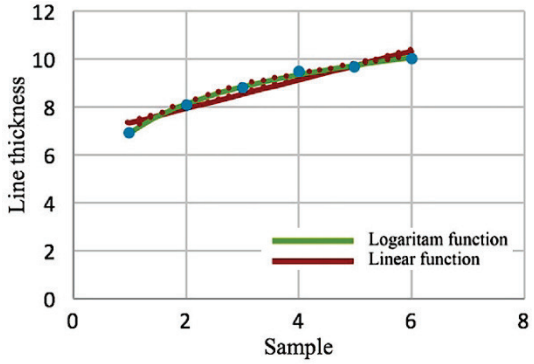

Figure 11 Linear and logarithmic function of the line thickness and the thickness of the ink layer on the print

4 CONCLUSIONS

This research confirms that the thickness of the white color film is directly influenced by the quality of the prints. It has been established that by increasing the thickness of the white layer, the increase in the width of thin strips is performed, and affects dot elements that can lead to decrease in print quality. As the width of the line was increased when printing, the increase in the printing element resulted in a dot gain.

The amount of white printing in flexographic printing should be as small as possible for commercial reasons. However, as the amount of white color affects the material sliding coefficient and the transparency of the material when the foil is printed for non-white products, then the thickness of the white coat affects the gliding factor but also reduces the opacity that affects the experience of non-white packaging as showen on Fig. 4.

This research has established a correlation between the thickness of the white layer and the reduction of print quality over thin lines (Fig. 11). By calculating the dependence

obtained by the least squares method, the dependence of decreasing the print quality by increasing the line thickness can be better illustrated by the logarithmic function since the deviations in relation to the linear function are considerably smaller.

5 REFERENCES

[1] Kipphan, H. (2001). Handbook of Print Media, Springer, Berlin, Chapter 2-a.

[2] Miljković, P., Valdec, D., Matijević, M.,The Impact of Printing Substrate on Dot Deformation in Flexography. *Tehnički vjesnik, 25* (Supplement 2), 509-515. https://doi.org/10.17559/TV-20170710152140

[3] Valdec, D., Zjakić, I., & Milković, M. (2013). The influence of variable parameters of flexographic printing on dot geometry of pre-printed printing substrate. *Tehnički vjesnik, 20*(4), 659-667. Retrieved from https://hrcak.srce.hr/106698.

[4] Zjakić, I., Bates, I., & Milković, M. (2011). A study of dot gain and gamut for prints made with highly pigmented inks. *Tehnički vjesnik, 18*(2), 227-235. Retrieved from https://hrcak.srce.hr/69588.

[5] Foundation of Technical Association. (2013). FLEXOGRAPHY: Principles and Practices 6.0. 6th ed., New York.

[6] Wypych, G. (Ed.) (2019). *Handbook of Solvents* (Third Edition), Volume 2: Use, Health, and Environment, 901-1124.

[7] Izdebska, J. (2016). Flexographic printing. *Printing on Polymers* (Fundamentals and Applications), ScienceDirect, 179-197. https://doi.org/10.1016/B978-0-323-37468-2.00011-7

[8] Krystosiak, K. (2017). Prediction Method for Winding Parameters in Label Converting Process with Data Mining Tools. The 7th International Conference on Engineering, Project, and Production Management, *Procedia Engineering, 182*, 373-380. https://doi.org/10.1016/j.proeng.2017.03.116

[9] Gooran, S. (2005). Hybrid halftoning, a useful method for flexography. *Journal of Imaging Science and Technology, 49*(1), 85-95.

[10] Bould, D. C., Claypole, T. C., Bohan, M. F. J., & Gethin, D. T. (2004). Deformation of Flexographic Printing Plates. *The 56th TAGA Technical Conference*, 146-162.

[11] Stebani, U. (2012). New UV expose technology for photopolymer plates. *Flexo & Gravure Global, 18*(3), 14-15.

[12] Lorenz, A., Kalio, A., Hofmeister, G. T., Nold, S., Kraft, A., Bartsch, J., Wolf, D., Dreher, M., Clement, F., & Biro, D. (2013). Flexographic Printing – High Throughput Technology for Fine Line Seed Layer Printing on Silicon Solar Cells. *Proceedings of the 28th EUPVSEC*, 1017-1023. https://doi.org/10.4229/28thEUPVSEC2013-2EO.2.6

[13] Gustavson, S. (1997). Dot Gain in Colour Halftones. *PhD Thesis*, (Linköping University, Linköping, 25-36.

[14] Lorenz, A., Gredy, C., Senne, A., Beyer, S., Yao, Y., Papet, P., Ufheil, J., Reinecke, H., & Clement, F. (2016). Flexo-printed busbarless solar cells for multi-wire interconnection. *Energy Procedia, 98*, 46-60. https://doi.org/10.1016/j.egypro.2016.10.080

[15] See https://web.math.pmf.unizg.hr/~bruckler/pdf/mnk.pdf

[16] Claypole, T. C., Bould, D., Hall, R., Jewell, E., & Gethin, D. (2008). Flexo printing of fine lines. *TAGA Proceedings*, 252-266.

[17] Johnson, J. (2008). Aspects of Flexographic Print Quality and Relationship to some Printing Parameters. *PhD Thesis*, Karlstad University, Germany.

[18] Valdec, D. (2013). Utjecaj promjenjivih parametara fleksotiska na geometriju rasterskog elementa predotisnute tiskovne podloge. *PhD Thesis*, Grafički fakultet, Zagreb, Croatia (in Croatian).

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Preliminary communication

Design and Implementation of a Web-Based Application for Code Smells Repository

Lida Bamizadeh*, Binod Kumar, Ajay Kumar, Shailaja Shirwaikar

Abstract: Pitfalls in software development process can be prevented by learning from other people's mistakes. Software practitioners and researchers document lessons learned and the knowledge about best practices is spread over literature. Presence of code smells does not indicate that software won't work, but it will reveal deeper problems and rising risk of failure in future. Software metrics are applied to detect code smells whereas refactoring can remove code smells, improve code quality and make it simpler and cleaner. Detection tools facilitate management of code smells. Knowledge about code smells and related concepts can assist the software maintenance process. Exploratory analysis of code smells carried out in this paper, covers collecting data about code smells, identifying related concepts, categorizing and organizing this knowledge into a code smell repository, which can be made available to software developers. A detailed literature survey is carried out to identify code smells and related concepts. An initial list of 22 code smells proposed in 1999 has grown over the years into 65 code smells. The relationship between code smells, software metrics, refactoring methods and detection tools available in literature is also documented. Templates are designed that capture knowledge about code smells and related concepts. A code smell repository is designed and implemented to maintain all the information gathered about code smells and related concepts and is made available to software practitioners. All the knowledge about code smells found in literature is collected, organized and made accessible.

Keywords: code repository; code smell; detection tool; refactoring; software metric

1 INTRODUCTION

Software quality goes to ruin over time because of various reasons such as software ageing, improper design, unsuitable requirement analysis and inappropriate coding practices. Code smell is an indication of some obstacles in the code that shows something is wrong in some parts of code or system design [1]. Bad smell occurrence has a drastic influence on the quality of code. It makes system more complex, less comprehensible and causes maintainability problems [2, 3]. Bad smells are usually not bugs; however, researchers have proposed that a huge number of bad smells connect with bugs and maintainability issues [4-7]. Bad smells don't currently inhibit the functioning of code. But, they detect clear signs in design which may lead to slowing down development or growing the probability of bugs or software rot because of long term decays. In 1990, Kent Beck proposed that refactoring can modify source code to improve its quality. Refactoring is a systematic process of improving source code without creating new functionality that can change a disorder into spotless code and uncomplicated design [8]. Code smell detection can be effectively carried out by using appropriate software metrics [9]. Software metric is a measurement indicator for the latent attributes possessed by software system or software development process [4, 10, 11]. These detection approaches interpret code metrics which are evoked from a particular system element by applying a set of threshold filter rules [12]. The main target of this strategy is providing a mechanism for engineers that give permission to them to work on a more abstract level that conceptually is closer to real goals in using metrics. Furthermore, several tools have been developed for detection of code smells and improve the code quality during software development [13]. Software tools support developers by automatic or semi-automatic detection of bad smells. Tools focus on the entities which most likely present code smells [14].

This paper proposes an exploratory study of code smells. Literature survey shows that there are plenty of code smells with corresponding detection methods using software metrics. Also, there is a large set of tools that support code smells detection. Moreover, there are well defined Refactoring methods that can be used to remove code smells. There is a need to organize this knowledge into a Code smells repository so that it is readily available to developers and practitioners.

The contribution of this paper is organized as follows: section 2 describes background and related work. Exploratory analysis of code smells is explained in section 3. Organizing the code smell knowledge is presented in section 4 which is followed by conclusion in section 5.

2 BACKGROUND AND RELATED WORKS

Several scientists such as Opdyke et al. [15] showed that some situations in source code may need refactoring. The process of changing a software system in this manner that external behaviour does not change but improves its internal structure is called refactoring. It can improve the design of a software process and reduce its complexity. After refactoring, software systems are easier to comprehend and maintain. Webster [16] and Brown et al. [17] discovered some code smells such as Blob, Spaghetti Code, etc. [18]. Later, Kent Beck and Martin Fowler [19] called those situations, which may need refactoring as the bad smells. An initial list of code smells was proposed by them which was indicative of something incorrect in the system code. They introduced a list of 22 code smells without categorizing them and claimed that there is not a set of precise metrics which can be specified to recognise the need of refactoring. Thus, bad smells are kind of cooperation amongst the ambiguous programming and precise source code metrics. Fowler presented a group of refactoring with step wise comments on how each smell can be removed. He did not give the particular characteristics, detecting techniques and refactoring process. Van Emden and Moonen [20] proposed the first formalization of code smells. They revealed the undesirable effect of bad smells on the software product.

They suggested an automatic detection and visualization of code smell, with a methodology for reducing the impact of code smells on java source code. "Jcosmo" was the name of resulted work in code smell browser. Later, they had other survey and discovered that presence of smells has maximum influence on quality of software [18]. Kerievsky [21] presented more refactoring. Also, he introduced some new code smells such as Conditional Complexity, Combinatorial Explosion and Indecent Exposure in his refactoring book. Mantyla [22] presented Divergent Change as concealed smell. This smell cannot be detected by a simple look at the code or by tools. Also, detecting process need good understanding of the code and having experience for implementing the changes to the source code. Then, in 2003, he [23] introduced more smells. In addition, he discovered a classification of 22 code smells into seven units where every individual unit reveals a similar impression [23, 13]. Li and Shatnawi [24] examined the association among class error probability and code smells for three different levels such as High (Blocker and Critical), Medium (Major), and Low (Normal and Minor). They described that refactoring of a class improves the architectural quality as well as decreases the probability of the class errors when system is released. Also, in 2008 they [25] extended their study about relationship between software metrics, code smells and class error probability. Fontana et al. [26] proposed a comparative study of code smells which are detected by various refactoring tools and their support of semi-automatic refactoring. Ouni et al. [27] defined a search based refactoring strategy for maintaining domain semantic of a code when refactoring is decided/ implemented automatically. They discussed that refactoring may be syntactically correct and have right behaviour but model incorrectly the domain semantics. Palomba et al. [28] surveyed observations of developers about bad smells. They mentioned that there is a gap between theory and practice. Their survey promised insights about bad smells which are not yet explored sufficiently. Pinto and Kamei [29] examined StackOverflow's data for exploring obstacles for approval of code smell detection tools. They prepared a list of problems that revealed the adoption/usability problems, which users explained about StackOverflow. Tufano et al. [30] surveyed hundreds of projects to explore the problems of bad smells. They discovered the reason for bad smells in the code. Kaur and Dhiman [31] had a detailed survey on Search-Based Tools and Techniques to Identify Bad Code Smells in Object-Oriented Systems. Authors point out lack of a standard benchmark system for comparing outcomes of existing's code smell detection strategies. Fontana et al. [32] believed that code smells and architectural smells are not same. They suggested developers to more focus on hazardous architectural smells. Reis et al. [33] performed a Systematic Literature Review (SLR) on the state-of-the-art methods and tools applied for code smells detection and visualization. Their results showed that the most repeatedly applied detection methods are based on search-based techniques, which mainly apply ML algorithms. Martins et al. [34] presented a survey on harmfulness of co-occurrences of code smells and its influences on Internal Quality Attributes. The elimination of code smells co-occurrences reduce complexity of the system. Kaur [35] published a Systematic Literature Review on Empirical Analysis of the Relationship between Code Smells and Software Quality Attributes. Researcher observed that most used data sets for studies are small in size and written in Java programming language. Also, most impact of code smells is on external quality attributes. Al-Shaaby et al. [36] recently presented a systematic literature review with reference to bad smell detection using machine learning techniques. Their research outcomes showed that God Class and Long Method, Feature Envy, and Data Class are the most occurring detected code smells and Java programing and Weka have most used by researchers.

3 EXPLORATORY ANALYSIS OF CODE SMELLS

Exploratory Analysis of code smells involves collecting data about code smells, identifying related concepts, categorizing and organizing this knowledge into a code smell repository so that it can be made readily available to software developers and practitioners.

3.1 Collection of Data about Code Smells

Kent Beck as the originator of extreme programming revealed the importance of design quality through the developing software in 1990s and made popular the usage of word code smell. This word grew into a universal term in coding when it was introduced in the book Refactoring: Improving the Design of Existing Code by Martin Fowler, a famous software scientist which propagated the practice of refactoring. An initial list of 22 code smells was introduced by Kent Beck and Martin Fowler in 1999 as situations revealing of something improper in the system code. Initial list has grown over the years and knowledge about a large set of code smells is spread out across the literature. For the exploratory study, 65 code smells are gathered from the existing literature as shown in Tab. 1. Name of Code smells are a part of designer's language vocabulary. Sometimes newbies designers don't certainly know code smell's particular definitions and simply use them out of familiarity. Researcher has prepared uncomplicated short definitions via Tab. 1 to assist designers and other researchers to identify promising motivations for solving code smell problems.

Table 1 Code Smells and Their Brief Definitions

No	Name	Definition
1	Duplicate Code	Presence of same code structure at more than one place.
2	Long Method (Function)	Method is too long in the sense of the functionalities executed by it.
3	Large Class	Class has large number of instance variables and attempts to organize many works.
4	Long Parameter List	List of parameters is very lengthy.
5	Divergent Change	Single class requires many changes in the code for the various objectives.
6	Shotgun Surgery	Single change applies to several different classes of code simultaneously.
7	Feature Envy	Method looks to be more concerned in other class than it is real occupied.

8	Data Clumps	Same set of data items often appear together in different places.
9	Primitive Obsession	Instead of small objects, extreme use of primitive data types.
10	Switch Statements	Equal switch statements scattered across the code in the several places.
11	Lazy Element	An element which is not doing sufficient work.
12	Lazy Class (Freeloader)	A class which is not doing sufficient work.
13	Data Class	Class is container for data used by other classes and cannot work independently in own data.
14	Excessively Large (long) Identifier	Identifier length is very large and makes disambiguation in the software architecture.
15	Excessively Small (short) Identifier	Identifier length is very small and does not reveal its function obviously.
16	Contrived complexity	Design pattern is overcomplicated where a simpler design could be used.
17	Complex conditionals	Large conditional logic blocks, especially blocks that tend to grow larger or change considerably over time.
18	Temporary fields	They acquire their values, are required by objects under certain situations, and are empty outside of these situations.
19	Refused Bequest	Child class does not use derivative functionality of the superclass to happen inheritance rejection.
20	Middle man	When a class performs only delegating work to another class.
21	God (Blob) Class	Class has tendency to localize the intelligence of the system and trying to do much.
22	Alternative Classes with Different Interfaces	Two different classes perform similar functions with different method signatures.
23	Parallel Inheritance Hierarchies	Two parallel class hierarchies stand and each of these hierarchies must to be extended.
24	Message Chains	When in the code, there are a series of calls resembling a->b( )->c( )->d( )
25	Comments	When a method is full of descriptive comments.
26	Dead Code	The code which has been used earlier, but is not presently used.
27	Brain Class	Class centralize system functionality but does not use considerable data of foreign classes and is more cohesive.
28	Brain Method	Brain Methods centralize the functionality of a class.
29	Extensive (Dispersed) Coupling	A single operation calls one or few methods from extreme number of provider classes.
30	Intensive Coupling	A method calls many other operations in the system from one or a few classes.
31	Tradition Breaker	Inherited class hardly concentrates inherited services which are unrelated on inherited functionality by base class.
32	Spaghetti Code	A class without structure executes long and complex methods, connects among them without parameters using global variables.
33	Speculative Generality	An abstract class that is unused, but will be used in the system in coming system releases.
34	Inappropriate Intimacy	Two classes exhibiting high coupling between them or one class consumes the internal fields and methods of another class.
35	Complex Class	Classes having high complexity.
36	Class Data Should Be Private (CDSBP)	A class exposes its attributes and violates the principle of data hiding.
37	Instanceof	Having a chain of "instanceof" operators in the same block of code.
38	Typecast	The process of explicitly converting an object from one class type into another.
39	Missing Template Method	Two different components have major similarities, but do not use an interface.
40	Cyclic (Circular) Dependencies	Two or more subsystems are involved in one cycle and this is contravention of Acyclic Dependencies Principle.
41	Blob Operation	Huge and complex operation have a tendency to centralize too much of the functionality of a class or module.
42	Sibling Duplication	An equivalent functionality described by two or more siblings in an inheritance hierarchy.
43	Internal Duplication	Duplication among portions of the one class or module.
44	External Duplication	Duplication among unrelated capsules of the system.
45	Distorted Hierarchy	Uncommonly narrow and deep Inheritance hierarchy. A popular value for this depth is six.
46	Unstable Dependencies	Dependencies between subsystems in a design are not in direction of the stability of subsystems.
47	Schizophrenic Class	A class includes separate sets of public methods that are used by separate groups of client classes.
48	Incomplete Class Library	Library hasn't prepared the features or has declined to implement them.
49	Stable Abstraction Breaker (SAPBreakers)	A subsystem is not as abstract as it is stable.
50	Mysterious (Uncommunicative) Name	A mysterious name of functions, modules, variables and classes does not lead into its intent well enough.
51	Mutable data	Unexpected consequences and bugs can be produce after changing the data.
52	Global data	Everyone from everywhere can modify global data and this is a problem of it.
53	Similar subclasses	There is a bunch of almost similar subclasses of a class.
54	Inconsistent Names	A group of standard terminology should choose and then, use it among the methods. Example: Open () ► Close ().
55	Combinatorial Explosion	Lots of code does almost the same thing, but with tiny variations in data or behaviour.
56	Type Embedded in Name	Placing types in method names.
57	Oddball Solution	Two similar problems in one system, and one problem solves one way and other solves other way.
58	Indecent Exposure	When methods or classes unnecessarily expose their internals.
59	Solution Sprawl	Code and/or data used in execution of a responsibility becomes sprawled through several classes.
60	Excessive return of data	A function or method which returns more than what each of its callers requires.
61	Excessively long (God) line of code	When a line of code is too long.
62	Functional Decomposition	Writing highly procedural and non-object oriented code in an object oriented language. It happens while a class is considered with the intent of performing a single function.
63	Deficient encapsulation	Declare availability of one or more members of an abstraction is more permissive than actually necessary.
64	God Method	Method gets more functionality until it becomes out of control and difficult to maintain and extend.
65	Type checking	Presented for Selecting a variation of an algorithm that should be executed based on the value of an attribute.

3.2 Identifying Related Concepts

Code smells are some symptoms in the source code that probably indicates a deeper problem in software system. Detection of code smells is challenging for practitioners and developers. Different viewpoints conduct to the application of several detection metrics, detection tools and refactoring actions [14]. Software metrics are a standard measurement by using performance value named threshold to assess the maintainability of the software systems and to distinguish code smells. Tools are another way of code smells detection. A variety of detection tools have been developed for detection of bad smells based on different approaches and specific parameters for detecting particular smells. Refactoring is an organized procedure for improving source code without making new functionalities that change code to clean code with a simple design. Fig. 1 depicts that code smells are the centre of study along with the related concepts that are software metrics, detection tools and refactoring actions.

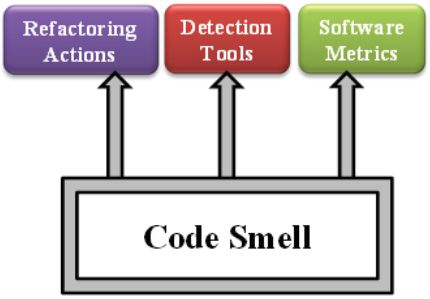

Figure 1 Concepts related to code smells

Following subsections are used for describing these related concepts in further detail.

3.2.1 Detection Tools

There are several tools and IDE (integrated development environment) available for detecting of code smells [37]. Code smells are suggested as an attempt by programmers to reform their software. When programmers are writing their code, bad smells go unnoticed. Therefore, detection tools are developed to make programmers aware about the existence of bad smells in their code and to aid them recognize the reason of those bad smells. Several code smell detection tools are available but it is difficult to enumerate all of them and define exactly which bad smells they are able to detect. Therefore, a short introduction is provided to some of the well-known tools.

a) **infusion**: inFusion is the modern and commercial development of iPlasma and detects 22 code smells. Refactoring is not available but it is linked to the code. [13, 14, 26, 38]

b) **iPlasma**: iPlasma is for quality assessment of object-oriented systems, supports all steps of analysis. Refactoring and link to code are not available. [26, 38]

c) **JDeodorant**: JDeodorant automatically recognizes code smells and is able to determine proper sequence of refactoring. Also, it is linked to code. [11, 13, 14, 38]

d) **JSpIRIT**: JSpIRIT supports java codes to recognize and arrange code smells. Automated refactoring and link to code are not available. [14, 26, 38, 39]

e) **PMD**: PMD supports programs and searches for faults. Refactoring is not available and detection technique is based on software metrics. [13, 14, 26, 38]

f) **Checkstyle**: Checkstyle is similar to PMD for using software metrics and thresholds for detection of bad smells. Automatic refactoring is not available and it is linked to the code. [13, 26, 38]

g) **Stench Blossom**: Stench Blossom gives a visualization environment to show the programmers a high-level outlook of the bad smells in their code. Automated refactoring is not available but there is direct link to code. [13, 26, 38]

h) **DÉCOR**: DÉCOR automatically permits the specification and detection of bad smells. Refactoring is available as well as code links. [13, 26, 38]

i) **inCode**: inCode is commercial and based on inFusion for detecting of bad smells that supports programmers for writing code in programming environment. [13, 40]

Table 2 Code Smells and Detection Tools That Detect Them

No	Code Smell	Tools								
		Checkstyle	DÉCOR	inFusion	iPlasma	JDeodorant	PMD	Stench Blossom	Jspirit	inCode
1	Brain Class			✓	✓					
2	Brain Method			✓	✓				✓	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
28	Dispersed Coupling				✓				✓	

Tab. 2 shows relationship between code smells and detection tools. According to the table, iPlasma scores maximum points on detection of code smells with 17 detected code smells. It can be interpreted that iPlasma is a functional tool compared to other tools and should be selected by developers as it covers the detection of larger set of code smells. There are only 28 code smells that are detected by one or other of these 9 detection tools.

3.2.2 Software Metrics

Software Quality Metrics refer to measurement of software attributes related to software quality during software development process. Many software metrics are available to systems realized in various paradigms like Objects Oriented Programming (OOP). Finding factors of software quality and planning them into quantitative measures is a critical issue in sustainable success of an end product. Software metric has involved a lot of consideration between researchers and developers in last one decade [41]. Computer science experts are placing all their struggles in measuring quantitative information from software component. Therefore, software metrics are often classified into some types [42]. It is depending on different lookouts. Shepperd and Ince [43] proposed a classification of two metrics: traditional metrics and object-oriented metrics.

Later, Saker [44] suggested a category of software metrics established upon subject and paradigm. In his category software metrics divided to project based metrics and design based metrics. Fenton and Bieman [45] offered different category that it was two dimensional classifications and divided to project metrics (product, process or resources) and the level of visibility that can be internal or external metrics [42]. Also, by other researchers it was divided into basic and additional metrics, objective or subjective, project classification, and static and dynamic. For assessment of quality of software systems, it is significant to define thresholds for software metrics [46]. Software metrics are deliberated for bad smell detection in source code. Existing bad smells in source code shows inacceptable architecture design of software that makes it severe to maintain in future. Software measurement is a process that represents software product or process characteristic to a numeric value [45]. The results are compared with a set of standards that are defined by individuals or organizations and a software quality is concluded [47]. Software metrics can be used to each phase of software development process such as requirements, design, implementation, testing and evaluation, maintenance and use for evaluating of quality of software. Tab. 3 shows 49 software metrics used for detection of code smells with abbreviation and a short definition. All code smells in Tab. 1 do not have metrics to detect.

Table 3 Software Metrics, Their Abbreviations and Brief Definitions

No	Metrics	Abbreviation	Definition
1	Number of Lines of code	LOC	Counting of lines of source code.
2	McCabe Cyclomatic Complexity per module	VG	It measures complexity of source code using number of linearly independent paths of a program.
⋮	⋮	⋮	⋮
49	Number of concerns per component	NCC	Number of concerns per component

Each code smell can be detected by one or more metrics. For instance, Feature Envy can be detected by three metrics [13].

In programming, objects are used as a structure for keeping together data and operations which process that data. Feature Envy indicates Methods that look to be more concerned in other classes than its real occupied. Feature Envy methods access a variety of data of foreign classes. This may possibly is because of misplacing methods and they should move to another class. Data and operations should be close as feasible. This proximity can help to improve the cohesion and ripple effects reduction. Detection of Feature Envy considers counting the number of data members that used by method outside of its own class. Detection technique follows below steps:

1) Method uses more than few attributes of other classes and this measures by *ATFD* (Access To Foreign Data) metric.
2) Method uses more attributes from other classes compare as its own class and this measure by *LAA* (Locality of Attribute Accesses) metric.
3) The used foreign attributes are from a few outside classes and this measure by *FDP* (Foreign Data Providers) metric. This step considers because, if method uses foreign attributes of one or two outside classes it is feature envy smell but if method uses foreign attributes of more outside classes this is Brain Class smell. Therefore, for separation of this two smells researchers consider third condition.

In additional, researchers consider counting of all dependencies of the method, either inside its own class or outside its own class, and they use *FDP* metric because if method uses a few attributes from foreign classes, method can move easily to foreign classes and dispersion of classes will decrease. Also, foreign class includes less functionality and Feature Envy method has high complexity and size.

Feature Envy can be detected by the Eq. (1) and Fig. 2.

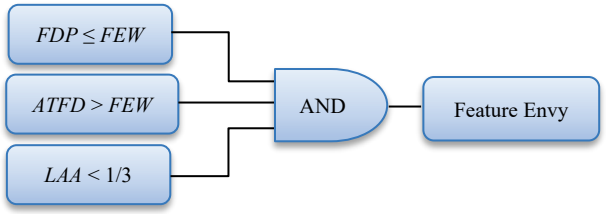

Figure 2 Detection technique for Feature Envy [13, 48].

$$FDP \le FEW \wedge ATFD > FEW \wedge LAA < \frac{1}{3} \quad (1)$$

where *FEW* takes the value of 5 [13, 48].

On the other hand, Large Class can be detected only by LOC [13].

Tab. 4 illustrates the relationship between some code smells and their code smell detection metrics.

Table 4 Code Smells and Software Metrics Used in Detection Them

No	Code Smells						
	No	1	…	19	20	21	22
	Metrics	God Class	…	God Method	Inappropriate Intimacy	Divergent change	Shotgun surgery
1	LOC	✓	…				
2	VG		…	✓			
.	.	…	…	…	…	…	…
36	CM		…			✓	✓
38	NCC		…			✓	

3.2.3 Refactoring Actions

As reported by Fowler, code smells can be removed by refactoring. Refactoring develops the design of existing code of software system by modification of internal structure without affecting its external structure. The main target of refactoring action is improving software design quality and developing quality features like understandability, flexibility, and reusability. Refactoring is not developing the design of the software system through its initial step of design, but

developing its design through the maintenance phase [7]. Tab. 5 shows refactoring actions name and definition. In addition, Tab. 6 describes relationship between code smells and corresponding refactoring actions.

Table 5 List of Refactoring Methods

No	Refactoring Action Name	Definition
1	Add Parameter	If there is not available enough data to execute particular actions for a method, then make a new parameter to pass the essential data.
2	Inline Method	If body of a method is clearer rather than the method itself, then replace calls to the method with the method's content and remove the method itself.
…	…	…
87	Unify Interfaces with Adapter	Clients cooperate with two classes, but one of them has a preferred interface. Then, these interfaces unify with an adapter.

Table 6 Code Smells with Corresponding Refactoring Actions

No	Code Smells	Refactoring Actions
1	Long Method	Extract Method, Replace Temp with Query, Replace Method with Method Object, Substitute Algorithm, Decompose Conditional, Introduce Parameter Object, Preserve Whole Object, Replace Parameter with Explicit Methods, Replace Conditional Logic with Strategy, Replace Conditional Dispatcher with Command, Compose Method, Move Accumulation to Collecting Parameter, Move Accumulation to Visitor
⋮	⋮	⋮
27	Indecent Exposure	Encapsulate Classes with Factory
28	Solution Sprawl	Move Creation Knowledge to Factory

3.3 Categorization of Code Smells and Related Concepts

Categorization is grouping objects according to their similarities and common features or relationship between all members in the group. It is an essential process for cognition of things. Categorization organises knowledge and improves understandability as element inherits categorical attributes. Fig. 3 shows as an overall view of categorization of code smells and related concepts.

Each of these categories is explored further in detail in following subsections.

3.3.1 Categorization of Code Smells

Mantyla [23] proposed a classification of code smells because; some of the code smells are closely related. Each category has an appropriate name which is according to relationship between the bad smells in each category. This classification is provided to better understanding of smells and to identify relationship between them. Over the years, the initial categorization is slightly changed by researchers. As follows in Tab. 7, classification of bad smells with their definition is explained [23, 49, 50].

In literature 22 code smells are classified. Researcher tried to find out the classification of all code smells that are covered in Tab. 1, and Tab. 8 shows categorization of each code smell.

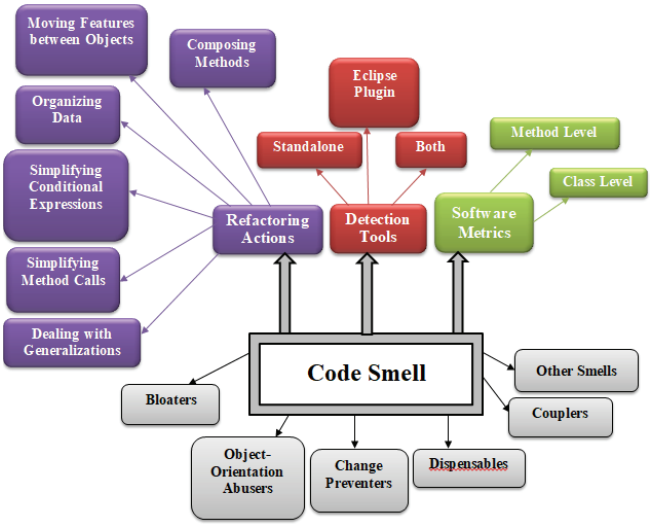

Figure 3 Categorization of code smells and related concepts

Table 7 Code Smells Categories with Their Definitions

No	Category	Definition
1	Bloaters	It reveals one part of code that has grown so large and cannot be successfully handled.
2	Object-Orientation Abusers	It reveals incorrect or incomplete use of object-oriented concepts.
3	Change Preventers	If changing in one place of code requires many changes in other places too.
4	Dispensables	Display something unnecessary in the code whose absence would make the code more effective.
5	Couplers	Lead to excessive coupling among classes or indicate what happens if coupling replaced by excessive delegation.
6	Other Smells	These smells do not fit in any of the above classification.

Table 8 Category-Wise Distribution of Code Smells

No	Classification	Code Smells	Total
1	Bloaters	Long Method, Large Class, Primitive Obsession, Long Parameter List, Data Clumps, Complex conditionals, Blob Operation, Excessively long line of code,	8
2	Object-Orientation Abusers	Switch Statements, Temporary Fields, Refused Bequest, Alternative Classes with Different Interfaces, Parallel Inheritance Hierarchies, God Class, Brain Class, Brain Method, Tradition Breaker, Spaghetti Code, Complex Class, Class Data Should Be Private, Typecast, Cyclic Dependencies, Distorted Hierarchy, Unstable Dependencies, Schizophrenic Class, Stable Abstraction Breaker, Functional Decomposition, God Method, Indecent Exposure, Solution Sprawl, Deficient encapsulation, Type checking	24
3	Change Preventers	Divergent Change, Shotgun Surgery	2
4	Dispensables	Duplicate Code, Lazy Class, Data Class, Dead Code, Speculative Generality, Lazy Element, Contrived complexity, Comments, Instanceof, Sibling Duplication, Internal Duplication, External Duplication, Similar subclasses, Excessive return of data	14
5	Couplers	Feature Envy, Inappropriate Intimacy, Message Chains, Middle Man, Intensive Coupling, Extensive Coupling,	6

6	Other Smells	Missing Template Method, Incomplete Class Library, mysterious name, Mutable data, Global data, Inconsistent Names, Combinatorial Explosion, Type Embedded in Name, Oddball Solution, Excessively Large Identifier, Excessively Small Identifier	11

3.3.2 Categorization of Tools

Various detection tools are able to execute automatic code inspection. Smell detection tools are categorized either as plug-in or as stand-alone application [13]. These tools adopt a little different approaches for detecting code smells. The Eclipse framework is a common integrated advance environment, planned to assist tools that can be used to develop applications and tools or to handle all varieties of documents. A small plug-in loader is placed at the core of Eclipse and entire extra functionalities are performed by plugins [51]. A standalone tool performs locally on the device and doesn't need anything else to be functional. Standalone tools have continuity and interpretation disadvantages. For development of code detection, tool requires a visual integration into the IDE (Integrated development environment). A standalone tool cannot understand which part of code is edited by programmer, therefore continuity cannot be achieved.

Table 9 Detection Tools with Category and Supported Languages

No	Tool	Type	Languages
1	inFusion	Standalone Application	Java, C, C++
2	iPlasma	Standalone Application	C++, Java
3	JDeodorant	Eclipse Plug-in	Java
4	JSpIRIT	Eclipse Plug-in or Standalone Application	Java
5	PMD	Eclipse Plug-in or Standalone Application	Java, C, C++ and others
6	Checkstyle	Eclipse Plug-in	Java
7	Stench Blossom	Eclipse Plug-in	Java
8	DÉCOR	Standalone Application	Java
9	inCode	Eclipse Plug-in or Standalone	Java, C, C++ and

On the other hand, a smell detector plugin shows continuously whether any code smells have been realized without forcing the programmer to leave his IDE. After finding a smell, tool can easily shows the existence of the smell and a suggestion how to remove it. This performance underlines the usability factor. Thus, Smell detection tools with integrated IDEs are more effective compared to stand-alone detection tools. Tab. 9 shows categorization of covered detection tools, and also languages supported by each of them.

3.3.3 Categorization of Software Metric

Every bad smell involves a particular kind of system element like classes or methods which can be appraised by its inner and external characteristics. Metrics can use in file-level, class-level, component-level, method-level, process-level and quantitative values-level metrics [52]. In this exploration study, Software metrics are categorized as class level and method level metrics. Class level metrics measure features of class as well as information on the collaboration among classes. Class level metrics that measure class communications give information for design the system more than code. Some of the class level metrics determine division of labour between methods while others determine the amount of code affect in other classes with changing a special class. The best situation is changes in one class have minimum changes in other classes. When a high level dependency is between classes, they should locate in same package. Method level metrics are one of the most useful metrics. One of the ideal guidelines of programming is that each method should execute a single clear distinct function because a long part of code is difficult to understand [53, 54]. Tab. 10 shows categorization of covered software metrics in Tab. 3.

Table 10 Software Metric's Categorization

No	Metrics Categorization	Software Metrics	Total
1	Class Level	LOC, WMC, DIT, CC, CBO, LCOM, TCC, NOM, NOA, NOC, RFC, NOAM, NBM, WOC, NOPbA, NProtM, BUR, BOvR, AMW, NOPvA, NOProtA, NOPvM, NOPbM, NOProtM, NLOCC, CDE, DAC, LCC, IVMC, NOFF, NOFM, LOMC, NOVC, CHC, DOCM, NCC	36
2	Method Level	VG, PAR, MLOC, LAA, MNL, NOAV, NODM, CP, HM, UP, ATFD, FDP, CM	13

3.3.4 Categorization of Refactoring Actions

Various refactoring actions are available that some researchers have divided them into 6 categories as follows [50].

1) **Composing methods**: Most of the refactoring is concerned with accurately composing methods because extremely long methods are root cause of all destructive qualities. Therefore, this group restructures methods, eliminates code duplication, and provides better future improvements.

2) **Moving features between objects**: Moving functionality between classes, building new classes, and hiding performance features from public access is supported by these refactoring actions.

3) **Organizing data**: This group assists data management, replacing primitives with rich class functionality and helps to solve class associations that construct classes more portable and reusable.

4) **Simplifying conditional expressions**: Preventing conditionals from getting more and more complicated in their logic over time is facilitated by this group of refactoring actions.

5) **Simplifying method calls**: This group streamlines the interfaces for collaboration between classes and creates method calls uncomplicated and more obvious to understand.

6) **Dealing with generalizations**: Moving functionality across the class inheritance hierarchy, building new classes and interfaces, and substituting inheritance with delegation

and vice versa or anything related to abstraction is handled by this group of actions. Researcher tried to classify all refactoring actions in Tab. 5 and shows each code smell belongs to which categorization in Tab. 11.

Table 11 Refactoring Action's Categorization

Categorization of Refactoring	Refactoring Actions	Total
Composing methods	Extract Method, Inline Method, Extract Variable, Inline Temp, Replace Temp with Query, Split Temporary Variable, Remove Assignments to Parameters, Replace Method with Method Object, Substitute Algorithm, Compose Method, Replace Implicit Tree with Composite	11
⋮	⋮	⋮
Dealing with generalizations	Pull Up Field, Pull Up Method, Pull Up Constructor Body, Push Down Field, Push Down Method, Extract Subclass, Extract Superclass, Extract Interface, Collapse Hierarchy, Form Template Method, Replace Inheritance with Delegation, Replace Delegation with Inheritance, Chain Constructors, Extract Composite, Introduce Polymorphic Creation with Factory Method	15

4 ORGANIZING THE CODE SMELL KNOWLEDGE

One of the most important objectives of code smell exploratory study is organisation of knowledge of code smells. Designing of a code smell repository improves software process, decreases the research gaps and prepares structural sources to developers. Organising the code smell knowledge is showed in follows steps.

4.1 Designing Code Smell Template

Designing code smell template is according to relationships between code smells, software metrics, detection tools and refactoring actions. A code smell template is designed and an instance of it is presented.

Code smell Template

Name: name of special code smell
Alias: This is an alternate name for Code Smell
Definition: Definition of special code smell
Links: The list of databases that information about special code smell is available
Category: The name of category that special code smell belongs to
Detection Tools: The name of tools that can detect special code smell
Software Metrics: The name of metrics that can detect special code smell
Refactoring Actions: The name of refactoring techniques that are able to remove special code smell

4.2 Designing Code Smell Database Schema

Based on designed code smell template a schema is designed for describing of its structure. A code smell database schema characterizes the tables and corresponding fields contained in a database. It displays as a list of tables that every table contains a sub list of fields beside the related data type. Code smell database schema includes main tables such as code smell table, metric table, tool table, refactoring table and relational tables between the main tables.

Example of Code smell Template

Name: Lazy Class
Alias: Freeloader
Definition: A class which is not doing sufficient work
Links: https://refactoring.guru/smells/lazy-class, Martin, F. (1999). Refactoring: improving the design of existing code. Pearson Education India.
Category: Dispensables
Detection Tools: DÉCOR, PMD
Software Metrics: LOC, VG, WMC, DIT, CBO, NOM, NOA
Refactoring Actions: Inline Class, Collapse Hierarchy, Inline Singleton

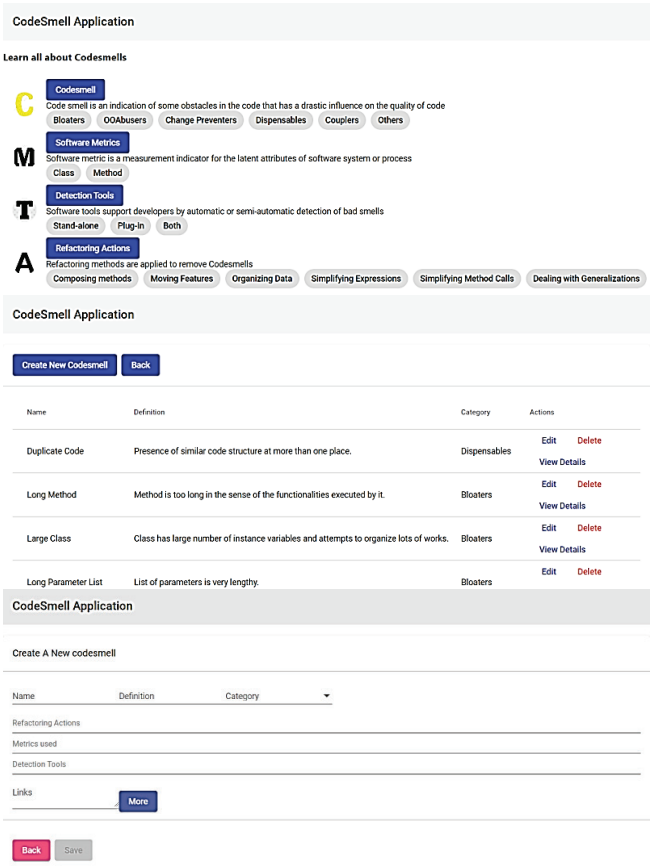

Figure 4 Web page showing Code smell Listing

4.3 Designing Code Smell Database Schema

Based on designed code smell template a schema is designed for describing of its structure. A code smell database schema characterizes the tables and corresponding fields contained in a database. It displays as a list of tables that every table contains a sub list of fields beside the related data type. Code smell database schema includes main tables such as code smell table, metric table, tool table, refactoring table and relational tables between the main tables.

4.4 Making the Knowledge Accessible on Cloud Platform

Code smell knowledge collected from different sources, is organized and made accessible on cloud platform. A new code smell web application is designed using Angular, Material Design, Node Js, Express JS and MongoDB for organization of code smell knowledge. Angular is an application design framework and development platform for

creating efficient and sophisticated mobile and desktop single-page applications. Some screenshots of code smell web application are given in Fig. 4.

The application is available on Heroku cloud platform at https://serene-tundra-28026.herokuapp.com and is under construction. All the tables from 1 to 11 with details are available in the site.

5 CONCLUSION

Code smell topic requires to be understood in depth. The objective of this exploratory study is to explore the code smell problem and its related concepts. A code smell repository is designed and code smell knowledge is arranged systematically. It is accessible on cloud platform. It enables developers and practitioners to set up a powerful foundation for exploring their idea about code smells. Also, this study can help other researchers to preserve a lot of time and resources. In the future, researcher plans to enhance the code smell repository by adding formulas and threshold values. Further this repository can be used to analyse the relationship between code smells and related concepts for identifying a minimal set of metrics, tools or refactoring actions to detect maximum set of code smells. Data mining techniques such as association rule mining can be used for finding representative software metrics for each code smell category. Clustering can be used to get a new way of categorizing code smells. Code smell repository and techniques of extracting insights from it can be made available to developers and practitioners.

6 REFERENCES

[1] Kaur, A. & Singh, S. (2018). Detecting Software Bad Smells from Software Design Patterns using Machine Learning Algorithms. *International Journal of Applied Engineering Research, 13*(11), 10005-10010.

[2] Singh, G. & Chopra, V. (2013). Design and implementation of testing tool for code smell rectification using c-mean algorithm. *International Journal of Advanced Research in Computer Science, 4*(9).

[3] Guggulothu, T. (2019). Code Smell Detection using Multilabel Classification Approach. *arXiv* preprint arXiv:1902.03222.

[4] Lanza, M. & Marinescu, R. (2007). *Object-oriented metrics in practice: using software metrics to characterize, evaluate, and improve the design of object-oriented systems*. Springer Science & Business Media.

[5] Olbrich, S., Cruzes, D. S., Basili, V., & Zazworka, N. (2009). The evolution and impact of code smells: A case study of two open source systems. *The 3rd IEEE International Symposium on Empirical Software Engineering and Measurement*, 390-400. https://doi.org/10.1109/ESEM.2009.5314231

[6] Mannan, U. A., Ahmed, I., Almurshed, R. A. M., Dig, D., & Jensen, C. (2016). Understanding code smells in Android applications. *IEEE/ACM International Conference on Mobile Software Engineering and Systems (MOBILESoft 2016)*, 225-236. https://doi.org/10.1145/2897073.2897094

[7] Fowler, M. (2018). *Refactoring: improving the design of existing code*. Addison-Wesley Professional.

[8] Wangberg, R. (2010). A Literature Review on Code Smells and Refactoring. *Master's thesis*. Department of Informatics, University of Oslo, Norway.

[9] Humayoun, S. R., Hasan, S. M., Al Tarawneh, R., & Ebert, A. (2018). Visualizing software hierarchy and metrics over releases. *Proceedings of the 2018 International Conference on Advanced Visual Interfaces*, 1-5. https://doi.org/10.1145/3206505.3206548

[10] Srinivasan, K. P. (2015). Unique Fundamentals of Software Measurement and Software Metrics in Software Engineering. *International Journal of Computer Science & Information Technology (IJCSIT), 7*(4). https://doi.org/10.5121/ijcsit.2015.7403

[11] Eisty, N. U., Thiruvathukal, G. K., & Carver, J. C. (2018). A survey of software metric use in research software development. *The 14th IEEE International Conference on e-Science (e-Science 2018)*, 212-222. https://doi.org/10.1109/eScience.2018.00036

[12] Do Vale, G. A. & Figueiredo, E. M. L. (2015). A method to derive metric thresholds for software product lines. *The 29th IEEE Brazilian Symposium on Software Engineering*, 110-119. https://doi.org/10.1109/SBES.2015.9

[13] Fontana, F. A., Braione, P., & Zanoni, M. (2012). Automatic detection of bad smells in code: An experimental assessment. *Journal of Object Technology, 11*(2), 5-1. https://doi.org/10.5381/jot.2012.11.2.a5

[14] Paiva, T., Damasceno, A., Figueiredo, E., & Sant'Anna, C. (2017). On the evaluation of code smells and detection tools. *Journal of Software Engineering Research and Development, 5*(1), 7. https://doi.org/10.1186/s40411-017-0041-1

[15] Fowler, M. (2003). *EtymologyOfRefactoring*. https://martinfowler.com/bliki/EtymologyOfRefactoring.html (accessed 16 October 2020).

[16] Webster, B. F. (1995). *Pitfalls of object-oriented development*. M and T books.

[17] Brown, W. J., Malveau, R. C., Brown, W. H., & McCormick, W. H. III, & Mowbray, T. J. (1998). *AntiPatterns: Refactoring Software, Architectures, and Projects in Crisis*. Wiley, 336 pages.

[18] Singh, S., & Kaur, S. (2018). A systematic literature review: Refactoring for disclosing code smells in object oriented software. *Ain Shams Engineering Journal, 9*(4), 2129-2151. https://doi.org/10.1016/j.asej.2017.03.002

[19] Fowler, M. & Beck, K. (2019). *Refactoring: Improving the Design of Existing Code*. Addison-Wesley, 418 pages.

[20] Van Emden, E., & Moonen, L. (2002). Java quality assurance by detecting code smells. *Proceedings of the Ninth IEEE Working Conference on Reverse Engineering*, 97-106. https://doi.org/10.1109/WCRE.2002.1173068

[21] Kerievsky, J. (2005). *Refactoring to patterns*. Pearson Deutschland GmbH. https://doi.org/10.1007/978-3-540-27777-4_54

[22] Mäntylä, M. (2002). Experiences on applying refactoring. *Software Engineering Seminar*, 1-32.

[23] Mantyla, M. (2003). *Bad smells in software-a taxonomy and an empirical study*. Helsinki University of Technology.

[24] Li, W. & Shatnawi, R. (2007). An empirical study of the bad smells and class error probability in the post-release object-oriented system evolution. *Journal of Systems and Software, 80*(7), 1120-1128. https://doi.org/10.1016/j.jss.2006.10.018

[25] Shatnawi, R. & Li, W. (2008). The effectiveness of software metrics in identifying error-prone classes in post-release software evolution process. *Journal of Systems and Software, 81*(11), 1868-1882. https://doi.org/10.1016/j.jss.2007.12.794

[26] Fontana, F. A., Mariani, E., Mornioli, A., Sormani, R., & Tonello, A. (2011). An experience report on using code smells detection tools. *The Fourth IEEE International Conference on Software Testing, Verification and Validation Workshops*, 450-457. https://doi.org/10.1109/ICSTW.2011.12

[27] Ouni, A., Kessentini, M., Sahraoui, H., & Hamdi, M. S. (2012). Search-based refactoring: Towards semantics preservation. *The 28th IEEE International Conference on Software Maintenance (ICSM 2012)*, 347-356.

https://doi.org/10.1109/ICSM.2012.6405292
[28] Palomba, F., Bavota, G., Di Penta, M., Oliveto, R., & De Lucia, A. (2014). Do They Really Smell Bad? A Study on Developers' Perception of Bad Code Smells. *Proceedings of the 30th International Conference on Software Maintenance and Evolution (ICSME 2014)*, 101-110. https://doi.org/10.1109/ICSME.2014.32
[29] Pinto, G. H. & Kamei, F. 2013. What programmers say about refactoring tools? An empirical investigation of stack overflow. *Proceedings of the 2013 ACM Workshop on Refactoring Tools*, 33-36. https://doi.org/10.1145/2541348.2541357
[30] Tufano, M., Palomba, F., Bavota, G., Oliveto, R., Di Penta, M., De Lucia, A., & Poshyvanyk, D. (2015). When and why your code starts to smell bad. *The 37th IEEE/ACM International Conference on Software Engineering*, Vol. 1, 403-414. https://doi.org/10.1109/ICSE.2015.59
[31] Kaur, A. & Dhiman, G. (2019). A review on search-based tools and techniques to identify bad code smells in object-oriented systems. *Harmony search and nature inspired optimization algorithms*, Springer, Singapore, 909-921. https://doi.org/10.1007/978-981-13-0761-4_86
[32] Fontana, F. A., Lenarduzzi, V., Roveda, R., & Taibi, D. (2019). Are architectural smells independent from code smells? An empirical study. *Journal of Systems and Software*, *154*, 139-156. https://doi.org/10.1016/j.jss.2019.04.066
[33] Reis, J. P. D., Carneiro, G. D. F., & Anslow, C. (2020). Code smells detection and visualization: A systematic literature review. *arXiv* preprint arXiv:2012.08842
[34] Martins, J., Bezerra, C., Uchôa, A., & Garcia, A. (2020, October). Are code smell co-occurrences harmful to internal quality attributes? A mixed-method study. *Proceedings of the 34th Brazilian Symposium on Software Engineering*, 52-61. https://doi.org/10.1145/3422392.3422419
[35] Kaur, A. (2020). A systematic literature review on empirical analysis of the relationship between code smells and software quality attributes. *Archives of Computational Methods in Engineering*, *27*(4), 1267-1296. https://doi.org/10.1007/s11831-019-09348-6
[36] Al-Shaaby, A., Aljamaan, H., & Alshayeb, M. (2020). Bad Smell Detection Using Machine Learning Techniques: A Systematic Literature Review. *Arabian Journal for Science and Engineering*, *45*(4), 2341-2369. https://doi.org/10.1007/s13369-019-04311-w
[37] Alkharabsheh, K., Crespo, Y., Manso, E., & Taboada, J. A. (2019). Software Design Smell Detection: a systematic mapping study. *Software Quality Journal, 27*(3), 1069-1148. https://doi.org/10.1007/s11219-018-9424-8
[38] Lake, A. & Cook, C. (1994). Use of factor analysis to develop OOP software complexity metrics. *Proceedings of the 6th Annual Oregon Workshop on Software Metrics*, Silver Falls, Oregon.
[39] Vidal, S., Berra, I., Zulliani, S., Marcos, C., & Pace, J. A. D. (2018). Assessing the refactoring of brain methods. *ACM Transactions on Software Engineering and Methodology (TOSEM 2018), 27*(1), 1-43. https://doi.org/10.1145/3191314
[40] Fontana, F. A., Mangiacavalli, M., Pochiero, D., & Zanoni, M. (2015). On experimenting refactoring tools to remove code smells. *Scientific Workshop Proceedings of the XP2015*, 1-8. https://doi.org/10.1145/2764979.2764986
[41] Srinivasan, K. P. & Devi, T. (2014). A complete and comprehensive metrics suite for object-oriented design quality assessment. *International Journal of Software Engineering and Its Applications, 8*(2), 173-188.
[42] Alshayeb, M., Shaaban, Y., & Al-Ghamdi, J. (2018). SPMDL: software product metrics definition language. *Journal of Data and Information Quality (JDIQ), 9*(4), 1-30. https://doi.org/10.1145/3185049
[43] Shepperd, M. & Ince, D. (1993). *Derivation and validation of software metrics*. Oxford University Press, Inc.
[44] Sarker, M. (2005). *An overview of object oriented design metrics*. From Department of Computer Science, Umeå University, Sweden.
[45] Fenton, N. & Bieman, J. (2014). *Software metrics: a rigorous and practical approach*. CRC press. https://doi.org/10.1201/b17461
[46] Mori, A., Vale, G., Viggiato, M., Oliveira, J., Figueiredo, E., Cirilo, E., & Kastner, C. (2018). Evaluating domain-specific metric thresholds: an empirical study. *The IEEE/ACM International Conference on Technical Debt (TechDebt 2018)*, 41-50. https://doi.org/10.1145/3194164.3194173
[47] Núñez-Varela, A., Perez-Gonzalez, H. G., Cuevas-Tello, J. C., & Soubervielle-Montalvo, C. (2013). A methodology for obtaining universal software code metrics. *Procedia Technology, 7*, 336-343. https://doi.org/10.1016/j.protcy.2013.04.042
[48] Lanza, M. & Marinescu, R. (2007). *Object-oriented metrics in practice: using software metrics to characterize, evaluate, and improve the design of object-oriented systems*. Springer Science & Business Media.
[49] Saranya, G. (2017). *Code smell detection and prioritization of refactoring operations to enhance software maintainability*. Faculty of Science and Humanities, Anna University.
[50] Refactoring.guru. (n.d.b). *Refactoring Techniques*. https://refactoring.guru/refactoring/techniques (accessed 16 October 2020)
[51] Slinger, S. (2005). *Code smell detection in Eclipse*. Delft University of Technology.
[52] Singh, M. & Salaria, D. S. (2013). Software defect prediction tool based on neural network. *International Journal of Computer Applications, 70*(22). https://doi.org/10.5120/12200-8368
[53] Virtual Machinery. (n.d.a). Object-Oriented Software Metrics - Class Level Metrics. Refactoring. http://www.virtualmachinery.com/jhawkmetricsclass.htm#:~:text=of%20Methods%20Called%20in%20class,Fan%20In%20and%20Fan%20Out (accessed 16 October 2020)
[54] Virtual Machinery. (n.d.b). Object-Oriented Software Metrics - Method Level Metrics. Refactoring. http://www.virtualmachinery.com/jhawkmetricsmethod.htm#:~:text=We%20can%20start%20at%20the,as%20a%20measure%20of%20productivity.&text=This%20is%20a%20measure%20of,through%20a%20piece%20of%20code (accessed 16 October 2020)

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Preliminary communication

Model for Predicting the Machinability of Continuously Cast and Subsequently Rolled Steel Using the Artificial Neural Network

Miha Kovačič*, Shpetim Salihu, Uroš Župerl

Abstract: The paper presents a model for predicting the machinability of steels using the method of artificial neural networks. The model includes all indicators from the entire steel production process that best predict the machinability of continuously cast steel. Data for model development were obtained from two years of serial production of 26 steel grades from 255 batches and include seven parameters from secondary metallurgy, four parameters from the casting process, and the content of ten chemical elements. The machinability was determined based on ISO 3685, which defines the machinability of a batch as the cutting speed with a cutting tool life of 15 minutes. An artificial neural network is used to predict this cutting speed. Based on the modelling results, the steel production process was optimised. Over a 5-month period, an additional 39 batches of 20MnV6 steel were produced to verify the developed model.

Keywords: calcium treated steel; continuous casting; machinability; modelling; neural network; steelmaking

1 INTRODUCTION

Research in the steelmaking industry is usually focused on analysing the individual characteristics of one type of material or one type of steel and often does not include the possibility of direct practical implementation of the results in mass production of steel. Thus, it is not possible to find in the literature practical instructions for changing the technology of the steel production process.

This article deals with the analysis of the influences of material properties on machinability. In the literature, machinability is defined as the material's ability to be machined at the lowest possible machining cost [1]. Improved machinability of the material leads to increased tool life, increased cutting performance, lower energy consumption and optimal surface quality. Machinability is influenced by the properties of the material and machining. For example, the machinability of carbon and alloyed steel is affected by the chemical composition; size, morphology, distribution and type of inclusions; macrostructure; microstructure; machining parameters and cutting tool.

The effects of individual chemical elements on the machinability of steels have been well known for decades [1–4]. Silicon, sulfur, phosphorus, lead, tellurium, bismuth, and antimony positively affect machinability. These elements are added to form inclusions with the correct chemical composition, morphology, size, and distribution. The effects of individual alloying elements on the steel matrix and consequently on the material's mechanical properties are not known [1, 4-5].

Researches dealing with the impacts of inclusions can be divided into two groups. The first group analyses the addition of inclusions to form additions, while the second group deals with the effects of chemical composition, morphology, size and distribution of inclusions [6-8].

In this study, the effects of the entire steelmaking process on the machinability of 25 different calcium treated steel grades were analysed. Chemical composition, deoxidising agents and casting parameters were included in predicting the machinability of continuously cast and later rolled material.

The first part of the paper presents the problem of achieving steel machinability and collecting data for predicting machinability. The process for determining workability according to ISO 3685:1993 [9] is briefly presented. The following section presents a model for predicting machinability based on artificial neural networks. Then, the results of optimisation of the 20MnV6 steel production process using predictive analytics are given. The last chapter provides conclusions and plans for future work.

2 STEEL MAKING PROCESS, MATERIALS AND METHODOLOGY

The steel plant in Štore is one of the largest European producer of flat spring steels. The steel plant produces more than 40 grades of calcium-treated steel with various chemical compositions, representing up to 15% of total production. Steel grade 20MnV6 is the most produced steel in Štore steel.

Spring steel production is carried out by melting scrap steel in an electric arc furnace, tapping, ladle treatment and continuous casting of the billets. The ladle treatment process is also known as secondary metallurgy. The cooled billets are then reheated and rolled in a rolling hall. The billets are rolled into a bar with a round cross-section and a diameter of 90 mm The rolled bars are then further straightened, inspected, cut to lengths (1.2 m), drilled, peeled, and chamfered in a cold finishing hall. The rod is now ready for the machinability test according to ISO 3685:1993. This standard defines the implementation of tool life testing with single-current turning tools [9]. ISO 3685:1993 stipulates that a constant cutting speed must be maintained during the turning process when reducing the workpiece diameter. The rods are turned to a diameter of 35 mm with a cutting depth of 4 mm and a feed rate of 0.24 mm / rev. Tool wear measurements at specified cutting speeds are made at appropriate intervals and recorded in time-tool wear diagrams with at least five experimental points for each wear curve (Fig. 1). The following cutting

tool wear criteria for sintered carbide cutting inserts are used in this research (Fig. 2): The maximum flank wear VBB max is equal to or greater than 0.5 mm, the average flank wear is equal to or greater than 0.3 mm, crater wear is equal to or greater than 0.17 mm, the front distance of the crater is reduced to the value of KF = 0.03 mm and cutting-edge failure.

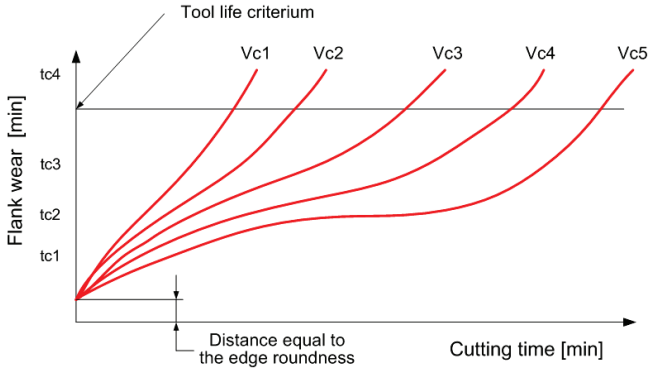

Figure 1 Construction of flank wear curves with respect to machining time for different cutting speeds

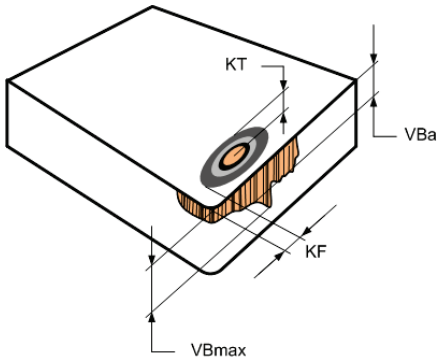

Figure 2 Maximum and average flank wear (*VB*max, *VB*), crater wear (*KT*) and the crater front distance (*KF*).

Tool wear was determined using a profile projector, stopwatch, a microscope and a dial. The tool wear measurements at different cutting speeds were then presented in cutting tool life diagrams concerning cutting speeds (Fig. 3). Under certain conditions, tool life can be expressed in minutes of tool life at only one selected cutting speed.

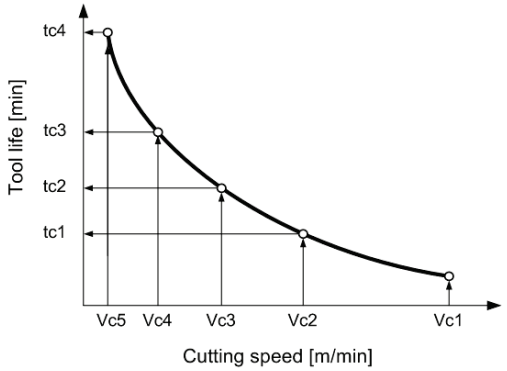

Figure 3 Graph of tool life versus cutting speed

In subsequent machinability tests of the same type of steel, the test always begins with machining at a previously obtained cutting speed, where the tool wears out in 15 minutes. During the machinability test, the time in which the tool wears out is measured. Time in minutes represents the tool life, based on which the actual cutting speed is determined from the diagram (Fig. 4). Then, the calculated actual cutting speed is compared to the previously obtained cutting speed at which the tool wears out in 15 minutes (Fig 4). The machinability of the test material is adequate if the actual speed is greater than or equal to the cutting speed at which the tool wears within 15 minutes.

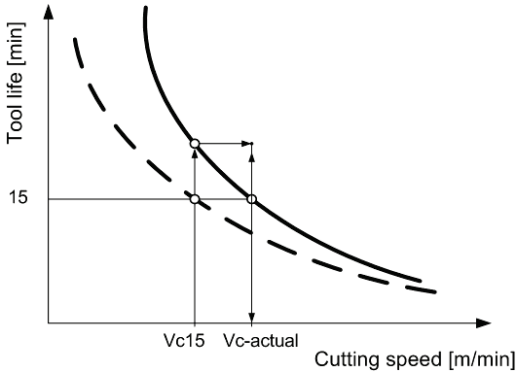

Figure 4 Determination of actual cutting speed for tested material

Therefore, the cutting speed at which the tool has a tool life of 15 minutes was chosen as the machining criterion (Fig. 4). From 2018 to March 2020, 255 batches with 26 different calcium treated steel grades were cast in succession. During the continuous casting process, the following parameters were monitored:

- Calcium carbide cored wire length [m] is used to modify aluminum silicate inclusions (Ladle treatment).
- Ladle treatment time [min] includes raffination, argon stirring, alloying, heating, slag forming, taking of samples and technological delays.
- Calcium silicon cored wire length [m] is used to modify aluminium silicate inclusions.
- Alloying elements added to the melt via automatic feeders: Ferrochromium with low carbon content (kg), Ferrochromium with high carbon content (kg), Ferromanganese (kg), Ferromolybdenum (kg), Ferrosilicon (kg), Ferrovanadium (kg), Nickel (kg), Sulfur cored wire [m] and Silicon manganese (kg).

Parameters of the continuous casting process:

- The average temperature of casting (°C)
- The difference between the inlet and outlet temperature of the coolant in the process of primary cooling (°C).
- Cooling water pressure directly below the mold and in the second secondary cooling zone (bar).
- Chemical composition (%) affects the microstructure and mechanical properties. The chemical composition includes carbon, silicon, manganese, sulfur, chromium, molybdenum, nickel, aluminium, vanadium and calcium.

- The cutting speed at which the tool wears out within 15 minutes for individual batch (m/min).

Tab. 1 shows the ranges of the monitored parameters.

Table 1 Monitored parameters with limit values

Label	Parameter	Unit	Min.	Max.
AL	Aluminium content	%	0.011	0.031
TEMPC	Average casting temperature	°C	1516	1564
DELTATEMP	Average difference between input and output water temperature for each mold	°C	4.66	8.78
CAC2	Calcium carbide cored wire	m	0	215
CA	Calcium content	%	0.0011	0.005
CASI	Calcium silicon cored wire	m	0	340
C	Carbon content	%	0.08	0.55
CR	Chromium content	%	0.06	2
FECRC	Ferrochromium with high carbon content	kg	0	1578
FECRA	Ferrochromium with low carbon content	kg	0	597
FEMN	Ferromanganese	kg	0	1004
FEMO	Ferromolybdenum	kg	0	274
FESI	Ferrosilicon	kg	0	337
FEV	Ferrovanadium	kg	0	106
TIMEL	Ladle treatment time	min	24	100
MN	Manganese content	%	0.34	1.59
MO	Molybdenum content	%	0.01	0.37
NIKG	Nickel	kg	0	1001
NI	Nickel content	%	0.05	1.96
SI	Silicon content	%	0.02	0.45
SIMN	Silicon manganese	kg	0	1199
S	Sulfur content	%	0.013	0.059
SM	Sulfur cored wire	m	0	110
P1	The average cooling water pressure in the first zone of secondary cooling	bar	2.61	6.68
P2	The average cooling water pressure in the second zone of secondary cooling	bar	1.53	4.93
Vc15	The cutting speed where the tool wears out within 15 minutes for individual batch	m/min	210	450
V	Vanadium content	%	0	0.14

3 MODEL FOR PREDICTING THE CUTTING FORCE AT WHICH THE CUTTING TOOL LIFE IS 15 MINUTES

This research aims to design and test the methodology for predicting the cutting speed Vc15, which serves as a criterion for the machinability of all calcium-treated steel grades produced in Štore steel plant. Furthermore, the chapter presents in detail the adaptation of the artificial neural network (ANN) architecture to the problem of cutting speed prediction.

The average deviation between the predicted and experimental data is selected for the Fitness function, which is calculated according to the equation:

$$\Delta = \frac{\sum_{i=1}^{n} \left| Q_i - Q'_i \right|}{n}, \tag{1}$$

where n is the size of the acquisition data and Q'_i and Q_i are the actual and the predicted actual cutting speed. The popular four-layer feedforward neural network architecture perfectly aligned with the back propagation learning algorithm was used to perform Vc15 cutting speed modeling. The designed ANN has 26 input neurons for modelling (see Fig. 5). The optimal number of hidden layers, the number of neurons in each hidden layer, the training parameters, and the optimal type of activation function were determined by systematically varying the parameters in the simulations. The optimal ANN architecture contains 15, 12, 6, and 10 neurons in each hidden layer. The output from the ANN is the cutting speed; therefore, only one output neuron is required. Signals are transmitted between neurons, which are transformed on neurons by the ArcTangent activation function. Fig. 5 shows a detailed architecture of the developed neural model for cutting speed predictions.

Four steps are required to develop a neural model of cutting speed. In Step 1, data sets for learning and testing were presented to ANN. A total of 2800 scaled data points were used as inputs and outputs for ANN training. In addition, 30% of this data was used to test the ANN to verify the accuracy of the predicted values. In step 2, the ANN topology and learning parameters were defined. The number of hidden layers, the number of neurons, the momentum rate (β), the learning rate (α), the total network error and the maximum number of training iterations were determined. To determine the effects of individual parameters on ANN performances, 72 different network topologies were trained, tested, and analysed. In addition, neural networks performances were evaluated by fitness function and number of training iterations. Based on the simulation results, it is determined that the Optimal number of neurons in the hidden layers is 24, the learning rate α should be less than 0.2 and the momentum rate β should be between 0.008 and 0.01. In step 3, the network training and testing process is performed. During training, ANN adjusts its internal structure by adjusting the weights on the synapses to get the correct output results according to the input features.

2800 sets of experimental data are used to conduct 1075 iterations of training. Artificial neural network training stops when the prediction error reaches the lower defined limit within 1075 iterations of training. It was found that the test

error for 30% of all data points converged to 2.9%. Fig. 6 shows the scatter diagram of the predicted values and experimentally determined values of the Vc15 for testing data.

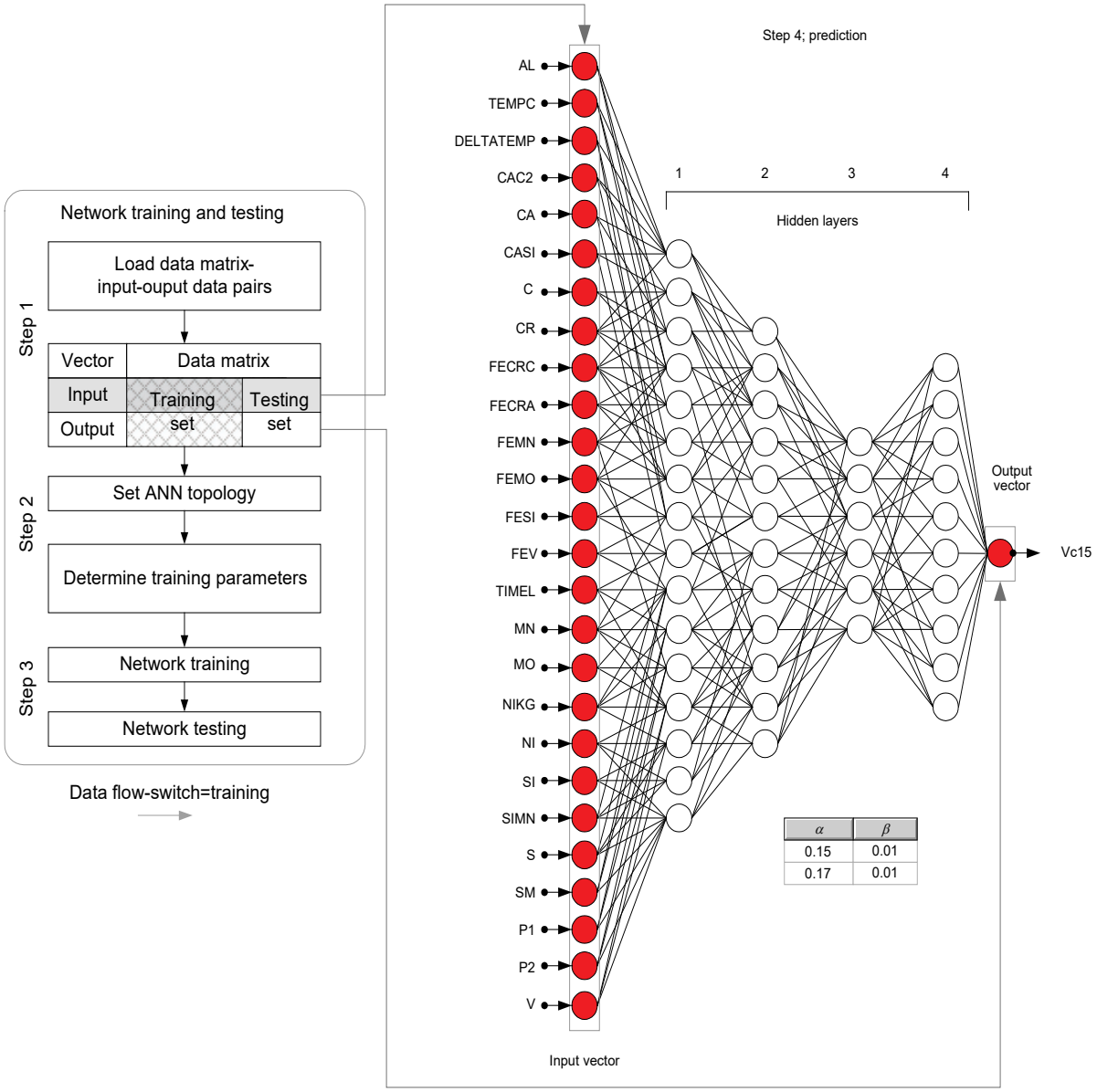

Figure 5 Flow chart for training and employing the ANN- based cutting speed model with its detail structure

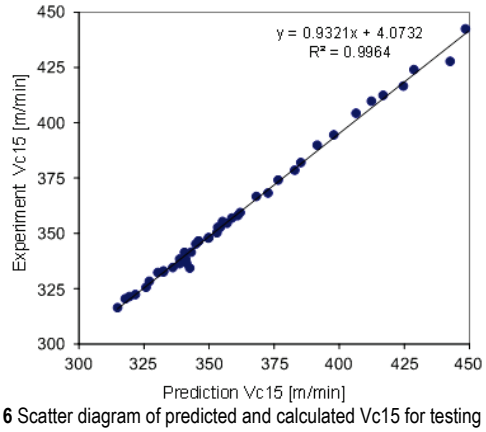

Figure 6 Scatter diagram of predicted and calculated Vc15 for testing data set

After training, the model is made and ready for prediction. The model is then verified with additional input-output data pairs that were not included in the training process. The output vector values were not delivered to the model, so the ANN had to predict them itself. Finally, the predicted values were compared with the actual cutting speeds and the prediction errors were calculated. Finally, in the fourth step, the trained ANN is used to predict the cutting speeds.

Fig. 5 shows a basic flow diagram for training ANN and for predicting cutting speeds via ANN.

4 OPTIMISATION OF THE 20MnV6 STEEL MAKING PROCESS USING PREDICTIVE ANALYTICS

From 2018 to March 2020, 58 batches of 20MnV6 steel grade out of a total of 255 were produced. For this grade of steel, 39.8% of batches with inadequate machinability were detected. In 25 baches out of the 58 batches, the desired machinability was not achieved. The actual cutting speed, which enables tool life of 15 minutes, was lower than the reference cutting speed calculated according to ISO-3685:1993. In process optimization, the performance machinability function according to ISO-3685:1993 is used. ANN was used to predict the maximum cutting speed with a tool life of 15 minutes. A 5.21% discrepancy was found between the experimentally obtained data and the results of the neural model. Fig. 7 shows the effects of process parameters on the maximum cutting speed Vc15 at which the cutting tool has a tool life of 15 minutes. Influences are determined using a neural network prediction model based on separate variation of individual parameter (the others are fixed) within the allowable parameter range.

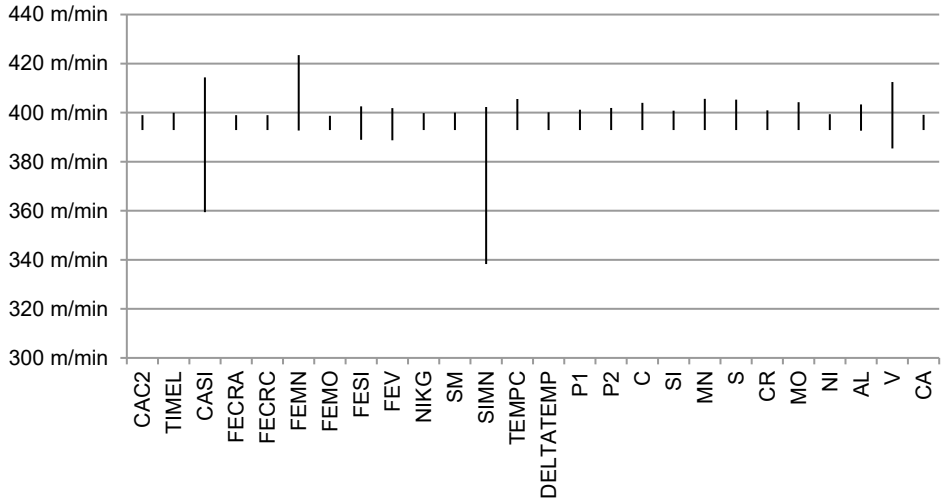

Figure 7 Influences of individual process parameters on the maximum cutting speed with the corresponding tool life of 15 minutes

The results in Fig. 7 show that calcium silicon (CASI), ferromanganese (FEMN) and silicomanganese (SIMN) have the greatest impact on steel machinability. In 2020, based on the determined influences of process parameter, the following changes were made during ladle treatment of 20MnV6 steel. First, Pheromanganese and ferrosilicon were partially replaced by silicon manganese. Second, the addition of sulfur wire has increased. Initially installed, secondary cooling nozzles were replaced with self-cleaning water nozzles due to frequent clogging.

The influence of other parameters that were not included in the process changes is explained below.

It follows from determining influences of vanadium content and ferrovanadium additives on machinability that at the required vanadium content in the melted material, ferrovanadium is added during ladle treatment according to the variable initial scrap vanadium content.

Water spraying during secondary cooling affects the temperature field of molten steel in the mold, which in turn affects the gradual solidification of melt, which forms a layered and chemically non-homogeneous cast structure.

Variation of the chemical composition within the technical delivery conditions does not affect the machinability of the steel.

Changes in steel production resulted in a statistically significant decrease of ferromanganese and ferrosilicon by 58.66% and 32.02%, respectively, increased sulfur cored wire by 50.88%, and a decrease of water pressure by 1.5 bar. However, the analysis of cleanliness before and after the change of the steelmaking process showed that micro cleanliness did not change significantly.

For 24 batches of 20MnV6 steel produced in 2020, the achieved machinability was adequate, which confirmed the developed neural network model results. There was a 2.91% discrepancy between the experimentally obtained data and the results of the neural model.

5 CONCLUSION

Data for the development of the machinability model were obtained from two years of serial production of 26 steel grades from 255 batches and include seven parameters from secondary metallurgy, four parameters from the casting process, and content of ten chemical elements. The machinability was determined based on ISO 3685.

The maximum cutting speed at which the cutting tool has a tool life of 15 minutes was calculated from the existing tool life-cutting speed curves for a particular steel grade and the actual experimentally determined tool life for an individual batch of steel.

The calculated cutting speeds together with the influential variables from the production process, were then used to train the ANN model.

The artificial neural network was used to predict the maximum cutting speed with a tool life of 15 minutes. A 5.21% discrepancy was found between the experimentally

obtained data and the results of the neural model. Predictive analytics is then used to optimise the steel making process of one of the most problematic batches with inconsistent machinability of the otherwise most produced 20MnV6 steel grade. From 2018 to March 2020, 58 batches of 20MnV6 steel grade were produced out of a total of 255 produced batches of steel. For this grade of steel, 40.35% of batches with inadequate machinability were detected. In 24 of the 58 batches, the desired machinability was not achieved. Therefore, the actual cutting speed, which enables tool life of 15 minutes, was lower than the reference cutting speed calculated according to ISO-3685:1993.

In 2020, based on the results of the prediction model, the following changes were made during ladle treatment of 20MnV6 steel:

- Pheromanganese and ferrosilicon were partially replaced by silicon manganese
- The addition of sulfur wire has increased.
- Initially installed, secondary cooling nozzles were replaced with self-cleaning water nozzles due to frequent clogging.

Changes in steel production resulted in a statistically significant decrease of ferromanganese and ferrosilicon by 56.68% and 31.77%, respectively, an increase in a sulfur cored wire by 51.41% and a decrease of water pressure by 1.5 bar. However, micro cleanliness did not change statistically significantly. The achieved machinability was adequate for all 24 batches of 20MnV6 steel produced in 2020, which confirmed the developed neural network model results. However, there was a 2.91% discrepancy between the experimentally obtained data and the results of the neural model. The goal of further research is to use a predictive model to optimise other grades of steels with an emphasis on reducing micro cleanliness and additional agents while ensuring the desired machinability.

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Notice

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6 REFERENCES

[1] Stephenson, D. A. & Agapiou, J. S. (1997). Metal Cutting Theory and Practice Manufacturing.

[2] Leskovar, P. & Grum, J. (1986). *The metallurgical aspects of machining. CIRP Annals, 35*(2), 537-550. https://doi.org/10.1016/S0007-8506(07)60199-2

[3] Davim, J. P. (Ed.). (2008). *Machining: fundamentals and recent advances*. Springer Science & Business Media.

[4] Desaigues, J. E., Lescalier, C., Arzur, A. B., & Bomont, O. (2013, September). High Strength Steel solutions for automotive parts: State of the art of machinability enhancement and further developments. *The Tenth International Conference on High Speed Machinin*g, Technische Universität Darmstadt, 270-277.

[5] Kovach, C. W. & Moskowitz, A. (1969). Effects of manganese and sulfur on the machinability of martensitic stainless steels. *Trans Met Soc Aime*, *245*(10), 2157-2164.

[6] Ånmark, N., Karasev, A., & Jönsson, P. G. (2015). The effect of different non-metallic inclusions on the machinability of steels. *Materials*, *8*(2), 751-783. https://doi.org/10.3390/ma8020751

[7] Sathyamurthy, P., Vetrivelmurugan, R., & Sooryaprakash, J. (2018, February). Improving the machinability of leaded free cutting steel through process optimisation. *The IOP Conference Series: Materials Science and Engineering, 314*(1), p. 012019. https://doi.org/10.1088/1757-899X/314/1/012019

[8] Vasconcellos da Costa e Silva, A. L. (2019). The effects of non-metallic inclusions on properties relevant to the performance of steel in structural and mechanical applications. *Journal of Materials Research and Technology, 8*(2), 2408-2422. https://doi.org/10.1016/j.jmrt.2019.01.009

[9] ISO. (1993). ISO 3685:1993 Tool-life testing with single-point turning tools.

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Preliminary communication

The Conceptual Design of a Smart Wrist Orthosis and Functional Performance - Project Overview

Zoran Domitran*, Robert Mašović, Jure Serdar, Mislav Jelić

Abstract: The idea of the project was to find a conceptual design of a multi-functional smart orthosis for wrist fixation. The application of additive technologies presents the potential in designing a customised orthosis for every patient individually. By using pre-generated 3d models of various hand shapes it is possible to prepare models for several shapes and sizes of forearms and hands. The conceptual design provides a possible solution for a two-part orthosis bound around the forearm and a modular extension to stabilize the wrist without additional compression. The multi-functionality occurs with the development of a small pre-defined electronic plate located in the bottom part of the orthosis. The temperature and heart rate are constantly monitored and displayed wirelessly on a smartphone. The target group are the patients active in sports or patients with minor injuries. Moreover, the orthosis can be used for body temperature and heart function monitoring during recovery period.

Keywords: orthosis design; smart orthosis; wrist orthosis; 3D print

1 INTRODUCTION

The work-related injuries of joints and hands represent one of the most common causes of immobilisation of hands and wrists. Studies [1] indicate a very significant amount in medical costs and a high degree of the absence of workers from work. At the same time the authors state that on the average 20-27% of all injuries in sport are the injuries of hands and joints, especially regarding sports that rely on more intensive use of the hands during physical activity [2]. Immobilisation as one of the ways to treat wrist injuries is a topic dealt with by many authors. By implementing digitalisation and additive technologies Koutny et al. [3] dealt with the possibility and methods of producing CAD models and customised orthoses. Apart from technology recommendation, the authors also give the solutions for a device which can be used for body parts digitalization and CAD models processing. In the development of customised orthoses, some of the authors [4-7] made tests with additive technologies with the aim of merging digitalised model for every patient individually. With the development of additive technologies, J. Li and H. Tanaka [4] showed the impacts of manufacturing time and time shares of pre-preparation and production of single orthosis. Additionally, the impact of modelling skill and individual model production considering the weight reduction and breathability of the orthosis is studied. Koutny et al. [3] compared the scanning devices as the basis for developing credible models of body extremities to make the orthoses and prosthetic aids. Fromme et al. [8] focused on the design of orthosis made of light materials such as fabrics and fixators with air in the form of muscles wrapped in fabric and adhesive Velcro strips. By changing the pressure inside the air pocket, the suspension of the joint and a restriction in the joint movement are allowed. A parallel branch of rehabilitation in orthopaedics relies on the application of sensors in medicine. A review by Reinkensmeyer [9] indicated an increasing trend in the implementation of sensors and active measuring devices in real time over the last fifteen years. It indicates the possibility of connecting wireless protocols in connecting the sensors to mobile devices. Avila et al. [10] presented a development concept of a device that can activate individual muscles for the rehabilitation purpose aimed for home use. Another possible application of sensors and devices can be found in the rehabilitation of the patient after heart attack. Toth et al. [11] described the derived conceptual design of the orthoses with actuators and their application in rehabilitation of the patients after a heart attack.

Jovanov et al. [12] provided a concept of wireless network for multiple devices that can communicate through a joint platform in a constant body monitoring. The authors state a possibility of centrally connecting several sensors all over the body in a single common platform. Such approach allows active monitoring of the body condition with a possibility of real-time monitoring if there is a feedback to the person who is supervising the patient.

The concept of smart orthosis device is aimed towards standardizing the parts of the orthosis through combining adaptive parts into a whole resulting in a predefined final product for the user. The combination of sizes and forms makes it possible to simplify the long process of digitalizing and modelling patient's forearm along with reducing the production costs. Another function of a smart orthosis is the daily monitoring of the patient's condition using basic temperature and heart rate sensors aiming at early diagnosis and active monitoring of the patient's condition.

2 MATERIALS AND METHODS

General approach to orthosis design is based on using available tools and optimisation methods which can be applied to develop personalised devices for every individual patient. In order to use the already pre-prepared models of the patients' forearms the 3D CAD software Inventor is used to create the 3D architecture of the orthosis model. The baseline for the basic model was the average adult male, aged 26 to 35, of average height and size. Although arm and body models are not generally strictly standardised, a variation with respect to age and height can be noted. Due to a large number of models and variations, a standardisation model according to the 50th percentile is proposed, and ready-made models of the body and forearm shape are taken as the basis

for prototype dimensions of the orthosis shape. In this case the orthosis is designed for the left arm only. According to the adopted model the selected version of the product is divided longitudinally in two parts (Fig. 1). This ensures relatively easier installation on the injured forearm in the event of immobilization. Other methods of orthosis modelling were considered which include putting the orthosis on in the form of a glove or the minimalist approach with flat surfaces. However, due to the problem of implementing sensors and the danger of relatively poor contact of the sensor with the hand, a poorer signal transmission from skin to the sensors can occur in abovementioned cases.

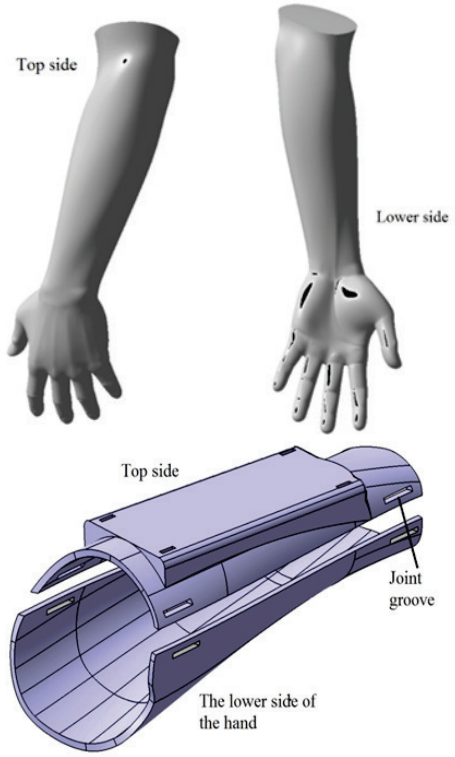


Figure 1 3D model of the arm and initial 3D model of the orthosis cut longitudinally

Modularity is ensured in a such way that the upper part of the orthosis is at the same time the central part on which other elements of the system are connected. Each part can be produced in a different size thus ensuring modularity based on the size of the human forearm. The part production is carried out by means of multi-material 3D printing on commercially available 3D printer model *Prusa i3 MK3S*. The materials used were PLA and 5G. The performed design indicates a satisfactory degree of accuracy, very low mass whereas the stiffness of the parts is obtained by applying curved surfaces. The connection of the upper and lower part of the orthosis is achieved by connecting grooves and application of flexible materials and self-adhesive Velcro strips.

The fixation of the wrist is the basic orthopaedic function of the presented orthosis. The fixation is ensured through a profiled groove and separate three inserts – Z bracket (Fig. 2), which is connected to the fingers by means of an elastic band. After design iteration, the angle of 15° is employed ensuring optimal position of the hand which maximally relaxes the fixated joint.

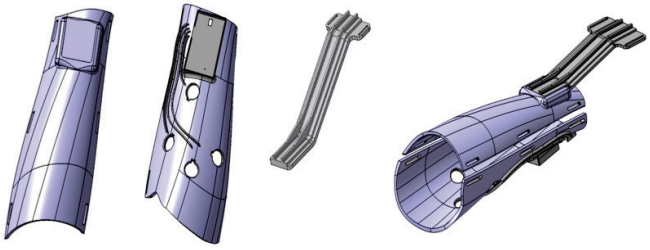
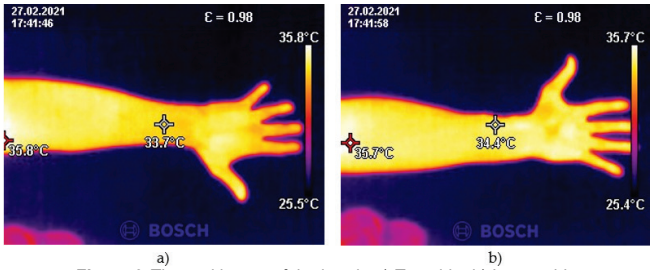


Figure 2 Basic parts of the orthosis (final model) and Z bracket fixation

The lower part of the orthosis (Fig. 2) is used for installation of sensors, wires and PCB electronics. Integrated PCB electronics controls the entire system and transmits the signal to the mobile device or computer wirelessly. To determine the optimal measurement points for temperature sensor locations, infrared recording of the temperature field of the patient's arm is performed. An infrared camera model BOSCH GTC 400 C was used for the recording, with emissivity factor $\mathcal{E} = 0.98$ according to [13]. The presented results of the forearm area (Fig. 3) show that there is no significant change in temperature over the surface of the hand. The temperature differences for the upper part of the forearm are within 2.1 °C whereas the lower arm is in a total temperature difference of 1.3 °C. Since there are no major differences in the temperature field on three respondents, it is concluded that the impact of the position is not a significant variable for the measurement of the body temperature in the forearm area. Four test points were selected for the implementation of the temperature sensors. The selected positions of the temperature sensors have been selected according to the positions on the hand that ensure the greatest possibility of good contact with the skin during use. The area around the wrist, due to the constant contact with the orthosis during tightening, is made solid with a through hole for the heart rate sensor placement.



a) b)

Figure 3 Thermal image of the hand: a) Top side; b) Lower side

2.1 Selection of Sensors and Components

The measurement sensors used in the presented design:

- The temperature sensor DS1921H, Tab. 1, Fig. 4
- The heart rate sensor ROHM's BH1790GLC, Tab. 2, Fig. 5
- Bluetooth communication module RN42

The temperature sensor DS1921H is a wide temperature range and long battery life sensor. Fit for moderately long logging rates, this simple sensor is perfect for any business looking to track and regulate temperature in their working environment. Applications for this sensor include tracking and regulating human or animal temperatures.

Table 1 Technical specification DS1921H

Temperature range	+15 °C to +46 °C
Accuracy	± 1 °C
Resolution	0.125 °C
Logging rate	1-255 min

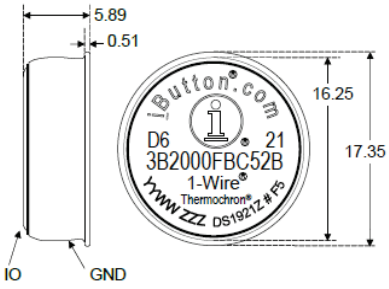


Figure 4 DS1921H temperature sensor - dimension

BH1790GLC is optical sensor for heart rate monitoring in which LED driver and green light detection photodiode are incorporated. This device drives LED and provides the intensity of light reflected from the body. LED brightness can be adjusted by LED driver current and light emitting period. The photodiode having the high sensitivity for green light, excellent wave-length selectivity and excellent circuit characteristics results in accurate pulse wave detection.

Table 2 Technical specification BH1790GLC

VCC1 Voltage Range	2.5 V to 3.6 V
VCC2 Voltage Range	1.7 V to 3.6 V
Current Consumption	200 µA (Typ)
Standby Mode Current	0.8 µA (Typ)
Operating Temperature Range	–20 °C to +85 °C

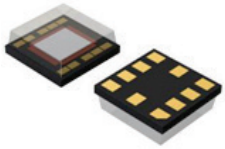


Figure 5 BH1790GLC optical sensor

The project defines the significance of interactive orthosis and for this purpose a special PCB electronic circuit is developed, which connects several sensors and transfers signals from the measuring points to a computer wirelessly. Due to the need for a compact size and robustness, it is decided to place the heart rate sensor as close to the skin as possible. The electronic circuit according to Fig. 6 shows the connected modules around the ATmega 644 microcontroller. The electronics has been designed for full mobility and independence: it contains an independent source of power by a separate battery and acts as an independent device that transmits data to the paired device. During the design phase, special attention is placed on the size of the electronic assembly. A design requirement was that maximum allowable dimensions of the electronics should not exceed half width of the orthosis in the wrist area. The electronics concept is based as a universal module with four inputs for temperature measurement and one sensor for heart rate measurement. It is possible to expand the number of sensors that could provide more information about the patient's condition, such as a pressure sensor or a sweat analyser. This would open the possibility of further expansion of the application. The presented PCB concept is only the basic idea of a central system of data collection which provides information to a mobile device where post-processing and data analysis are performed.

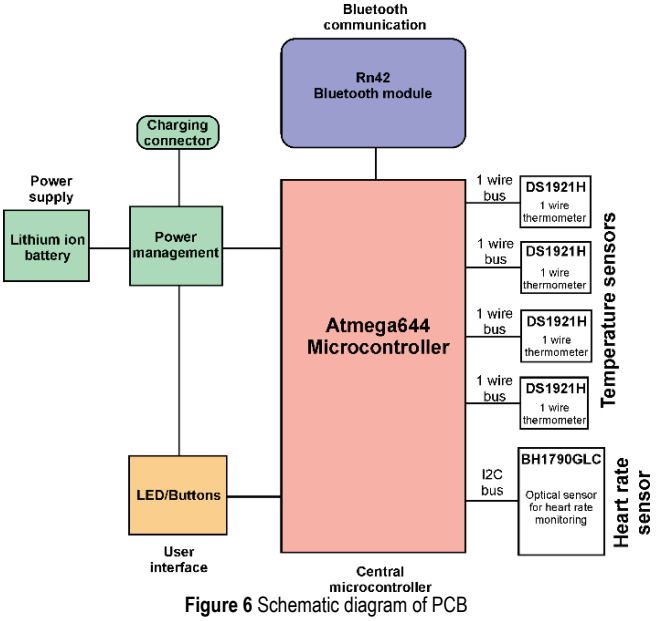


Figure 6 Schematic diagram of PCB

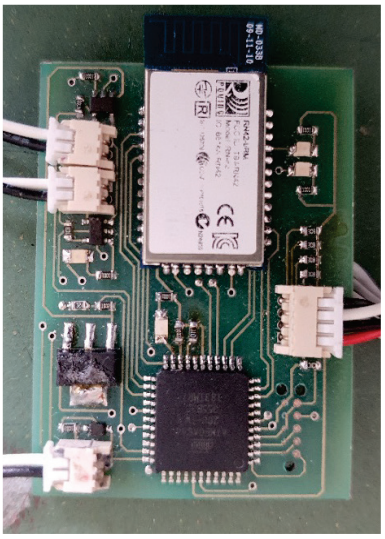


Figure 7 Produced PCB sample

3 TEST OPERATION AND RESULTS

PCB, as a central unit, is located on the lower part of the orthosis (Fig. 8). Fixator is placed within the protected housing and fixed together with the battery to the housing. The lower part's thickness, i.e. the distance between the

heart rate sensor and the skin, amounts to 1.5 mm. Tests have shown that with changing the distance it is necessary to adjust the signal strength and to regulate the sensor sensitivity.

Figure 8 Prototype of 3D printed and assembled smart orthosis

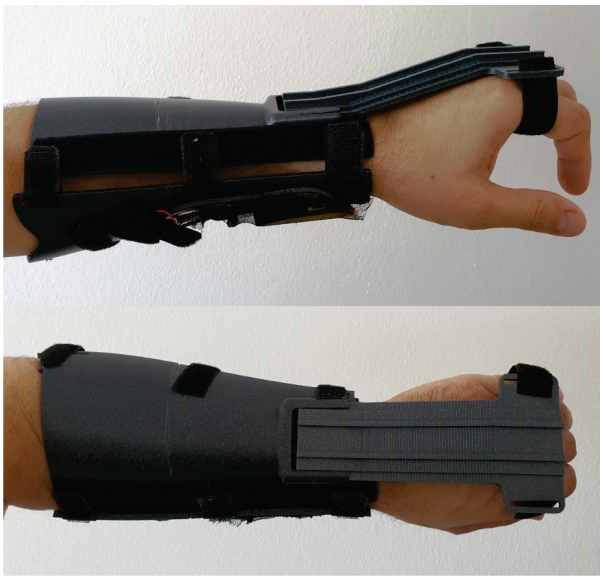


Figure 9 Prototype of smart orthosis in test operation

The test operation and the proof of concept start by connecting electronics with 3D printed mechanical parts (Fig. 9). By turning on the electronics the sensor readings start and the rise of temperatures at four measuring points with predicted converge towards normal human body can be observed. Individual deviations of the measuring point do not indicate significant differences according to the diagram in Fig. 10. At the same time, the diagram in Fig. 11 shows that the heart rate measurement does not provide expected heart rates. Average display of the normal resting heart rate for a human body ranges between 60 and 100 beats per minute. In the case of physical activity, the heart rate rises to higher values. The test measurements showed that the average heart rate ranges from 50 to –5, and the effect of light penetration to the photosensitive sensor was observed. This confirmed that perhaps the position of the heart rate sensor is not optimal. Based on the observations, the proposal is to create a separate PCB for patient's heart rate measurement only. Apart from unequal distance, the possible problem may be inappropriate point of measurement, although it has been proven that the place on the wrist can be used as one of the measuring points.

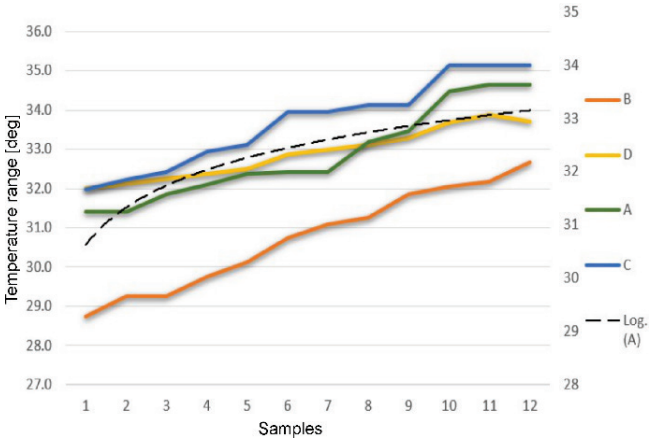


Figure 10 Temperature changing in time on 4 measuring sensors (A, B, C, D), log A -temperature tendency changing

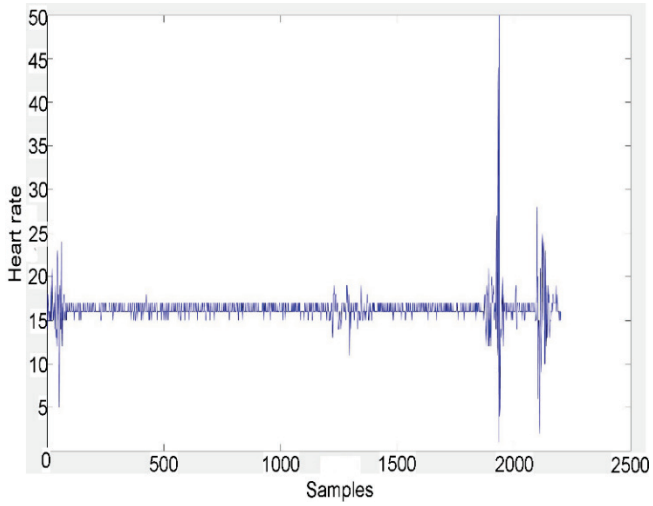


Figure 11 Heart rate optical sensor data

4 CONCLUSIONS

In the initial phase of the project, the possibility of measuring the temperature by skin contact was analysed based on the assumption that the places on the forearm with the highest blood flow and the thinnest skin provide the most reliable measuring points. According to the measurements, it was found that the lower part of the forearm is a slightly better variant than the upper part. The reason may be the thinner skin and less hair coverage. From the design point of view, the placement of electronics in the lower part of the orthosis is more suitable due to the proximity of the PCB and compactness of the design. The choice of orthosis production method by applying additive technology satisfies the moderate use rate. With the proposed shape of the orthosis it is possible to achieve sufficient rigidity of the structure which ensures joint fixation. This has been achieved by producing a Z bracket which is connected over a quick connection to the profiled groove in the upper part of the orthosis. Connecting the fingers to the Z bracket via the Velcro strip and the

bandage allows the joint to be fixed in the position which maximally relieves it and allows recovery. The suggested structure of the PCB allows compact design that can be worn on the arm without interference during use. The distribution of the temperature sensors performed according to the area of the highest temperature differences on the skin surface by measuring, shows a correlation on four measuring points and a small influence of the choice of the measuring point on the measurement in the area of the lower part of the forearm. The pulse measurement by photosensitive sensors is commonly employed method of determining pulse. The presented design with integrated heart rate sensor in the PCB body indicates a possible discontinuity of measurement and greater scatter in the collected data. Eventually, during use, this could lead to unreliable results and it is recommended to exclude the sensor from the basic electronics and to create a module that would have a better and more constant contact with the skin. The used measuring point can be considered reliable for the tested type of measurement.

In future considerations, the changes that should be implemented in order to improve the presented concept of smart orthosis refer to the shape optimisation in order to reduce the contact surfaces in the upper part of the orthosis and standardisation of the joints to conform to different forearm sizes. Considering the presented concept in the terms of a measurement system, the size and response time of temperature sensors could be reduced by implementing more optimized sensors. Moreover, the separation of the heart rate sensor into a separate module and integration with the housing should be a priority. The control system and mobile application provide the possibility of optimisation and addition of other types of sensors into the presented concept, such as sweat sensors and pressure sensors.

Notice

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5 REFERENCES

[1] Barr, A. E., Barbe, M. F., & Clark, B. D. (2004). Work-Related Musculoskeletal Disorders of the Hand and Wrist. *Epidemiology, Pathophysiology, and Sensorimotor Changes, 34*(10), 610-627. https://doi.org/10.2519/jospt.2004.34.10.610

[2] Heath, L. (2010). Wrist and hand injuries in sport, Wrist and Hand Injuries in Sport. In book: *Sports Rehabilitation and Injury Prevention*, Publisher: John Wiley & Sons, Ltd. January 2010. https://doi.org/10.1002/9781118685150.ch19

[3] Koutny, D., Palousek, D., Koutecky, T., Zatocilova, A., Rosicky, J., & Janda, M. (2012). 3D digitalization of the human body for use in orthotics and prosthetics. *World Academy of Science, Engineering and Technology*; 6. https://doi.org/10.5281/zenodo.1331055

[4] Li, J. & Tanaka H. (2018). Feasibility study applying a parametric model as the design generator for 3D– printed orthosis for fracture immobilization. *3D Printing in Medicine, 4*(1). https://doi.org/10.1186/s41205-017-0024-1

[5] Banga, H. K., Kalra, P., Belokar, R. M., & Kumar, R. (2020). Design and Fabrication of Prosthetic and Orthotic Product by 3D Printing. In book: *Orthotics and Prosthetics*. https://doi.org/10.5772/intechopen.94846

[6] Fernandez-Vicente, M., Chust A. E., & Conejero, A. (2017). Low Cost Digital Fabrication Approach for Thumb Orthoses. *Rapid Prototyping Journal, 23*(6). https://doi.org/10.1108/RPJ-12-2015-0187

[7] Mohammed, M. I. & Fay, P. (2018). Design and additive manufacturing of a patient specific polymer thumb splint concept. *Solid Freeform Fabrication 2018: Proceedings of the 29th Annual International; Solid Freeform Fabrication Symposium – An Additive Manufacturing Conference*, Reviewed Paper.

[8] Fromme, N. P., Camenzind, M., Riener, R., & Rossi R. M. (2020). Design of a lightweight passive orthosis for tremor suppression. *Journal of NeuroEngineering and Rehabilitation*, 17. https://doi.org/10.1186/s12984-020-00673-7

[9] Reinkensmeyer, D. J. (2019). JNER at 15 years: analysis of the state of neuroengineering and rehabilitation. *Journal of NeuroEngineering and Rehabilitation*, 16. https://doi.org./10.1186/s12984-019-0610-0

[10] Romero Avila, E., Junker, E., & Disselhorst-Klug, C. (2020). Introduction of a sEMG Sensor System for Autonomous Use by Inexperienced Users. *Sensors, 20*(24). https://doi.org/10.3390/s20247348

[11] Toth, L., Schiffer, A., Nyitrai, M., Pentek, A., Told, R., & Maroti, P. (2020). Developing an anti-spastic orthosis for daily home-use of stroke patients using smart memory alloys and 3D printing technologies. *Materials & Design*, 195. https://doi.org/10.1016/j.matdes.2020.109029

[12] Jovanov, E., Milenkovic, A., Otto, C., & and de Groen, P. C. (2005). A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation. *Journal of NeuroEngineering and Rehabilitation*, 2. https://doi.org/10.1186/1743-0003-2-6

[13] Bernard, V., Staffa, E., Mornstein, V., & Bourek, A. (2012). Infrared camera assessment of skin surface temperature-Effect of emissivity. *Physia Medica, 29*(6), 583-591 https://doi.org/10.1016/j.ejmp.2012.09.003

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Preliminary communication

Information Practices and Digital Perspectives of Municipal Waste Recovery Providers in Europe

Ljerka Luić*, Krešimir Labura

Abstract: The priority of modern business systems of municipal waste management is recycling of waste materials while the imperative of their mission is determined by the degree of digital transformation which enables their reproduction, distribution, usage, and storage of information in digital form, as well as new ways of digital communication with the general public. In this paper the focus is on examining the information practices and digital perspectives of municipal waste recycling service providers in Europe. The goal of this paper was to detect information concepts relevant for establishing the degree of their digital maturity. Five data classes were created for the purpose of content analysis method to conduct research on practices on digital communication channels in seven countries to evaluate their availability and accuracy. The designed information model defines a unique conceptual framework of the digital communication information set of the municipal waste recycling service providers.

Keywords: digital communication; digital transformation; Europe; information model; recycling; waste recovery

1 INTRODUCTION

Digital media and technologies play a key role in shaping society's perception of waste management. [1] They have the ability to influence public opinion and change public awareness, making it a powerful tool which can persuade the public to take action. [2] In this paper, by applying the research method of content analysis, it is considered and determined how utility companies communicate the waste recycling message to the public. Waste management is certainly one of the most important issues of civilization, but also an increasingly important economic issue, especially in the sense of conservation of natural resources and management of environmental protection costs. [3, 4] The priority in modern waste management systems is the recycling of waste materials. Most European countries have implemented regulations in their legislation that aim to reduce the amount of municipal waste and increase the amount of usable waste.

1.1 Material Recycling of Municipal Waste

According to the Law on Sustainable Waste Management (Article 4, para. 35), the term *waste* is any substance or object that the holder discards, intends or must discard. Waste is also considered to be any object and substance whose collection, transport or treatment is necessary for the purpose of protecting the public interest. [5]

Municipal waste is just one of the types of waste that requires enormous efforts in researching technologies (material, energy, chemical recycling), access and information, in order to drastically reduce the share of its production. However, much can be done by an individual, so through informing it is possible to acquire new knowledge and aid technology in reducing waste production. Materials recovery (recycling) is just one of the ways in which a new purpose is given to municipal waste either through the production of new products, compost, or biofuels.

Waste recovery is defined by the Law on Sustainable Waste Management (Article 4, para. 34) as "any operation whose main result is the use of waste for useful purposes when waste replaces other materials which should otherwise be used for that purpose or waste prepared to meet that purpose, in the factory or in a broader economic sense". [5]

Hrnjak-Murgić [6] distinguishes three types of recovery: Energy recovery, Chemical recovery and Material recovery.

Energy recovery or energy recycling essentially means the incineration of waste, which is the process of exposing waste to heat, resulting in the release of heat and the products of complete or incomplete combustion. The released heat can be used to heat water or to produce electricity in power plants. In this type of waste treatment, it is extremely important to pay attention to the controls of the combustion process and the substances that go into the air and water. [6]

Chemical recovery, chemical recycling or chemical reclamation is the process of converting waste into a raw material in which molecular changes, changes in the shape and function of the primary product occur. This type of waste recovery requires prior preparation (such as cleaning, sterilization, etc.), which is why the costs of this type of recovery are extremely high, and to make the approach more economical, large quantities and an organized waste collection system are needed. [6]

Material recovery of waste is defined by The Law on Sustainable Waste Management (Article 4, para. 20) as "any recovery process that does not include energy recovery and processing into materials to be used as fuel". This method of waste treatment is the best known and simplest form, and the purpose is to reduce the use of natural resources, reduce the production of new waste and protect the environment. The terms material reclamation or material recycling are often used for material recovery. [5]

As a general rule, in this type of recovery the waste goes through a treatment process, and in the end the result is a new product or the basis for a new product.

Municipal waste can be found at practically every step of modern society and presents one of the main problems, which is why it is extremely important to bring closer and simplify information approaches to the extent where examples of good practice in municipal waste management are understandable to all ages through the availability of information through

websites, social networks and other communication channels, especially digital ones. [7, 8]

1.2 Digital Communication

Digital communication greatly helps to establish and maintain communication between a business organization and its public and enables fast access to data and transmission of relevant information to the target public. [9]

More recently, the term *digital* is gaining a meaning that refers not only to the technological aspect, but also to a new way of communication and culture of society. [10]

The construction of a global information infrastructure has led to the globalization of information systems, which is reflected in the use of computers in everyday life and work, communication using computers and an increasing amount of available information. All this leads to the competitiveness of media content producers and their constant adaptation to new conditions and needs of users. The content produced nowadays are mainly created in digital form, and those created in analogue form are also transferred to digital form and are further processed, distributed, and stored digitally. [11]

Technological development has brought changes in all areas of people's lives, including communications. The fact is that technology has changed the way information is accessed and the way we communicate. [12] With the emergence of the Internet, communication takes on a new dimension, becoming two-way, while allowing each participant to be a user (consumer) and / or content creator.

According to Tomić, "Digital communication is a way of connecting, sharing, and exchanging information between people via the Internet or connected devices using one of the communication tools such as e-mail, forums, chats, instant messages, blogs, websites, and contact forms on them and, more recently, social networks and services". [13]

What distinguishes digital communication from previous modes of communication is virtuality, mobility, high interactivity, high connectivity, multimediality and new media. [14, 15] The basic characteristic of digital communication is the fact that we receive, or send, information now and receive real-time feedback.

"Croatia must take the necessary measures to increase preparation for the reuse and recycling of municipal waste to at least 50% by 2025, 55% by 2030 and 60% by 2035." [16] In addition to the state, local government units and citizens, utilities companies in particular have a major role to play in achieving these goals. Waste management and informing the public how to properly recycle is of great importance for the sustainable development of society, where digital technologies and digital forms of communication can significantly contribute to achieving the goals related to waste reduction. [17]

1.3 Information Practices and Digital Communication Perspectives of Material Recovery of Municipal Waste

The research part of this paper is an interdisciplinary symbiosis of ecology, mechanical engineering, information science and communications studies, which is evident from the matrix of observed data shown in Tab.1.

The field of mechanical engineering is represented in a deliberate sample consisting of business entities whose production takes place primarily in the field of mechanical engineering. The field of ecology is also represented in a deliberate sample of companies whose activity is the material recovery of municipal waste, while the part related to the field of information and communication sciences is represented through research of digital communications and analysis of available data on social networks, applications, and digital platforms for each individual business entity.

The analysis was conducted by first defining the data classes to be researched, and then the main categories of digital communication channels, shown in columns in Tab. 1, which make up social networks, applications, and platforms. Data significant for business entities whose activity is the material recovery of municipal waste are listed in the rows of Tab. 1.

Table 1 Research data analysis matrix

	Digital communication channels						
Data class	WEB	YouTube	Twitter	Facebook	Instagram	LinkedIn	Other
Availability check							
Amount of waste							
Input material							
Amount of incoming material							
1 raw material							
2 raw materials							
3 or more raw materials							
Manufacturing check							
Amount of output product							
1 output product							
2 output products							
3 or more output products							
Informing users							

As can be seen from Tab. 1, the initial row of the analysis matrix is defined by the name Digital Communication Channels and contains fields for entering the results of available data via the Internet for each individual business entity, in the following order:

- Business entity's website
- YouTube
- Twitter
- Facebook
- Instagram
- LinkedIn
- Other.

The initial column is defined by the name *Data class* and the following categories:

- *Availability Check*
- *Amount of waste*
- *Input material*
- *Amount of incoming material*
- *Manufacturing check*
- *Amount of output product*
- *Informing users.*

2 METHODOLOGY

The research was conducted on a sample of business entities whose activity is the material recovery of municipal waste, provided that the same entities manufacture at least

one product or semi-product. Furthermore, the selection of business entities was followed by an analysis of the data based on the verification of each individual data category listed in the matrix column shown in Tab. 1 under the *Data Class* category. The research was conducted by the method of digital content analysis during the 4th quarter of 2019. In addition to Croatia and the neighbouring country of Bosnia and Herzegovina, the analysis was conducted on 5 other European Union countries. The criterion for selecting the European Union country was the percentage of the amount of recycled municipal waste, from the best to the worst result. According to Eurostat data, shown in Tab. 2 [18], it can be seen that the following countries have the highest rate of municipal waste recycling:

Table 2 Eurostat data on percentages of recycled municipal waste

	Data extracted on 27/08/2019 00:32:19 from [ESTAT]	
	Dataset: Recycling rate of municipial waste [T2020_RT120]	
	Last updated: 23/05/2019 23:00	
	Time frequency: Annual	
	Waste management operations: Recylcling	
	Unit of measure: Percantage	
	TIME	2017
	GEO (Labels)	
1.	Germany	67,6
2.	Slovenia	57,8
3.	Austria	57,7
4.	Netherlands	54,2
5.	Belgium	53,7

Based on the analysis of relevant sources, it was concluded that only one type of municipal waste should be processed. Recognizing environmental trends and related digital communication, the research is focused on the analysis of plastic waste.

According to the "ENF Recycling" register [19], in the category of plants for the processing of plastics from municipal waste, there are the following number of business entities that materially recover waste:

1) Germany -138 business entities [20]
2) Slovenia - 4 business entities [21]
3) Austria - 14 business entities [22]
4) Netherlands - 30 business entities [23]
5) Belgium - 10 business entities. [24]

Finally, up to five business entities whose activity is the processing of plastics from municipal waste were randomly selected for each of the countries. Consequently, the subject of the research was to investigate the application of digital communication channels in utility companies whose activity is the material recovery of municipal waste. The aim of this paper is to determine the degree of availability of information in these companies through available digital communication channels, based on which the hypothesis is set which claims that the level of digital communication of utility companies in Croatia is lower than the level of digital communication of utility companies in the observed countries.

3 RESULTS

Data analysis was performed on information objects of the *Data Class* category, shown in Tab. 1, according to the following validation elements:

- **Availability check** - analysis of this data implies the existence of a specific communication channel. If the result of the analysis was negative for a particular communication channel, it means that it does not even exist, which is why the other observed segment is also negative.
- **Amount of waste** - analysis of availability of data related to the amount of treated waste expressed in tons per year for each digital communication channel.
- **Input material** - analysis of this data means determining the availability of data on input raw materials for each individual digital communication channel. In case of a positive result of the analysis, an additional analysis of the amount of input raw materials was performed.
- **Amount of incoming material** - in the case where the Input material feature is confirmed, the quantity of input raw materials is analysed. This category is divided into three subcategories which define the data on the amount of input raw materials listed on each communication channel. The subcategories are defined as follows: One, Two, Three or more input raw materials.
- **Manufacturing check** - the analysis of this data determines the availability of data on the production of a new product. If the result of the analysis is positive, the next step is to determine the available data on the Amount of output product.
- **Amount of output product** - concerning criteria, the category is the same as the Amount of incoming material, with the difference of another target source of observation. Therefore, if the result of the Manufacturing check analysis is positive, the quantity of raw materials is investigated. This category is divided into three subcategories which are defined as follows: One, Two, Three or more output products.
- **Informing users** - the analysis of this category determines the availability of data whose purpose is to inform users as a form of a wide range positive practice, from informing in the field of general knowledge to detailed technical data.

The criteria for the minimum evaluation of data are defined depending on the purpose of each segment from the category *Digital communication channels*:

- **YouTube** – accepted cases are the ones in which the business entity is described by a third party, but with all the details related to the business entity. For example, a report by a TV company about a business entity with a conversation between representatives.
- **Twitter** – keywords that include details of the name of the business entity during which it can be unambiguously determined to be the same are evaluated.
- **Facebook** – the available information is evaluated regardless of the form (personal profile or page) with an emphasis on the possibility of unambiguously determining the details of the business entity.
- **Instagram** – company profiles or posts described by a third party that could unambiguously establish a link between the business entity and the topic of this paper were evaluated.
- **LinkedIn** – given the possibilities and purpose of the social network, the results of the analysis which were

allegations of the individual in which they have a connection with the business entity were excluded.

- **Other** – in this category, the available data of video recordings were observed (for example, Vimeo recordings for business entities and their content).

It is important to emphasize that this approach analysed the availability of data via the Internet and in the case of a negative result does not necessarily mean that the same data does not exist somewhere, but only that for analysis purposes it was not available within the observed criteria.

The following subchapters present the results of the analysis for business entities whose nature of business is the material recovery of municipal waste.

3.1 Croatia

The analysis on the example of Croatia was performed on four available business entities. Tab. 3 shows that in Croatia Twitter, Instagram and LinkedIn are not used as a means of information by business entities, while websites (75%), YouTube (25%), Facebook (25%) and Other (25%) are used.

Table 3 Results of data analysis for Croatia

	Digital communication channels						
Data class	WEB	YouTube	Twitter	Facebook	Instagram	LinkedIn	Other
Availability check	75%	25%	0%	25%	0%	0%	25%
Amount of waste	0%	25%	0%	0%	0%	0%	0%
Input material	75%	0%	0%	0%	0%	0%	25%
Amount of incoming material							
1 raw material	25%	0%	0%	0%	0%	0%	0%
2 raw materials	0%	0%	0%	0%	0%	0%	0%
3 or more raw materials	50%	0%	0%	0%	0%	0%	25%
Manufacturing check	75%	25%	0%	25%	0%	0%	25%
Amount of output product							
1 output product	25%	0%	0%	25%	0%	0%	0%
2 output products	0%	25%	0%	0%	0%	0%	0%
3 or more output products	50%	0%	0%	0%	0%	0%	25%
Informing users	75%	0%	0%	0%	0%	0%	25%

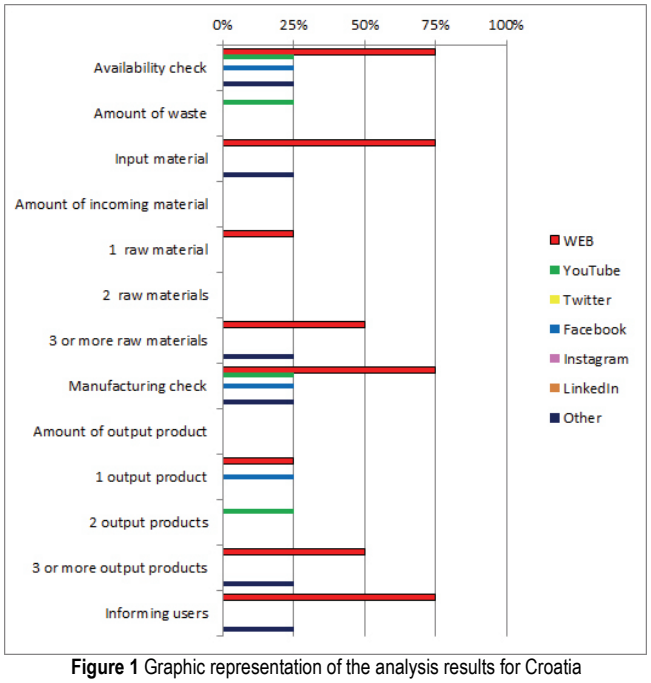

Figure 1 Graphic representation of the analysis results for Croatia

According to the graph shown in Fig. 1, it can be seen that in Croatia business entities most often use the web as a digital communication channel. However, in addition to being the most common, the web is also the most detailed source of information, so information on the *Input material* and its *Amount*, on *Manufacturing* and *Amount of output product* and *Informing users* is available on it. Data on *Amount of output product* is available on YouTube, which confirms the *Manufacturing check*. Only the data on the *Amount of output product* is visible on Facebook, which confirms the *Manufacturing check*.

3.2 Bosnia and Herzegovina

In Bosnia and Herzegovina, only one business entity was available and its available data were analysed. Tab. 4 shows that only websites (100%) and YouTube (100%) were used to inform users, while other communication channels did not give positive results. Although this is 100% data availability, it is important to emphasize that this is a small number of samples (1 business facility). Since this is a single business entity, the results are presented and analysed only in tabular form.

Table 4 Results of data analysis for Bosnia and Herzegovina

	Digital communication channels						
Data class	WEB	YouTube	Twitter	Facebook	Instagram	LinkedIn	Other
Availability check	100%	100%	0%	0%	0%	0%	0%
Amount of waste	100%	0%	0%	0%	0%	0%	0%
Input material	100%	100%	0%	0%	0%	0%	0%
Amount of incoming material							
1 raw material	0%	0%	0%	0%	0%	0%	0%
2 raw materials	0%	0%	0%	0%	0%	0%	0%
3 or more raw materials	100%	100%	0%	0%	0%	0%	0%
Manufacturing check	100%	100%	0%	0%	0%	0%	0%
Amount of output product							
1 output product	0%	100%	0%	0%	0%	0%	0%
2 output products	0%	0%	0%	0%	0%	0%	0%
3 or more output products	100%	0%	0%	0%	0%	0%	0%
Informing users	100%	100%	0%	0%	0%	0%	0%

The website displays details on the *Amount of processed waste*, *Input material* and its *Amount*, confirmed *Manufacturing* through the *Amount of three or more output products* and *Informing users* is available. Unlike the business entity's website, YouTube does not define data on the *Amount of processed waste*, and there is a difference in the result of the *Amount of output product*.

The analysis of YouTube could lead to results from *One output product*, while the results on the website point to *Three or more output products.* As in the example of the website, data on *Input raw materials* and *Amounts* are available on YouTube, *Manufacturing check* is confirmed by the *Amount of output Product,* and *Informing users* is available.

3.3 Germany

The analysis of Germany was done on a sample of five randomly selected business entities. Tab. 5 shows that the analysed data are available through almost all digital communication channels in the following order: websites (100%), LinkedIn (80%), YouTube and Twitter (60%), Facebook (40%) and Instagram (20%). Other digital channels do not have data available.

Table 5 Results of data analysis for Germany

	Digital communication channels						
Data class	WEB	YouTube	Twitter	Facebook	Instagram	LinkedIn	Other
Availability check	100%	60%	60%	40%	20%	80%	0%
Amount of waste	60%	20%	20%	20%	0%	0%	0%
Input material	80%	60%	20%	20%	0%	0%	0%
Amount of incoming material							
1 raw material	20%	0%	0%	20%	0%	0%	0%
2 raw materials	0%	0%	0%	0%	0%	0%	0%
3 or more raw materials	60%	60%	20%	0%	0%	0%	0%
Manufacturing check	80%	60%	20%	20%	0%	0%	0%
Amount of output product							
1 output product	20%	0%	0%	20%	0%	0%	0%
2 output products	40%	20%	20%	0%	0%	0%	0%
3 or more output products	20%	40%	0%	0%	0%	0%	0%
Informing users	60%	60%	0%	0%	0%	0%	0%

The results of the *Availability Check* give a positive impression of the availability of data on digital communication channels on the example of Germany because almost all channels are represented.

Regardless of the positive result in the category *Availability Check*, a closer inspection of certain categories of available data shows a low number of positive results. The example of LinkedIn, and then Instagram, shows that apart from the positive result of *Availability*, other data do not even exist.

Thus, these two communication channels do not contain the other observed data. Available data on the *Amount of incoming raw material* show that *Three or more input raw material* are most often listed on websites and YouTube (60%). The *Amount of output product* varies in relation to the observed subcategory, which can be seen from Tab. 5.

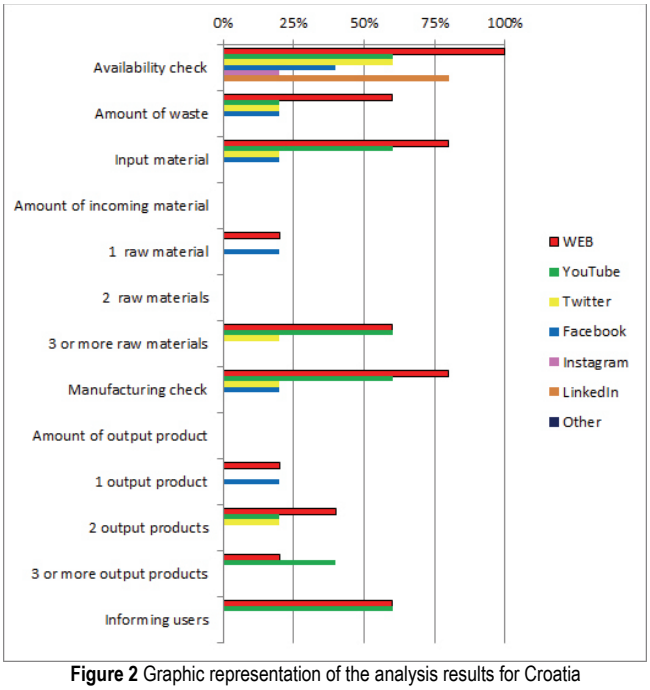

Figure 2 Graphic representation of the analysis results for Croatia

According to the graph shown in Fig. 2, it can be seen that business entities most often select the website and YouTube as a digital communication channel. Nevertheless, the website provides all the analysed data, with better availability compared to YouTube. The results of the analysis for Facebook and Twitter indicate that these communication channels are available, but to a lesser extent compared to the web and YouTube.

3.4 Slovenia

The analysis for Slovenia was performed on a sample of four randomly selected business entities. Tab. 6 shows that when analysing data for business entities in Slovenia, they were available on most digital communication channels, in order of percentage: websites (100%), YouTube (50%), and Twitter, Instagram and LinkedIn (25%). Facebook and Other did not have a positive result.

Table 6 Results of data analysis for Slovenia

	Digital communication channels						
Data class	WEB	YouTube	Twitter	Facebook	Instagram	LinkedIn	Other
Availability check	100%	50%	25%	0%	25%	25%	0%
Amount of waste	50%	0%	0%	0%	0%	0%	0%
Input material	100%	25%	25%	0%	0%	0%	0%
Amount of incoming material							
1 raw material	25%	0%	0%	0%	0%	0%	0%
2 raw materials	0%	0%	0%	0%	0%	0%	0%
3 or more raw materials	75%	25%	25%	0%	0%	0%	0%
Manufacturing check	100%	25%	25%	0%	0%	0%	0%
Amount of output product							
1 output product	50%	25%	25%	0%	0%	0%	0%
2 output products	0%	0%	0%	0%	0%	0%	0%
3 or more output products	50%	0%	0%	0%	0%	0%	0%
Informing users	25%	25%	25%	0%	0%	0%	0%

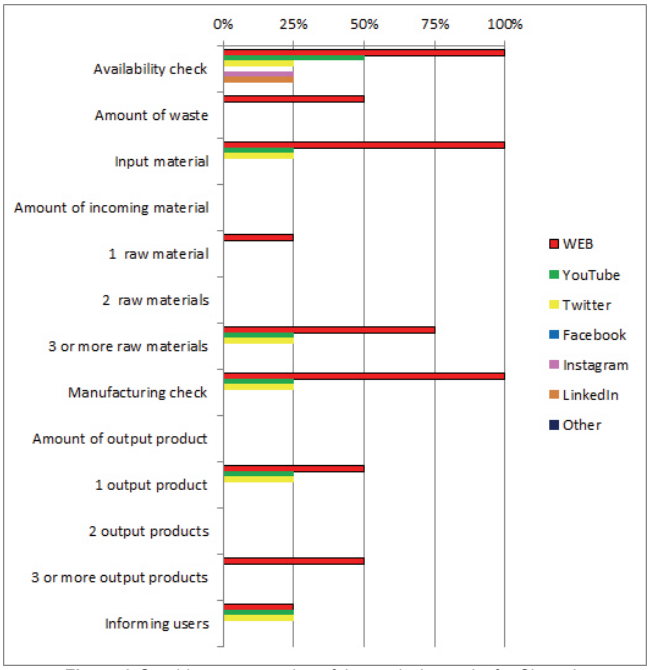

Figure 3 Graphic representation of the analysis results for Slovenia

According to the graph shown in Fig. 3, it can be seen that businesses most often use web pages. Given that all categories of data are present with an extremely high result of the availability of the website, they are also the most detailed form of information. Also, it can be seen that YouTube and Twitter are present as sources of *Available data*, but to a much lesser extent compared to websites.

3.5 Austria

The analysis of data availability for Austria was made on a sample of five business entities randomly selected from the register. Tab. 7 shows that the results of the data availability analysis are positive in the case of the website (100%), YouTube (60%), Twitter and Facebook (20%). Instagram, LinkedIn and Other digital communication channels did not have a positive result.

Table 7 Results of data analysis for Austria

	Digital communication channels						
Data class	WEB	YouTube	Twitter	Facebook	Instagram	LinkedIn	Other
Availability check	100%	60%	20%	20%	0%	0%	0%
Amount of waste	100%	0%	20%	20%	0%	0%	0%
Input material	100%	60%	20%	20%	0%	0%	0%
Amount of incoming material							
1 raw material	0%	0%	0%	0%	0%	0%	0%
2 raw materials	0%	0%	0%	0%	0%	0%	0%
3 or more raw materials	100%	60%	20%	20%	0%	0%	0%
Manufacturing check	100%	60%	20%	20%	0%	0%	0%
Amount of output product							
1 output product	60%	40%	20%	20%	0%	0%	0%
2 output products	0%	0%	0%	0%	0%	0%	0%
3 or more output products	40%	20%	0%	0%	0%	0%	0%
Informing users	40%	60%	0%	0%	0%	0%	0%

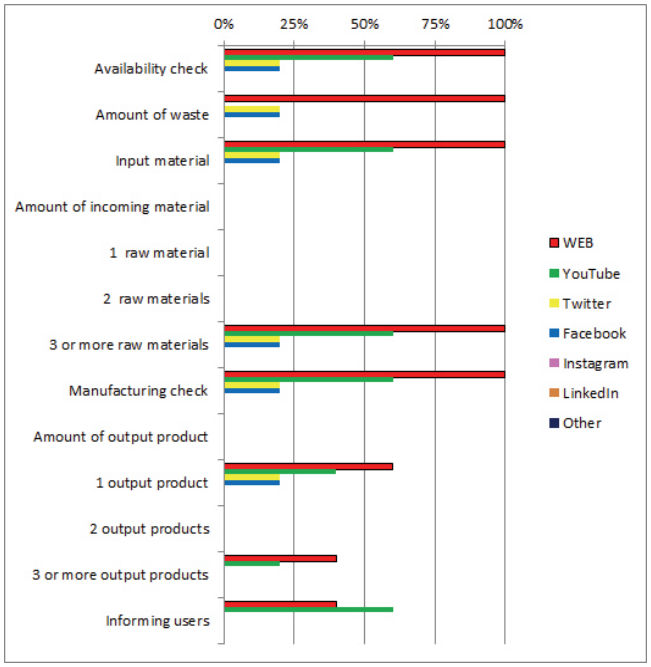

Figure 4 Graphic representation of the analysis results for Austria

According to the graph shown in Fig. 4, it can be seen that businesses in Austria most often choose websites as a source of information, and the *Data availability* on the websites of businesses is also the most detailed. Visible from the graph, and with reference to YouTube as a digital communication channel, only the lack of availability of data from the category of *Informing users* and *Amount of output product* can be noticed. Twitter and Facebook have equal analysis results with a lack of availability of *Informing users* data.

3.6 The Netherlands

The analysis of data availability for the Netherlands was made on a sample of five business entities randomly selected from the register. Tab. 8 shows the results of the analysis of data availability on digital communication channels, namely websites (100%), YouTube and LinkedIn (60%), Twitter and Others (40%), and Facebook (20%). The results of the analysis show that there were no positive results on Instagram within the observed criteria.

Table 8 Results of data analysis for the Netherlands

	Digital communication channels						
Data class	WEB	YouTube	Twitter	Facebook	Instagram	LinkedIn	Other
Availability check	100%	60%	40%	20%	0%	60%	40%
Amount of waste	40%	20%	0%	20%	0%	0%	0%
Input material	100%	60%	0%	20%	0%	20%	40%
Amount of incoming material							
1 raw material	0%	20%	0%	0%	0%	0%	0%
2 raw materials	0%	0%	0%	0%	0%	0%	0%
3 or more raw materials	100%	40%	0%	20%	0%	20%	40%
Manufacturing check	100%	60%	0%	20%	0%	0%	20%
Amount of output product							
1 output product	40%	20%	0%	20%	0%	0%	20%
2 output products	40%	40%	0%	0%	0%	0%	0%
3 or more output products	20%	0%	0%	0%	0%	0%	0%
Informing users	40%	40%	0%	0%	0%	0%	40%

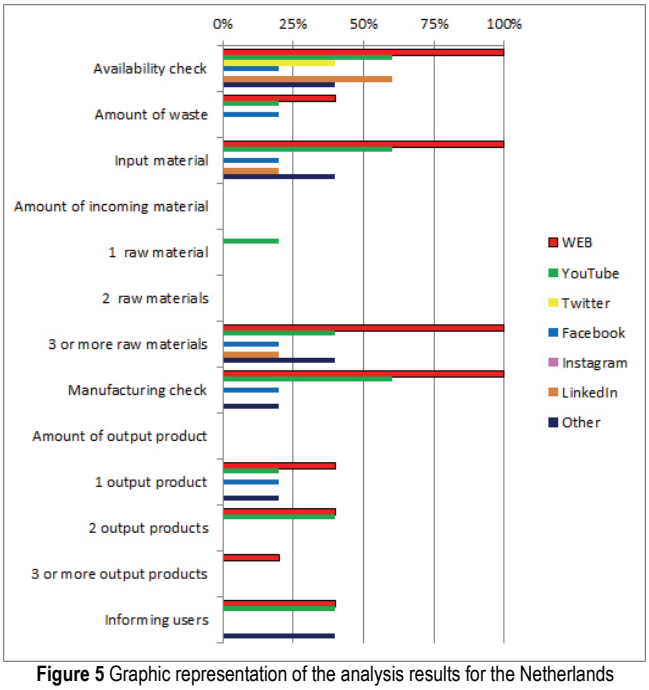

Figure 5 Graphic representation of the analysis results for the Netherlands

According to the graph shown in Fig. 5, it can be seen that for Twitter the results of the analysis are available in only one category, and that is for *Availability check* without additional results. The example of business entities from the Netherlands shows that websites are the main digital communication channel both in terms of the level of results and in terms of representation by category. The YouTube availability results shown in Chart 9 indicate the availability of this digital communication channel in all categories, but in a slightly lower score compared to web pages. Facebook, Instagram and Other have equal representation by category,

with the exception that only in the case of Facebook, the analysis of the availability of the *Amount of output product* was positive with a result of 20%.

3.7 Belgium

The data availability analysis for Belgium was made on a sample of two business entities randomly selected from the register. Tab. 9 shows positive results of the analysis in almost all categories of observed available data, except in the category Other, in order: websites, YouTube, Facebook, LinkedIn with 100%, and Twitter and Instagram with 50%.

Table 9 Results of data analysis for Belgium

	Digital communication channels						
Data class	WEB	YouTube	Twitter	Facebook	Instagram	LinkedIn	Other
Availability check	100%	100%	50%	100%	50%	100%	0%
Amount of waste	100%	50%	50%	50%	0%	0%	0%
Input material	100%	100%	0%	50%	0%	100%	0%
Amount of incoming material							
1 raw material	0%	0%	0%	0%	0%	0%	0%
2 raw materials	0%	0%	0%	0%	0%	0%	0%
3 or more raw materials	100%	100%	0%	50%	0%	100%	0%
Manufacturing check	100%	100%	0%	0%	0%	50%	0%
Amount of output product							
1 output product	50%	100%	0%	0%	0%	50%	0%
2 output products	50%	0%	0%	0%	0%	0%	0%
3 or more output products	0%	0%	0%	0%	0%	0%	0%
Informing users	100%	100%	0%	0%	0%	0%	0%

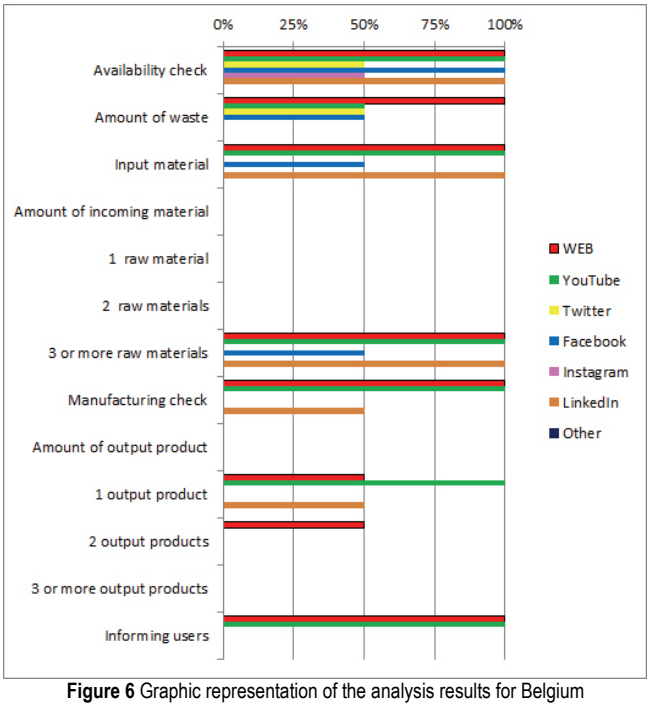

Figure 6 Graphic representation of the analysis results for Belgium

Businesses in Belgium mostly use websites as a source of *Availability check* of data, both by category and by detail. On the example of business entities from Belgium, it is interesting to see the increase in available data on LinkedIn, especially in the case of *Input material* and its *Amount* and *Manufacturing check* and results of the *Amount of output product*.

3.8 Comparative Overview of Researched European Countries

Results of the analysis of the *Availability check* data on the websites of business entities with regard to high results indicate that business entities most often opt for this type of digital communication.

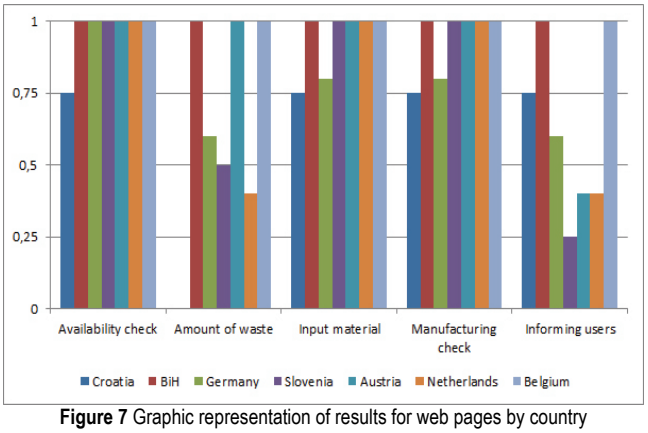

Figure 7 Graphic representation of results for web pages by country

4 DISCUSSION

Website results show that Croatia has the worst result in the categories: *Availability check, Amount of waste, Input material, Manufacturing check*. In the category of *Informing users*, Croatia is in third place behind Bosnia and Herzegovina and Belgium.

The results of the analysis for YouTube show that Croatia is the worst in the categories: *Availability check*, *Input material*, *Informing users*. For the *Amount of waste* category, it is in second place behind Belgium, while for the *Manufacturing check* category, it shares the lowest score with Slovenia.

There is no data available for Twitter for Croatia, which makes it the worst positioned compared to other countries in all observed categories.

The results of the analysis for Facebook show that Croatia does not have positive results in data availability for the categories: *Amount of waste*, *Input material* and *Informing users*. Nevertheless, Croatia has the best result in the *Manufacturing check* category and the third result in the *Availability check* category behind Belgium and Germany.

The results of the analysis of Instagram as a digital communication channel show that there is no data available for Croatia and it shares the same result with Bosnia and Herzegovina, Austria and the Netherlands. Belgium, Slovenia and Germany have a better result compared to Croatia.

For LinkedIn, there is no data available neither for Croatia, nor for Bosnia and Herzegovina, which is why they share the worst result through all of the observed categories.

Insight into the results through 6 categories shows that in 6 digital communication channels Croatia has the worst result, which confirms the hypothesis of this.

5 CONCLUSION

Waste, especially municipal waste, is a problem of modern civilization living in the digital age. Therefore, it is tentatively possible to assume that the use of digital communication channels can influence the environmental awareness of all stakeholders in the process of its material recovery, because digital communication channels allow rapid exchange of information on innovative communication approaches and technological solutions.

The results of the research suggest that the huge potential of currently available digital communication channels has been neglected, with the exception of the website. Achieving better availability of data on the material recovery of municipal waste is possible through the LinkedIn platform, which enables communication between business operators and users.

In addition to websites and LinkedIn, it is necessary to use the opportunities provided by other social networks, which is why it is necessary to work on increasing the use of Facebook, YouTube, Twitter, and Instagram by business entities whose activity is material recovery of municipal waste in all observed countries.

During the research, the problem of defining a set of information that is necessary to convey to the public was noticed, as well as the problem of detecting a set of feedback information from the public. Whether these sets of information correlate, whether data classes correlate with the type of digital channel, how to structure them into a standard information model – these are research questions relevant for further research with the purpose of designing a unique conceptual framework for a digital communication information set of a municipal waste material recovery service provider. In this sense, this paper represents an initiative step that can be further developed by creating additional data classes which do not appear in any of the existing information models that would include a statistically significant sample.

Notice

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6 REFERENCES

[1] Wang, S., Wang, J., Zhao, S., & Yang, S. (2019). Information publicity and resident's waste separation behavior: An empirical study based on the norm activation model. *Waste Management*, 87, 33-42. https://doi.org/10.1016/j.wasman.2019.01.038

[2] Wang, Z., Guo, D., Wang, X., et al (2018). How does information publicity influence residents' behaviour intentions around e-waste recycling? *Resources, Conservation and Recycling*, 133, 1-9. https://doi.org/10.1016/j.resconrec.2018.01.014

[3] Mateljak, D. (2015). *Strategija odnosa s javnošću u razvoju cjelovitog sustava gospodarenja otpadom u Splitsko-dalmatinskoj županiji za razdoblje od 2015. - 2018. godine*. http://rcco.hr/wp-content/uploads/2018/03/strategija-odnosa-s-javnoscu-u-razvoju-cjelovitog-sustava-gospodarenja-otpadom-u-splitsko-dalmatinskoj-zupaniji-za-razdoblje-od-2015-2018-godine.pdf

[4] Tomić, T. & Schneider, D. R. (2020) Circular economy in waste management – Socio-economic effect of changes in waste management system structure. *Journal of Environmental Management*, 267, 110564. https://doi.org/10.1016/j.jenvman.2020.110564

[5] Hrvatski sabor. (2013). *Zakon o održivom gospodarenju otpadom*. https://narodne-novine.nn.hr/clanci/sluzbeni/2013_07_94_2123.html

[6] Hrnjak-Murgić, Z. (2016). *Gospodarenje polimernim otpadom*, 81-86. https://www.fkit.unizg.hr/_download/repository/Skripta-Gospodarenje-polimernim-otpadom-Murgic.pdf

[7] Naughton, C. C. (2020). Will the COVID-19 pandemic change waste generation and composition? The need for more real-time waste management data and systems thinking. *Resources, Conservation and Recycling*, 162, 105050. https://doi.org/10.1016/j.resconrec.2020.105050

[8] Närvänen, E., Mesiranta, N., Sutinen, U.-M., & Mattila, M. (2018). Creativity, aesthetics and ethics of food waste in social media campaigns. *Journal of Cleaner Production*, 195, 102-110. https://doi.org/10.1016/j.jclepro.2018.05.202

[9] Vikram Bisen, P. (2009). *Business communication*. New Delhi: New Age International Ltd, p 40.

[10] Pasqualetti, F. & Nanni, C. (2005). Novi mediji i digitalna kultura. Izazov odgoju. *Kateheza, 27*(3), 244-265. https://hrcak.srce.hr/113804 (in Croatian)

[11] Stančić, H. (2011). Načela digitalne komunikacija. In N. Zgrljić Rotar (ed.), *Zbornik radova Digitalno doba*. Zadar: Sveučilište u Zadru, p 61. (in Croatian)

[12] Eshet-Alkalai, Y. (2009). Real Time Thinking in the Digital Era. In *Encyclopedia of Information Science and Technology*, (Chapter 514, pp 3219-3223). IGI Global.

[13] Tomić, Z. (2016). *Odnosi s javnošću, teorija i praksa* (II. Amended and modified edition). Zagreb: Synopsis, p 100. (in Croatian)

[14] Zgrabljić Rotar, N. (2017). Novi mediji digitalnog doba. In L. Josić (ed.), *Zbornik Informacijska tehnologija i mediji*. Zagreb: Hrvatski studiji Sveučilišta u Zagrebu, pp 57-67. (in Croatian)

[15] Jiang, P., Fan, Y. V., & Klemeš, J. J. (2021). Data analytics of social media publicity to enhance household waste management. *Resources, Conservation and Recycling*, 164, 105146. https://doi.org/10.1016/j.resconrec.2020.105146

[16] Ministry of environment and energy (2019). *Integrated Nacional Energy and Climate Plan for the Republic of Croatia for the period 2021-2030.* https://mingor.gov.hr/UserDocsImages/UPRAVA%20ZA%20ENERGETIKU/Strategije,%20planovi%20i%20programi/hr%20necp/Integrated%20Nacional%20Energy%20and%20Climate%20Plan%20for%20the%20Republic%20of_Croatia.pdf

[17] Schneider, D. R., Tomić, T., & Raal, R. (2021). Economic Viability of the Deposit Refund System for Beverage Packaging Waste – Identification of Economic Drivers and System Modelling. *Journal of Sustainable Development of Energy, Water and Environment Systems,* 9, 1–33. https://doi.org/10.13044/j.sdewes.d9.0386

[18] Eurostat Data Browser (2019). *Recycling rate of municipal waste*.https://ec.europa.eu/eurostat/databrowser/view/t2020_rt120/default/table?lang=en

[19] ENF Recycling. (2021). *Global directory of all types of recycling companies*. https://www.enfrecycling.com/
[20] ENF Recycling. (2019). *Plastic Recycling Plants in Germany*. https://www.enfrecycling.com/directory/plastic-plant/Germany
[21] ENF Recycling. (2019). *Plastic Recycling Plants in Slovenia*. https://www.enfrecycling.com/directory/plastic-plant/Other-Europe?country_id=218
[22] ENF Recycling. (2019). *Plastic Recycling Plants in Austria*. https://www.enfrecycling.com/directory/plastic-plant/Austria
[22] ENF Recycling. (2019). *Plastic Recycling Plants in Netherlands*. https://www.enfrecycling.com/directory/plastic-plant/Netherlands
[24] ENF Recycling. (2019). *Plastic Recycling Plants in Belgium*. https://www.enfrecycling.com/directory/plastic-plant/Other-Europe?country_id=18

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Preliminary communication

Automated and Controlled Data Collection Using Industrial IoT System for Smart Maintenance

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Abstract: Maintenance 4.0 is a concept that involves the use of IIoT (Industrial Internet of Things) technology to connect maintenance objects, which enables remote data collection, information exchange, analysis and potential improvement in productivity and efficiency, as well as planning maintenance activities. The purpose of this paper is to present the development of the Industrial Internet of Things data collection system, which relies on Tinkerforge IoT modules, that enables automated data collection alongside control of sensor and data collection parameters. To evaluate the ability of the system, an experiment was conducted where two equipment states were simulated using a rotational equipment failure simulator. The experiment determined that the presented IIoT system had successfully gathered information and that there is a clear distinction in acceleration patterns when simulating two different equipment states.

Keywords: accelerometer; automated data collection; Industrial Internet of Things; Tinkerforge

1 INTRODUCTION

The Industry 4.0 paradigm involves the interconnection of physical objects such as sensors, devices, and enterprise assets to the Internet. Industry 4.0 requires the evolution of ordinary machines into self-aware and self-taught machines to improve their performance, enable sustainable production, and reduce the need for unplanned maintenance.[1] Recently, Industry 4.0 has been considered the future, and today it is widely accepted as a reality that is changing the way companies do business and affecting almost every industry around the world. In the context of the definition of Industry 4.0, access to sustainable production can be linked to production systems developed to be transparent, intelligent, efficient, flexible, mobile and accountable. In this context, various initiatives and approaches have been established to help companies adopt the principles of the fourth industrial revolution in terms of sustainability. Within such initiatives, one of the predominant themes of smart and sustainable production uses a modern approach to maintenance such as Maintenance 4.0 (also called Smart Maintenance). [2]

Maintenance 4.0 is a subset of a smart manufacturing system that uses modern technologies and techniques that can predict when a failure will occur, suggest the best solution, and analyse possible decisions. Predictive maintenance involves the application of sensors to collect data which is then analysed using supervised or unsupervised machine learning methods to obtain a classification of the condition and to predict when a failure will occur. The key technologies involved in predictive maintenance are the Internet of Things (IoT), cloud computing, predictive analytics (machine learning, fuzzy logic, neural networks, evolutionary algorithms, etc.) as well as modern machine repair and parts replacement technologies. In addition to predictive maintenance, the term prescriptive maintenance also appears in Maintenance 4.0. Prescriptive maintenance uses advanced data analysis techniques that allow not only to predict failures and downtime but also to recommend actions to be taken to avoid failures and to optimize maintenance schedules as well as the resources required. Prescriptive maintenance uses a combination of advanced analytical methods, a collection of standardized maintenance procedures, historical maintenance data, and current data collected to predict downtime and propose a solution. [2]

Data collection is achieved by using sensors that translate physical phenomena emitted by the machine into digital signals that represent parameters such as temperature and vibration. However, simple collection of machine data is not enough. Maintenance 4.0 requires an Internet of Things (more precisely an Industrial Internet of Things (IIoT) [3]) infrastructure that reliably connects maintenance facilities to data centres and allows distributed sensor data collection. [4]

The main purpose of this paper is to present the development of an Industrial Internet of Things data collection system that enables automated data collection alongside control of sensor and data collection parameters. For this research, vibration data of rotary machinery fault simulator was collected as an example for demonstrating data collection capability. Vibration is the most popular and widely used parameter in predictive maintenance because the machine vibration response is sensitive to change, and it contains patterns about machine state which can, when analysed, lead to fault diagnosis. [5] This paper will examine the capability of high-frequency data sampling on two machine states (one with normal state and one with combined bearing fault) which will determine if the system is gathering data successfully.

The rest of the paper is organized as follows: **Section 2** overviews the related work in the field of IoT data collection, **Section 3** provides requirements and architecture of the developed system which is showcased in **Section 4** which contains experiment setup and methods. Results are presented and discussed in **Section 5** after which the conclusion is drawn in **Section 6**.

2 RELATED WORK

In this section related work in the field of IoT data collection has been reviewed. The previous research of authors [6] highlights the importance of the Internet of Things and imperfections of traditional data sampling such as human error, lack of data from some machines due to a

limited number of costly data collection devices, etc. To solve these problems, they have proposed to make a rotary machinery IoT enabled by adding adequate hardware to them which can stream continuous data to a web server. They have developed a web application that acts as a dashboard and displays the data. In this research, authors used hardware that supports data stream with up to 2.5 kHz sampling rate with the range of ± 3 g. In addition, the specified settings cannot be changed through the GUI. Finally, continuous data streaming can quickly build up data which poses a problem if there is limited storage space available.

In [7] authors propose an automatic data collection solution for an industrial metal stamping unit, which has the ability of monitoring, predicting and optimising based on collected data from the machine. This system uses several various observed parameters such as acceleration and environmental parameters (temperature, humidity, and pressure). Data is presented through web application that acts as a dashboard for visualization and monitoring of observed parameters. The system presented in this paper provides automatic condition-based monitoring as well as visualization but lacks any control functions which enables the management of the collection process. It should also be mentioned that the system uses Message Queuing Telemetry Transport (MQTT) technology for transmitting data from IoT devices to the server.

Another use case of IoT system is in [8] where authors proposed a smart solution based on IoT and cloud computing technologies to automatically monitor and control machines. However, this paper lacks information about the acquisition parameters. and as was the case in previous paper, the system uses MQTT as a transmission protocol.

Furthermore, in [9] the presented system is using the MQTT protocol for collecting temperature and humidity data. As well as in [6] and [7] the system also uses web application for online monitoring. MQTT protocol uses a publish-subscribe method opposite to the traditional server-client which allows it to have a smaller overhead than traditional HyperText Transfer Protocol (HTTP) protocol. This is useful because overhead size affects power consumption. However, if the number of devices increases, alongside the length of the topics, the overhead size grows linearly with respect to the length of the topics whilst the HTTP header remains constant. [10] On the other hand, the HTTP protocol has higher latency in comparison with the MQTT. This is crucial in cases with high data rates because otherwise there would be delays and missing data. Compromise between these two technologies is the WebSocket protocol. WebSocket protocol enables full-duplex constant data exchange between client and server and is more appropriate for applications that require high data rates. [11] Based on this premise as well as the fact that there are yet no use cases of using WebSocket protocol for vibration data acquisition which we could find, WebSocket is chosen as transmission protocol in the presented system.

The proposed IoT system in [12] is used to monitor large rotor vibrations. This system is closest to what we are presenting because it uses user-defined control modules such as sampling rate, sampling time and axis information. However, this system uses data rate up to 4000 Hz alongside UDP protocol which suffers from reliability issue (unlike WebSocket which is based on TCP protocol). [13] Furthermore, unlike in other papers, the web application that the system uses lacks data visualization modules that can be used for monitoring, and the feedback about the current sampling cycle and sampling status. The last thing that needs to be pointed out is that the sampled data is being saved to an ASCII-file which is locally bound to a single server (PC). A better solution is to store the data into the database from which the data can then be accessed from anywhere as was the case in the previously mentioned papers.

All compared articles have only one accelerometer as a source of data as opposed to presented IoT system which contains multiple accelerometers placed on different parts of the machine.

3 SYSTEM REQUIREMENTS AND ARCHITECTURE

After discussing related works in the previous section, it is possible to define IIoT system requirements and architecture. System requirements are as follows:

1) Data collection parameters input - the user must have a choice to choose from: location of the IIoT device and sensor from which the data will be collected, type of data collection (individual or collective) the frequency and range of accelerometer, duration of sampling and number of samples as well as the time between samples.
2) Data collection – the system needs to collect data based on user-defined setting, store it in a database and record the state of collection (whether it was successful or whether it failed). Also, it needs to inform the user about the progress of data collecting (current number of collecting cycles).
3) Data visualisation – finally, the system needs to visualise data after collecting it.

For better understanding, the system requirements are decomposed and shown in Fig. 1.

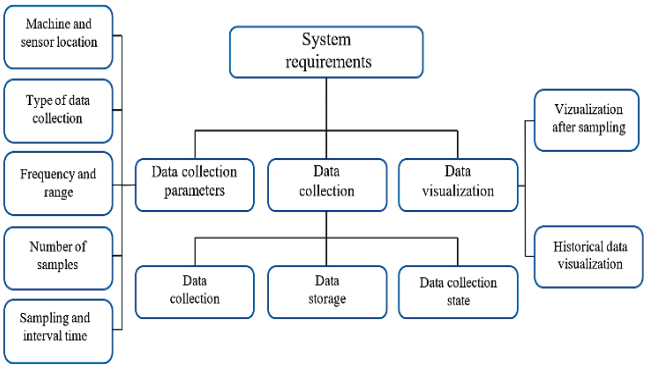

Figure 1 System requirements

To achieve the defined requirements, it is necessary to determine the system architecture. The system architecture is a conceptual model that defines the structure, behaviour, and overview of a system. The system architecture can be seen as a description of a system and its components organized to describe the functioning of the system.[14] The presented system architecture is shown in Fig. 2.

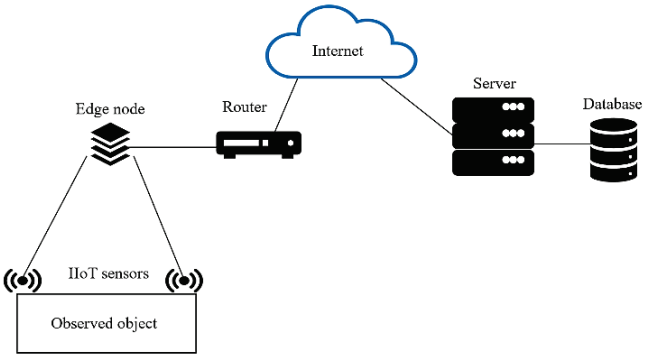

Figure 2 System architecture

The system architecture consists of IIoT sensors (accelerometers), edge node, edge gateway, server, and database. The architecture also has a software part which is a web application. The system components are described below.

3.1 Edge Node and IIoT Sensor

Edge node enables intelligent, automated access and collection, communication and exchange of information with an industrial environment. [15] In this paper, Tinkerforge modules are used as an edge node. Tinkerforge is a system of component blocks for professional use, blocks are widely used to implement projects quickly and efficiently. Blocks can be stacked on top of each other and do not depend on the order of stacking. The integration of blocks with the software is achieved through the use of API which is available for multiple programming languages such as C/C++, C#, Delphi/Lazarus, Java, JavaScript, LabVIEW, Mathematica, MATLAB/Octave, Perl, PHP, Python, Ruby, Shell and VB.NET. [16] Edge node consist of three Tinkerforge modules:

- Master module – is used to control other modules. It routes messages between the other modules on the set and the control device.
- Master extensions - expand the communication capabilities of the module. In this paper, an Ethernet module is used to connect the edge node to the router.
- RED module - can control other modules and execute programs. Programs that control modules can be placed directly on a RED module which is running the Debian Linux operating system located on the Micro-SD card on the bottom of the RED module. It is possible to use several programs at the same time, set the time of their execution as well as their monitoring.

The Edge node is stacked into three tiers, each tier containing one Tinkerforge module. The stack is configured in the following order:

- Tier 1: RED module.
- Tier 2: Master module.
- Tier 3: Ethernet master extension.

Fig. 3 shows the tiers with the modules and their parts.

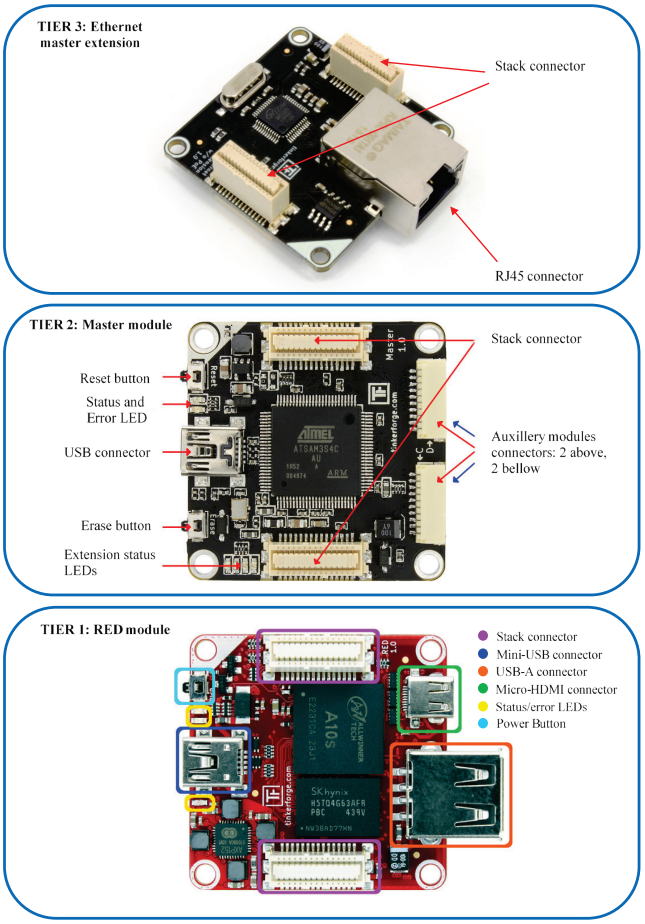

Figure 3 Edge node modules stack

Power to the stack is supplied through a 5 V USB plug which is connected to the Master module. The RED module provides computing power, the main module allows communication and connection of IIoT sensors while the Ethernet extension allows communication over the Internet. These three modules are the basis of the IIoT data collection system, and they must always be present (only the Ethernet extension can be replaced with a Wi-Fi extension). It is possible to add additional modules that allow some other functions (connection of more than 4 sensors, additional power supply, etc.) to the stack.

Tinkerforge also offers auxiliary modules. Auxiliary modules are used to expand the functionality of the master module. Their application can be in the form of measurement (sensors) or control. Each auxiliary module is connected to the other modules via a wired connection. As an IIoT sensor auxiliary module Accelerometer 2.0 was used. It is a three-axis accelerometer designed as an add-on for the main modules and allows the measurement of acceleration in x, y and z direction with the sampling frequency up to 25.6 kHz, which is suitable for use in predictive maintenance. [17] The accelerometer is Kionix KX122-1037 and it has a ± 2·g, ± 4·g, or ± 8·g collection range. The sensing element of acceleration is based on the principle of differential capacitance resulting from the movement of the sensing element caused by acceleration. The sensing element then uses a noise reduction process to reduce errors due to process

variation, temperatures, and other atmospheric influences. The sensing element is hermetically sealed, and a separate ASIC device allows signal conditioning and the application of intelligent control that can be programmed by the user. The accelerometer comes with a built-in analogue-to-digital converter, which reduces the need to purchase a special device that serves as a converter. [18] Fig. 4 shows the Tinkerforge Accelerometer 2.0.

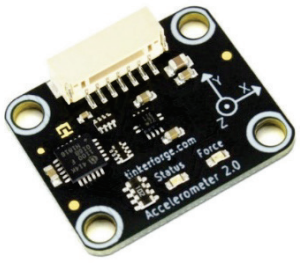

Figure 4 Tinkerforge Accelerometer 2.0 [17]

For proper use of the accelerometer, it is recommended to mount it in a housing so that the measured values are more accurate, and that the accelerometer is additionally protected from external influences. The technical specifications of the accelerometer are given in Tab. 1.

Table 1 Accelerometer specification [18]

Property	Value
Output data rate	0.781 Hz - 25.6 kHz
Full-scale range	± 8 g
Sensitivity	4096 - 16384 counts/g
Offset	± 20 mg
Non-Linearety	0.6 %
Resolution	0.0001 g, 16-bit
Input voltage	1.71 – 3.6 V
Current consumption	145 mA
Output voltage	1.368 - 28.8 V

The highest throughput (sampling data rate) depends on the selected resolution. Tab. 2 shows the dependence of the number of axes and the sampling data rate

Table 2 Dependence of the number of axes on the throughput of the accelerometer [17]

Number of axis	Throughput (8-bit) (Hz)	Throughput (16-bit) (Hz)
1	25 600	25 600
2	25 600	15 000
3	20 000	10 000

The number of used axes can be selected via the Tinkerforge accelerometer API. The IIoT data collection system uses three axes and a resolution of 16 bits which means that the highest possible data rate is 10 000 Hz.

3.2 Router, Web Server and Database

The MikroTik RB951-2nd hAP router is used as the gateway of the system, which is suitable for smaller systems that do not require a lot of users and traffic. Due to its small size, it is suitable for use in almost any location. Microsoft Internet Information Services is used as a web server because of the native support within the Microsoft Visual Studio development environment. The system also uses the Microsoft SQL Server database management system for creating, editing, and controlling the database.

3.3 Web Application

Tinkerforge modules can be controlled via the Application Programming Interface (API). An application programming interface is a way in which two computer applications communicate with each other over a network (Internet) using a common language that they both understand. [19] As mentioned before, Tinkerforge API supports a range of programming languages. The IIoT data collection system uses the JavaScript programming language API. Because JavaScript is a programming language that runs on the frontend, the data collection process will take place on the user's front-end while the data storage function will take place on the back-end. The structure of the web application for automated data collection is shown in Fig. 5. To connect the client to the edge node, a ZeroTier VPN connection was used which enables security and privacy.

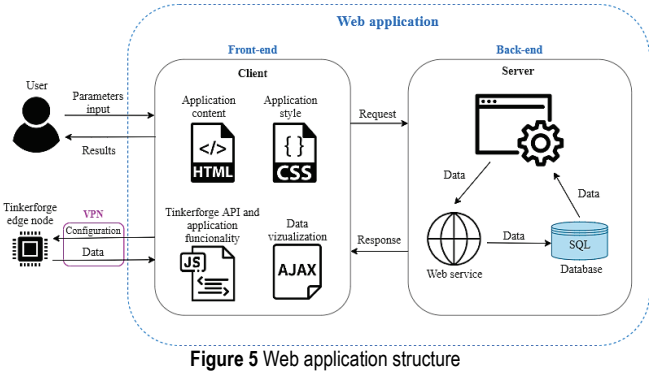

Figure 5 Web application structure

The front (client) side consists of HTML, CSS, JavaScript, and AJAX programming languages, and each of them serves a specific function. The function of HTML is to organize and display the content of the application. CSS defines element sizes, colours, text style, and all graphical user interface settings. For the web application to be used on different device sizes (computer, tablet, mobile phone ...), the Bootstrap CSS library is used, which contains a set of commands for easier manipulation of the size of the elements. JavaScript ensures the functionality of the application by communicating with the Tinkerforge edge node through which data is collected. Also, it serves to check parameter input, manipulate HTML text and objects, perform arithmetic operations, and visualize data. For data visualization, a Plotly JavaScript graphic library was used, which allows plotting data in the form of a graph. Using AJAX (Asynchronous JavaScript and XML) web application can asynchronously send and retrieve data from the server without interfering with the display and behaviour of the web page. The back-end (server) of the web application is used to retrieve data from the database, forward data to the web service, as well as monitor the state of data collection (number of collected samples). Web service is a special part of the application that is used exclusively to store

acceleration values in a database. The back-end of the web application uses the C# programming language. The interface of the application can be seen in Fig. 6.

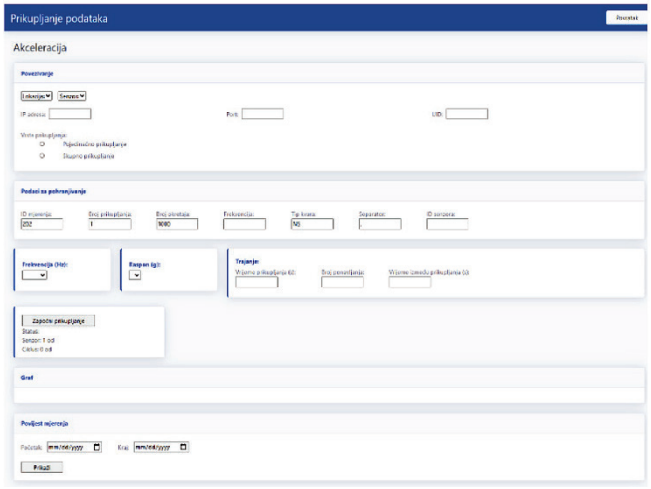

Figure 6 Web application interface

4 EXPERIMENTAL SETUP AND METHODS

The system performance is evaluated by using a rotational equipment failure simulator. The rotational equipment failure simulator is used to investigate and understand the various vibrational patterns, which simulate work at a normal (correct) condition of the equipment and in different states corresponding to the failures of individual parts of the machine. The data collected by the failure simulator is used for further analysis and research. The failure simulator uses a three-phase asynchronous electromotor whose speed is regulated using the frequency inverter containing the speed regulator. By changing the output frequency of the motor, the speed control is enabled, thus reaching the variable frequency of rotation ranging from 0 to 6000 rpm. The engine power is transmitted to the shaft over the claw coupling. The shaft is embedded with two ball bearings mounted with concentric safety rings and has a mass weight of 5 kg which increases the base load of the bearings. By changing the bearing type it is possible to simulate the following malfunctions [20]:

- Damage to rolling elements (BBF),
- Damage to the outer roll path (ORBF),
- Damage to the internal roll track (IRBF),
- Combined damage (CBF).

Also, with the simulation of the bearing failure, it is possible to simulate rotor failure such as:

- Rotor imbalance (IMRF),
- Rotor slot (CRF),
- Rotor eccentricity (ERF).

The IIoT sensors were mounted to the front and rear bearing and then connected to the edge node. The edge node was connected by a UTP cable to a router that connects to the Internet. The layout of the fault simulator, the IIoT sensor, the edge node and the router are shown in Figure 6. The data is collected from the rear bearing as the change is made on it. A laptop serves as the access to the web application that establishes a connection, assigns the sampling parameters, and stores data. The laptop is in another location to demonstrate remote data collection functionality.

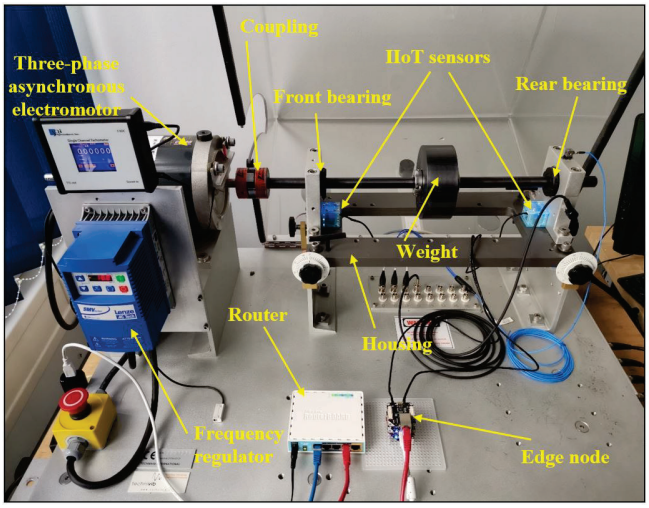

Figure 7 Experimental setup

For this paper, to showcase the operation of the system, a bearing fault experiment was concluded with combined damage to the individual elements (CBF), whose vibration patterns are compared to the normal state of the equipment (NS). The experiment parameters are in Tab. 3.

Table 3 Experiment parameters

Property	Value
Rotation speed	600 rpm
Sampling rate	6400 Hz
Accelerometer range	± 8·g
Equipment state	NS, CBF
Number of sampling per bearing	30
Sampling duration	1 s
Time between sampling	1 s

4.1 Data Collection Workflow

The Data collection process starts within the web application where the machine location and the sensor from which the data is collected are chosen. Then, the data rate of 6400 Hz and the range of 8·g is chosen after which the number of samples, sampling duration and time between sampling is entered. If all parameters were entered, by clicking the button, connection is established with the sensor and the desired data rate and range parameters are transmitted to the edge node. After the connection and transfer of parameters, the transmission of data from the sensor begins. Following the end of completion of sampling, the data is stored in the database and the system is waiting for the next sampling for 1 second after which the cycle starts again and so on another 29 times until all cycles are finished. At the end of the process, the data is visualized, and the user is notified that the collection is completed. The user has a choice to collect data again, review the history of collected data or exit

the application. Detailed system workflow is shown in the activity diagram on Fig. 8.

Additional function of this IIoT system is recording of process state. After each sampling cycle, if the connection was successfully established, the connection state is stored into a database as successful. Else, if there was an error in establishing a connection, the connection status is stored in a database as an error and the user is notified. The same procedure applies to collecting and storing process which enables the system to use stored states for later analysis. The results of the experiment are discussed in the next section.

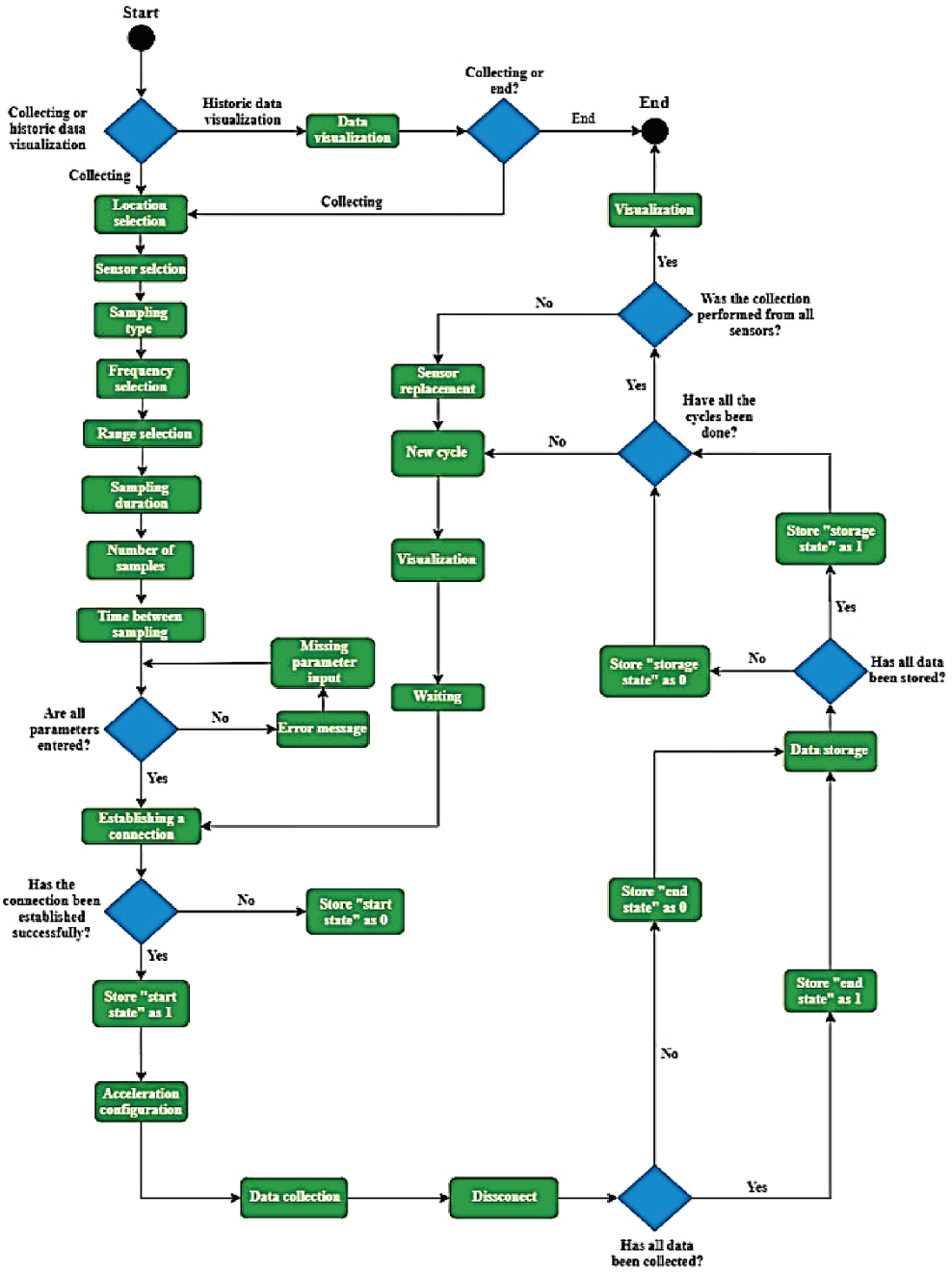

Figure 8 Activity diagram of system workflow

5 RESULTS

During the experiment, 384 000 data points were collected. 192 000 were in the normal state (NS) while another 192 000 were collected in the combined bearing failure (CBF) state. To visualize such a large amount of data, the MATLAB program was used. One collection cycle is set aside from the rest. Fig. 9 shows a graphical representation of one normal collection cycle.

The Fig. 9 shows that in the normal state there are no significant deviations of the acceleration value, as well as patterns that would indicate the presence of a fault. For comparison, Fig. 10 shows a graphical representation of the data collected when simulating a combined bearing failure.

The Fig. 10 clearly shows that there are significant deviations of the acceleration values when simulating the combined bearing fault state. Acceleration values assume patterns that are characteristic of such a simulated state. The same acceleration plot can be seen in web application during the data collection process. Fig. 11 shows the acceleration plot captured in web application.

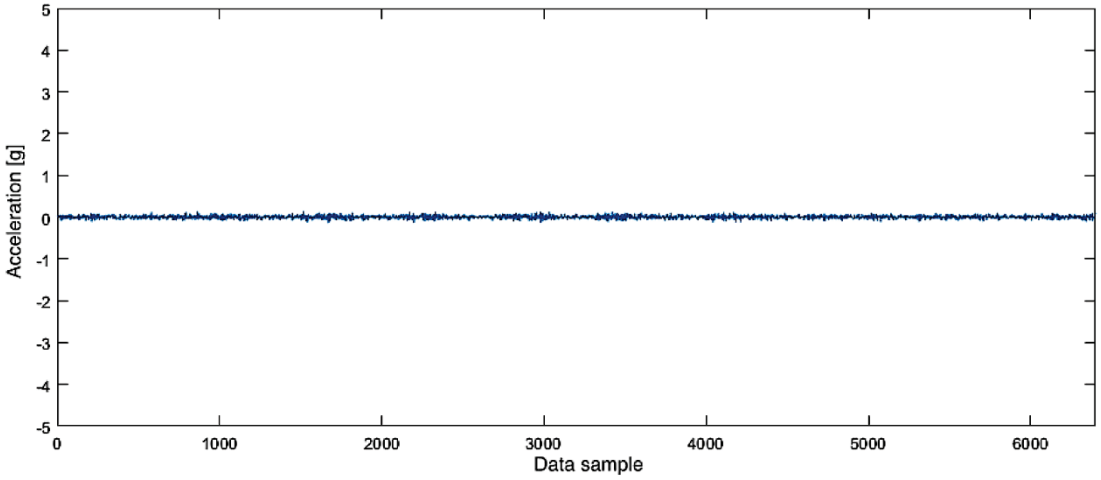

Figure 9 Graphical representation of collected data in normal state

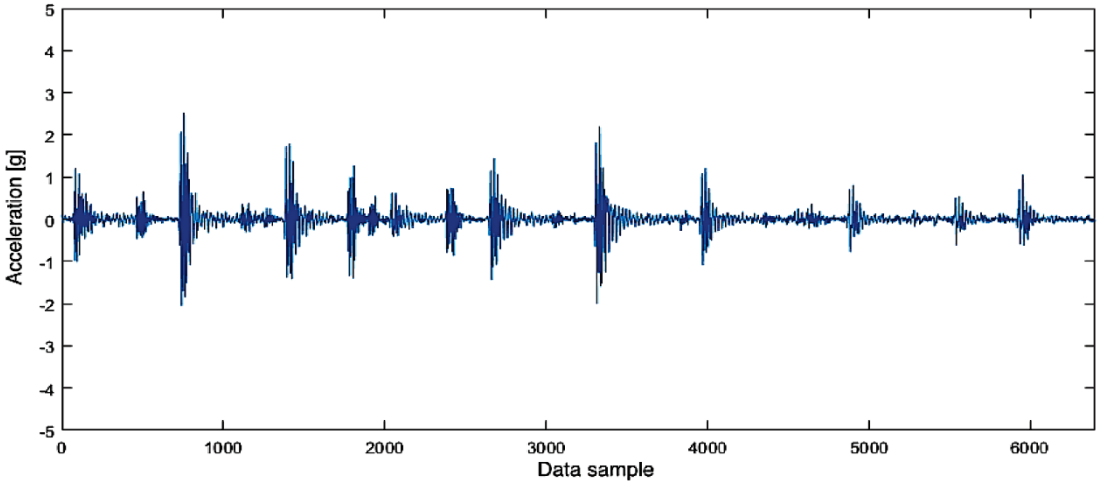

Figure 10 Graphical representation of collected data in combined bearing fault state

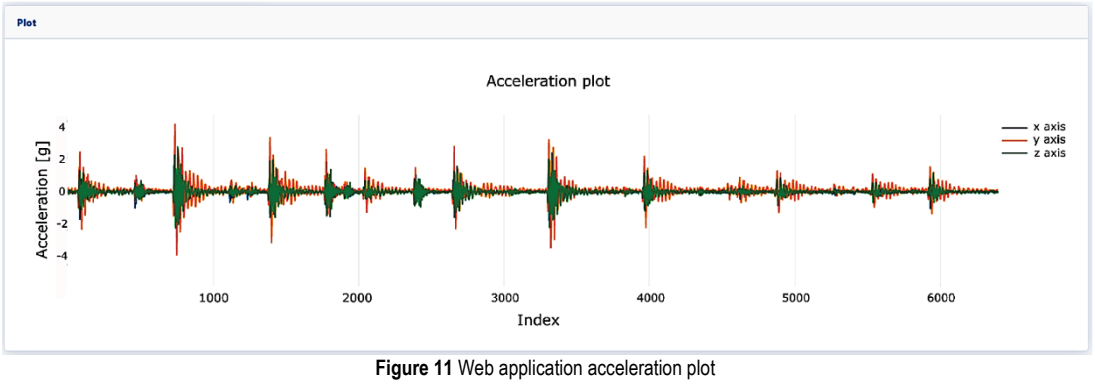

Figure 11 Web application acceleration plot

One of the main limitations of this new system is the impossibility of simultaneous collection from multiple sensors due to the very nature of data transfer which depends on establishing an IP connection between two devices. That means that connection cannot be established simultaneously with multiple devices and for this reason, the system collects data sequentially from each sensor. However, this system limitation is not a decisive factor when used in maintenance. It is expected that faults on certain equipment will be able to be detected by a certain sensor from the moment of

occurrence to the moment of elimination. It is difficult to expect that the system will return to initial state on its own. Therefore, synchronization in this case is not crucial and it is possible to allow a deviation, but this should be kept in mind when displaying and processing data.

This experiment was conducted to show that the IIoT system is successfully gathering information and that there is a clear distinction in acceleration values when simulating two different equipment states. The results indicate that there is a clear distinction in acceleration values which correlate with vibration patterns of normal and combined bearing fault state. In summary, these results indicate that the system is successfully collecting vibration data which can be used for further analysis.

6 CONCLUSION AND FUTURE WORK

As mentioned in the review of previous and related work, many studies use IoT as a framework for automated data collection. One initial objective of this study was to determine if high frequency (>5000 Hz) data sampling could be achieved by the means of IoT technology. The second objective was to enable automated and controlled data collection which allows for an easier data collection process compared to usual methods as previously mentioned.

By conducting an experiment with two equipment states it was shown that the system is successfully collecting high-frequency vibration data that are distinct to each state. This means that this data can be used for further analysis such as machine learning or time series analyses. Also, by enabling automation and control, the foundations for smart maintenance have been set. Future research will aim to improve the current system and explore the possibility of applying a fast Fourier transform to the data and send such data to the server which will speed up the analysis process.

The IIoT data collection system naturally has its limitations, but it is an initial step in the development of a larger system that will have the ability to analyse data from a variety of sources, predict failures, propose maintenance activities and decision support, which is the main feature of current maintenance trends such as prescriptive maintenance whose goal is to reduce downtime costs and increase productivity.

Notice

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7 REFERENCES

[1] Vaidya, S., Ambad, P., & Bhosle, S. (2018). Industry 4.0 – A Glimpse. *Procedia Manuf., 20*, 233-238. https://doi.org/10.1016/j.promfg.2018.02.034

[2] Jasiulewicz-Kaczmarek, M., Legutko, S., & Kluk, P. (2020). Maintenance 4.0 Technologies – New Opportunities for Sustainability Driven Maintenance. *Management and Production Engineering Review, 11*(2), 74-87. https://doi.org/10.24425/MPER.2020.133730

[3] Sisinni, E., Saifullah, A., Han, S., Jennehag, U., & Gidlund, M. (2018). Industrial Internet of Things: Challenges, Opportunities, and Directions. *IEEE Trans. Ind. Inform., 14*(11), 4724-4734. https://doi.org/10.1109/TII.2018.2852491

[4] Jasiulewicz-Kaczmarek, M. & Gola, A. (2019). Maintenance 4.0 Technologies for Sustainable Manufacturing - an Overview. *IFAC-Pap., 52*(10), 91-96. https://doi.org/10.1016/j.ifacol.2019.10.005

[5] Sinha, J. K. & Elbhbah, K. (2013). A future possibility of vibration based condition monitoring of rotating machines. *Mechanical Systems and Signal Processing (MSSP), 34*(1-2), 231-240. https://doi.org/10.1016/j.ymssp.2012.07.001

[6] Khademi, A., Raji, F., & Sadeghi, M. (2019). IoT Enabled Vibration Monitoring Toward Smart Maintenance. *The 3rd International Conference on Internet of Things and Applications (IoT)*, Isfahan, Iran, 1-6. https://doi.org/10.1109/IICITA.2019.8808837

[7] Cachada, A., et al. (2019). Using Internet of Things Technologies for an Efficient Data Collection in Maintenance 4.0. *2019 IEEE International Conference on Industrial Cyber Physical Systems (ICPS)*, Taipei, Taiwan, 113-118. https://doi.org/10.1109/ICPHYS.2019.8780217

[8] Ayad, S., Terrissa, L. S., & Zerhouni, N. (2018). An IoT approach for a smart maintenance. *2018 International Conference on Advanced Systems and Electric Technologies (IC_ASET)*, Hammamet, 210-214. https://doi.org/10.1109/ASET.2018.8379861

[9] Atmoko, R. A., Riantini, R., & Hasin, M. K. (2017). IoT real time data acquisition using MQTT protocol. *Journal of Physics: Conference Series, 853,* p. 012003. https://doi.org/10.1088/1742-6596/853/1/012003

[10] Yokotani, T. & Sasaki, Y. (2016). Comparison with HTTP and MQTT on required network resources for IoT. *2016 International Conference on Control, Electronics, Renewable Energy and Communications (ICCEREC)*, Bandung, Indonesia, 1-6. https://doi.org/10.1109/ICCEREC.2016.7814989

[11] Oliveira, G. M. B., et al. (2018). Comparison between MQTT and WebSocket Protocols for IoT Applications Using ESP8266. *2018 Workshop on Metrology for Industry 4.0 and IoT*, Brescia, 236-241. https://doi.org/10.1109/METROI4.2018.8428348

[12] Koene, I., Viitala, R., & Kuosmanen, P. (2019). Internet of Things Based Monitoring of Large Rotor Vibration with a Microelectromechanical Systems Accelerometer. *IEEE Access, vol. 7*, 92210-92219. https://doi.org/10.1109/ACCESS.2019.2927793

[13] Masirap, M., Amaran, M. H., Yussoff, Y. M., Rahman, R. A., & Hashim, H. (2016). Evaluation of reliable UDP-based transport protocols for Internet of Things (IoT). *2016 IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE)*, Penang, Malaysia, 200-205. https://doi.org/10.1109/ISCAIE.2016.7575063

[14] Jaakkola, H. & Thalheim, B. (2011). Architecture-Driven Modelling Methodologies, p. 21.

[15] Boyes, H., Hallaq, B., Cunningham, J., & Watson, T. (2018). The industrial internet of things (IIoT): An analysis framework. *Comput. Ind., 101*, 1-12. https://doi.org/10.1016/j.compind.2018.04.015

[16] Tinkerforge Documentation. (2021). https://www.tinkerforge.com/en/doc/ (accessed Mar. 05, 2021)

[17] Accelerometer Bricklet 2.0. (2021). Tinkerforge GmbH, https://www.tinkerforge.com/en/doc/Hardware/Bricklets/Accelerometer_V2.html (accessed Mar. 05, 2021)

[18] Kionix. (2018). KX122-1037: Akcelerometar. Kionix.

[19] Jacobson, D., Brail, G., & Woods, D. (2012). *APIs: A Strategy Guide*. Sebastopol: O'Reilly.
[20] Kolar, D. (2019). Deep learning-based early fault diagnosis model for rotary machinery. *Doctoral thesis*, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Zagreb.

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Preliminary communication

Transferring an Interdisciplinary Student Product Development Project to Full Online Conduction

Patrick Herstätter*, Andreas Kohlweiss, Maria Hulla, Christian Ramsauer

Abstract: "Product Innovation" is a 7-month product development course, conducted at the Institute of Innovation and Industrial Management with international and interdisciplinary student teams. A close connection and interaction between industry, students and research has been an important part of this project-based learning course. Due to the COVID-19 pandemic and the worldwide occurring lockdowns, students were not able anymore to interact and conduct their projects in the proven manner. Being in a critical phase of the project, the course concept had to be reorganized and transferred to online conduction by using computer supported collaboration work within a few days. Both observations and surveys were used to compare changes in student´s behaviour and results of the project. This paper will describe 1) the original situation and course concept, 2) show how the course was transformed to online conduction, 3) describe the observations made and 4) analyse how the students experienced the transformation.

Keywords: computer supported collaboration work; innovation project; online course conduction; project-based learning; rapid prototyping

1 INTRODUCTION

This paper deals with the transformation of the project-based learning course "Product Innovation" that relies on physical interaction between the stakeholders into a fully online conducted course. Project based learning can encourage collaboration and negotiation within a group and a crucial element of project based learning is the creation of tangible artifacts that solve authentic problems [1]. In order to support these elements, student teams within "Product Innovation" (PI) get full access to the Schumpeter Laboratory of Innovation – an academic makerspace facilitated by the Institute of Innovation and Industrial Management at Graz University of Technology (TUG). Equipped with modern equipment it serves as the central facility for PI and enables meetings, project work and rapid prototyping. Due to the impacts of COVID-19 and the subsequent lockdowns occurring all over the world throughout the first half of 2020, access to the Schumpeter Laboratory for Innovation (SLFI) was no longer possible for the student teams and major parts of the rest of the course had to be conducted online. This interruption of the course happened during a crucial time in the project that is heavily dependent on the usage of the facilities of the SLFI. The paper starts with an overview of the initial situation of the course "Product Innovation" and its supporting facility, the Schumpeter Laboratory for Innovation. The aim is to give an overview over the measures taken to continue PI despite access restrictions for the students. Further, the impact of the transformation on the student's behavior and project results should be investigated, to derive insights for future online project based learning projects. As input data for the investigation both observations as well as a conducted survey with the participants of PI are used. In the end the findings of the paper should be concluded as well as limitations be discussed and an outlook on further investigations given.

2 INITIAL SITUATION

The observations and investigations made in this paper deal with the course "Product Innovation" – a project based learning course by the Institute for Innovation and Industrial Management (IIM). The period under review is the project year 2019/2020 – starting midst of October 2019 until June 2020.

2.1 "Product Innovation"

Product Innovation, former "Product Innovation Project" is a course that is conducted by the IIM since the winter term 2006. Until today valuable learnings, insights, product ideas and even patents were delivered within this course for students as well as partner companies. It is a course that is originally based on the ME310 program from Stanford University, where Design Thinking (Fig. 1) is teached via project-based learning and the provided work environment is important as it affects students in various ways such as their behavior, their creativity or their independence. [2, 3]

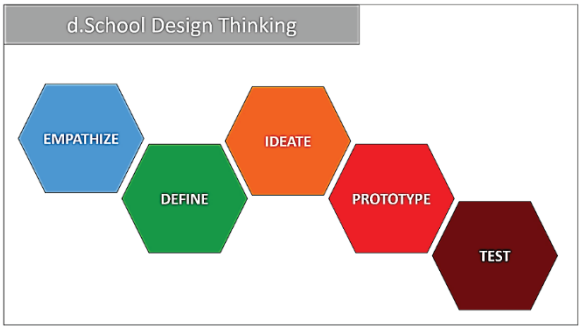

Figure 1 Design Thinking Process based on Stanford d. School [4]

Within the course of Product Innovation teams of interdisciplinary and international students work on real-life tasks that are provided by industrial partners. They are backed by a budget of 10.000 € to realize ideas, develop fully working prototypes and conduct experiments. While the majority of students is placed in Graz and works together at the same place, there are some remote members from other universities and countries, who collaborate remotely and just visit Graz for a few weeks within the project time. The course

is facilitated by the Institute for Innovation and Industrial Management at Graz University of Technology and throughout the course students have full access to the facilities of the institute, including the Schumpeter Laboratory for Innovation (chapter 2.2.).

Over time, incremental improvements have taken place but the overall process is still based on design thinking. The project lasts a full academic year and starts in October with the organisational preparation, meaning a recruiting and application phase. Teams are assembled in an international and interdisciplinary way and each team is working on a different task from a different company. To give them guidance and ensure good communication, each team additionally is supported by an academic supervisor. The official project kick-off takes place in November and starts – as soon as the teams have been gathered – with a problem analysis phase. During this phase, teams empathize on their problem, make field research, conduct benchmarking and finalize the phase by refining their initial problem statement and goals. At the end of this phase, usually midst of January, the teams enter the ideation process – where they try to create as many ideas as possible for their projects. They evaluate the ideas, conduct first experiments and combine them to a concept before entering prototyping – typically midst of March. The prototyping phase is used to get valuable data about the concepts, test them and iterate the concept for improvement. The project ends after roughly 7 months, when the teams present their final product in front of a public audience of industry representatives, university staff and students in the beginning of June. During all the phases, students are supported with topic related workshops, where they are provided with suitable knowledge, methods and techniques. [5]

2.2 Schumpeter Laboratory for Innovation

The Schumpeter Laboratory for Innovation (SLFI) is an academic makerspace with offices, multimedia presentation technology and conferencing rooms as well as digital production machines. Its machine park for prototyping includes among others laser cutters, 3D printers with different technologies (SLA, FDM) up to 1m³ in printing volume, a vinyl cutter, electronic workspaces, a waterjet cutter, CNC milling machines and various hand tools. First opened for students in fall 2018 it serves as central base of the product development course "Product Innovation". After the project year 2018/2019 and along with a lot of insights on the usage of the SLFI, the full potential of this modern facility should be unlocked for the first time in 2019/2020. [5]

Besides the machine park used during the prototyping phases, state-of-the-art multimedia equipment allows to conduct meetings with remote team members, sitting all over the world, in an easy and efficient way. The multimedia equipment includes 2 meeting rooms with video conferencing hardware as well as software. With over 200m² in size and a 30m² LED video wall, the biggest room, called design lab, is equipped with cutting edge communication and presentation technology. The room can be used versatile for prototyping, workshops, presentations and meetings and is open for the students of the PI. Making use of the space and the equipment, allows for more interactive meetings as several people can present live from the stage into a video conference. A representation of the layout of the SLFI is depicted in Fig. 2. After mid of March 2020, students were no longer able to access the facilities of the university for the rest of the course and it took until mid of April 2020 until the staff of the institute was able to make use of the extensive equipment again. It was therefore necessary to conduct major changes to the project´s procedure and processes and transfer it to online conduction within a few days in order to finish the project in time.

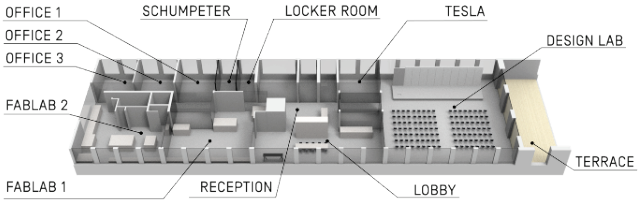

Figure 2 Schumpeter Laboratory for Innovation (SLFI) [5]

3 RESEARCH QUESTIONS AND METHODOLOGY

This paper deals with the transformation of PI into an online conducted project-based learning course due to the COVID-19 restrictions in Austria and should investigate the following research questions:

- RQ1: How can a highly interactive course be conducted in a full online setting?
- RQ2: Which impacts does the change to a virtual setting have on the student projects?

In order to investigate research question 1 different ways of computer supported collaboration work are investigated. Central processes that need to be supported are defined on base of the course structure of PI, as well as computer supported cooperative theory and compared with the abilities of software tools. Afterwards a set of tools is defined according to both suitability for the pre-mentioned processes, as well as the availability for project's participants and teaching staff.

In order to investigate research question 2 observations were made and compared to previous project volumes. In addition, a survey is conducted with the participants of PI who were sitting in Graz and therefore directly affected by the closing of the SLFI. The survey is developed based on OECD guidelines [6] and should also test insights and hypotheses from the observations.

4 LISTING AND EVALUATION OF COMPUTER SUPPORTED COOPERATIVE WORK SYSTEMS

In this chapter functions that need to be provided in order to conduct the course online should be listed and different solutions are shown. Especially the field of computer supported cooperative work was investigated to classify the requirements and investigate possible solutions. By using the

categorization according to the computer supported collaboration matrix by Johansen (Fig. 3) [7] the project had to be transferred from mainly face to face interaction as well as asynchronous interaction into synchronous and asynchronous distributed interaction. Due to the fact that some of the international teams also work with remote members, there was already some pre-experience in some teams on how to work in a distributed way.

	Same Time	Different Time
Same Place	Face to face interaction	Asynchronous interaction
Different Place	Synchronous distributed interaction	Asynchronous distributed interaction

Figure 3 Time-space matrix by Johansen [7]

In addition to the classification made by Johansen, possible groups of information and communications technology (ICT) processes were defined by Andriessen [8] for further categorization: Person interchange processes like communication, task oriented processes like cooperation or coordination or information sharing and group oriented processes like social interaction. These processes represent important functions that need to be supported throughout the Product Innovation course. For each process several solution technologies and systems have been listed, as seen in Fig. 4. As time was a crucial factor for the transition, the matrix has been assembled by gathering systems and technologies, the IIM already had some experience with.

The listed solutions were then evaluated. In a first step, knockout-criteria were used in order to reduce the number of potential usable systems. As the transformation was not planned, no costs for additional software or tools was accounted in the team's budgets. Therefore, the solution system needed to be available for both the teams as well as the institute's staff for free. Additionally, systems that already have been in place before the transition and were familiar to the whole project team should be maintained. The used systems – especially for information sharing – further needed to be in compliance with the non-disclosure agreements (NDAs) that are part of the contract between institute, students and partner companies and are a critical part to secure sensitive information, exchanged or developed throughout the "Product Innovation". The remaining solutions were then transferred into a final concept that provides all processes and functions needed throughout the project, with a focus on implementing as little systems unknown by the students, as possible and only systems which were evaluated as "easy-to-use" by the institute's staff.

ICT processes		Potential solution technologies/systems				
Person interchange	Communication	Communication Platforms (Slack, Discord,...)	Instant Messengers (Whatsapp, Signal,...)	E-Mail	Wikis and Blogs	Video Conference (WebEx, Zoom, Teams,...)
Task oriented	Cooperation	Shared Whiteboard (Miro, Microsoft Whiteboard,...)	Sharepoint	Video Conference (WebEx, Zoom, Teams,...)	Online Office (GoogleDocs, Office365,...)	
	Coordination	Group Calenders (Google Cal, Outlook Cal,...)	Project Management Software (Trello, Asana,...)	Newsletters (E-Mail)		
	Information Sharing	Shared Whiteboard (Miro, Microsoft Whiteboard,...)	File Hosting/Sharing (Google Drive, Dropbox,...)			
Group oriented	Social Interaction	Gaming Apps (Among us, HouseParty,...)	Browser Apps (skribbl.io, Gather.town,...)	Social Networks (Facebook, Instagram,...)	Video Conference (WebEx, Zoom, Teams,...)	Communication Platforms (Slack, Discord,...)

Figure 4 Overview of potential solution systems

5 TRANSFORMATION AFTER FIRST LOCKDOWN DUE TO COVID-19

Time was the most crucial factor for the transformation of this highly interactive course into a full online conduction, in order to provide students as well as partner companies with the information they needed to continue their project independent of the uncertain external conditions. Therefore, the final concept (as seen in Fig. 5) was developed in less than a week and introduced to the students in form of a workshop where they also received information on the usage and on online-collaboration best practices in general.

ICT processes		Final solution technologies/systems	
Person interchange	Communication	E-Mail	WebEx Video Conference
Task oriented	Cooperation	WebEx Whiteboard	Only Office (cloud-based)
	Coordination	Trello project management	Newsletter (E-Mail)
	Information Sharing	TUGraz Nextcloud (File Sharing)	
Group oriented	Social Interaction	WebEx Video Conference	Browser Apps (skribbl.io)

Figure 5 Final solution concept

For communication, E-Mails - including a regular newsletter - were already used throughout the whole year and supplemented by WebEx video conference, which was then used for the rest of workshops and meetings. TUG provided

all students with a full licence for WebEx, which was the main reason to use it over alternatives. For the same reason, Nextcloud – an online file storing/sharing system – was used for information sharing. It additionally ensured that the shared data was secure and in compliance with NDAs and delivered sufficient storage capacity without additional costs. Set in place already at the beginning of the project it was well known by all participants. As an addition it provided "only office", an office tool that allows to collaborate synchronous on various office files like documents, spreadsheets, diagrams or presentations and was introduced as additional cooperation system besides the shared whiteboard provided in WebEx. For coordination, Trello was already used as project management tool and was maintained, regular updates with newsletters via mail were introduced. For social interaction, regular gaming evenings were organized over WebEx video conferences combined with free multiplayer browser apps. It became clear after a few weeks that the facilities would remain closed until the end of the project, leading to prototyping possibilities that were added to the concept. The students were given access to virtual machines that enabled 3D CAD modelling and could send orders to the SLFI, which were processed by the institute staff and made available for pick-up. Most of the provided methods and techniques could be used further, with just slight adoptions to the online conduction. E.g. for brainstorming - instead of having face to face sessions - the students were introduced to brain writing techniques, still applying the same familiar rules of brainstorming, but making documentation during online sessions easier.

6 OBSERVATIONS AND SURVEY REGARDING IMPACTS

6.1 Observations

Although observations became hard after transition to online conduction, due to the fact that people spent no time at the SLFI anymore, it still was possible to recognize differences during checkpoint meetings and workshops. Comparisons with previous volumes of PI, especially regarding the work progress, showed that there were positive as well as negative impacts by the transition. It seemed that especially during the beginning the motivation of the participants decreased which could be observed by a reduced number of contacts between the institute´s supervisors and the team as well as by a slowed down project progress. Online organised social events received little response in the beginning. Overall, the teams seemed to struggle to adapt to the given online setting, which could be observed by the little use of the given software (low traffic on the file sharing platform Nextcloud). On the other hand, it was observable that especially remote members, who often lacked information because of bad communication before, were more included in the process of the project and were able to participate at the virtually held workshops – which was not the case before. Also meetings between the team members were conducted more often as feedback from the teams showed. One struggle was especially immanent. When it came to physical prototyping, it could be observed that, since the teams were no longer to use the facilities of the SLFI, the activities reduced significantly. Previous years have shown that teams usually start their prototyping phase latest with beginning to midst of March and make extensive use of the digital production machines, hand tools and workbenches provided at the SLFI. During the underlying project year, teams were at the very beginning of testing and prototyping, not yet making full use of the SLFI capacities when the lockdown occurred. It could be observed during checkpoints, that although the teams tried to transfer their prototyping efforts into virtual environments, for some tests it was indispensable to have physical prototypes. Further, it could be observed that several teams wanted to design prototypes in 3D-CAD software but lacked powerful computing machines. These observations led to the introduction of additional measures as mentioned in chapter 5. Besides access to virtual machines, the students received the possibility of consultation hours with institute's staff where they could discuss, which physical prototypes are crucial and how they could be realized. Besides advice, the staff also processed the data given by the students, ran the machines and made parts and tools available for pick-up, so that the students were able to build and test some physical prototypes as well. Regarding project results it could be observed that all teams provided good quality in results, comparable with previous project years. However, due to the limited possibilities in physical prototyping, the quality decreased in that criteria but this was compensated by an increase in terms of virtual prototypes. Students receive grades for conducting PI, ranging from 1 (best) to 5 (worst). Although there are many influence factors for student grades, a comparison regarding the grading with previous years showed that there was just a minor deviation of 0,003 in the grades mean value for the investigated period.

6.2 Survey Development

In addition to the observations, a survey was developed to get more insights. The survey is based on the six steps to better survey design by OECD, as depicted in Fig. 6.

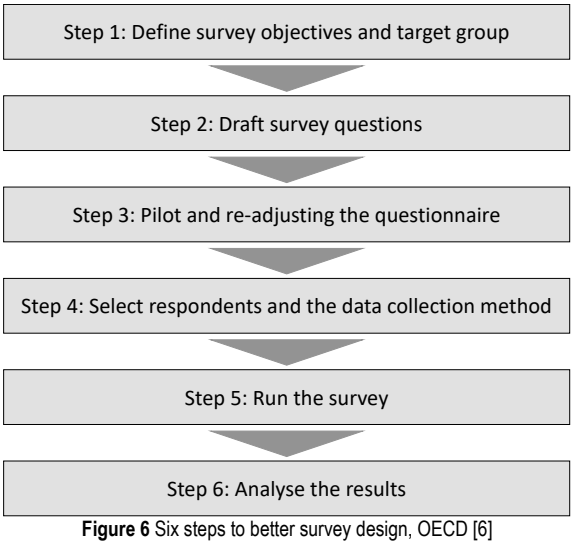

Figure 6 Six steps to better survey design, OECD [6]

Step 1: Define survey objectives and target group – The survey objectives are to get insights about the student's perspective and perception of the transition to a virtual

conduction. Additionally, the survey should support or withdraw conclusions that were made from observations and deliver information that can be used to improve the online conduction of the project. It is not the goal of the survey to test if the chosen technologies are the best technologies available, or to compare them to others. Regarding the target group, it should be stated, that remote students were already used to a mainly online conduction, therefore they should be excluded from the target group.

Step 2: Draft survey questions – The survey questions were mostly derived from interviews and discussions conducted after previous project volumes with the students. Key issues and aspects were identified and translated and categorized into the questions of the survey. Besides a general category where different aspects of the students are asked, the included categories are institute related communication/collaboration, company related communication/collaboration, the structure of PI in general, and facilities and culture. Due to the special challenges and for the investigation of the questions discussed in this paper a new category "virtual conduction" was added. The survey consists both of open and closed questions.

Step 3: Pilot and re-adjusting the questionnaire – The survey was tested partly already in previous years. Additionally, and especially regarding the new category of virtual conduction as well, a test-run with the survey was made by former students of the PI project as well as with supervisors and other staff from the institute. Feedback was included and the survey adapted accordingly.

Step 4: Select respondents and the data-collection method – Due to the fact that the survey is project-related and the target group well defined, the respondents should be all students that were participating in the PI project year 2019/2020, with the exception of exchange and remote students. As it was possible to use the facilities of the SLFI again after the project was finished and due to the fact that a final event was made after the ending of the project it was decided that the data should be collected by handing out a printed version of the survey to the participants.

Step 5: Run the survey – The survey was run at a final event that took place in October 2020, after the project already finished a few months earlier. Due to the fact that the survey was handed out physically, exchange students who took part in the project were no longer available for questioning. Staff from the institute was available during the students filled out the survey to answer questions, if something was not clear.

Step 6: Analyse the results – The survey was filled out by 26 students in total. Two responses were excluded from the results before the analysis as the given answers were inconsistent, therefore leaving a total of 24 questionnaires to be analysed.

6.3 Survey Analysis

In the following selected topics from the survey are discussed and analysed. The results are already summarized and categorized, only frequent mentions are to be discussed within this paper. For the survey scale a Likert scale from 1 to 5 was used where 1 was the worst and 5 the best rated value.

Perceived motivation influencers (negative) – the biggest influence on the student´s motivation was COVID-19 and the subsequent lockdown situation. 54% of the surveys stated that. More specific, the resulting lack of prototyping possibilities and the limited possibilities to see each other or get into contact with the companies were named. 21% of the students stated that they experienced some issues within the team, e.g. team member underperforming or not being active any longer.

Transition speed – With a mean value of 4.04 the transition speed was perceived as fast enough, but with slight room for improvement.

Newsletter (E-Mail) vs Trello Board – Students were asked about the usefulness of Newsletters (E-Mail) and the Trello Board – both used for coordination. Overall both showed plenty room for improvement with the newsletter being rated 3,58 on average and the Trello Board just slightly better with 3,83. Possible improvements named were for the newsletter to include a timeline and compress the information to an absolute minimum, while on Trello students wished for a more interactive and faster platform.

Perception of online conduction (chance or hindrance) – on the question (different scale used) if students saw the online conduction as a chance (1) or hindrance (5), the mean value was 2,91 showing that it was seen very ambivalent with a slight preference of seeing it as a chance.

Perception of difficulty of switch – the mean value of the perception is 3,26 but 50% of the students answered this question with a value of 3 or less, making it the worst rated value in the questionnaire. Obviously it was, despite the fact that students already were familiar with many of the used systems, the switch to an online conduction was unusual and difficult to implement.

Perception about final solution concept – the final solution concept with the different tools and systems in place was rated with a mean value of 4,17, showing that student´s satisfaction with the concept was high. Only 25% of the students evaluated it with 3 or lower. On the question which additional software the students used or would´ve wished for, alternative video conference software was named (MS Teams, Zoom) and instant messaging within the teams, thus showing that some students were not fully satisfied with the video conferencing software and an instant messaging system could be complemented in the future.

Perception of virtual workshops – with a mean value of 3,74 the virtual workshops are rated good but also leave room for improvement. The reasons named are that it is harder to keep concentrated during a virtual workshop, the interaction is less, more people should be involved during the workshop in general and there should be more time planned in general, due to lags and interruptions.

Positive impacts on the project – the answers have been categorized, multiple answers were possible: 50% of the students did not observe any positive impact on the project. 13% stroke out the better inclusion of remote students within the project. 25% of the students mentioned that they experienced more time for working on tasks of the project on

their own. Additionally, it was mentioned that more team meetings were conducted, no more time for commute needed, virtual prototyping made easier and learning about online collaboration valued.

Negative impacts on the project – the answers have been categorized, multiple answers were possible: 33% of the students did not observe or mention any negative impact on the project. 21% of the students stated that they needed to invest more time due to bad communication. 17% experienced issues due to a less motivated team, the same amount experienced issues with prototyping and testing. Other things mentioned were the restricted use of the SLFI, cancelled workshops and the continued conduction despite COVID.

Biggest challenges throughout the project – the answers have been categorized, multiple answers were possible: 25% of the students saw prototyping as their biggest challenge. 17% of the students had issues to keep the motivation high, the same amounts saw the communication within the team as the biggest challenge, as well as the lack of personal/physical social meetings. Another 17% mentioned organisational structure (time management, keeping structured, effectiveness) as their biggest challenge and furthermore presentations and keeping overview of the different tools used were mentioned.

Table 1 Survey Analysis Summary

	Transition speed	Newsletter	Trello	Difficulty of switch	Final solution concept	Virtual workshops
Mean value	4,04	3,58	3,83	3,26	4,17	3,74
Minimum	2	1	1	1	2	1
Maximum	5	5	5	5	5	5

7 DISCUSSION AND CONCLUSION

This paper showed how a highly interactive course, due to its project-based learning character, needed to be transformed into virtual conduction because of COVID-19 pandemic. It underlies the measures taken in order to make the transition fast and effective as the first lockdown happened in a crucial phase of the project, where usually an increased demand for the supporting facilities is seen. The measures were developed within just one week and implemented within 2 weeks after the lockdown started. Transition speed was seen fast by the students but they would have wished for more transparency. The final solution system used, was well accepted by the students, despite its short development time. A helping fact was that most systems used were already familiar to some extend to the students as many were already used throughout the rest of the project. Additional measures to enable prototyping efforts by the students allowed them to finish their projects without major delay. Nevertheless, observations and a conducted survey showed some difficulties and challenges that the students needed to cope with and that need to be addressed in future online conductions. First insights in the analysis of the survey are discussed within this paper but further investigations need to be taken in order to analyze interdependencies between the student's academic background or with project details with the impact of online conduction. It has also not been analyzed yet how the structure of the team influenced the perception of the changes. Learnings described in this paper have been taken to adapt the online conduction of the course "Product Innovation" further. Due to the fact that physical conduction of lectures and courses stayed restricted throughout the academic year 2020/2021, PI had to be conducted mostly online again in 2020/2021 and a re-evaluation for the impacts of the adaptions is therefore planned.

Notice

The paper was presented at MOTSP 2021 – 12th International Conference Management of Technology – Step to Sustainable Production, which took place in Poreč/ Porenzo, Istria (Croatia), on September 8–10, 2021. The paper will not be published anywhere else.

8 REFERENCES

[1] Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, 102, 101586. https://doi.org/10.1016/j.ijer.2020.101586

[2] Carleton, T. & Leifer, L. (2009). Stanford's ME310 course as an evolution of engineering design. *Proceedings of the 19th CIRP Design Conference – Competitive Design*, 547-554.

[3] Tomko, M. E., Hilton, E., Forest, C. R., Talley, K. G., Smith, S., Nagel, R., & Linsey, J. (2017). Observations on Guiding Principles, or Best Practices, in University Makerspaces. *International Symposium on Academic Makerspaces*, Paper No.: 056.

[4] d.school, Hasso Plattner Institute of Design at Stanford, *An Introduction to Design Thinking – Process Guide* (accessed on 30.06.2021).

[5] Herstätter, P., Schnöll, H. P., & Ramsauer, C. (2019). Product Innovation Project: Experiences and Learnings from 13 Years of Making at Academic Makerspaces. *Proceedings of the International Symposium on Academic Makerspaces*, Paper No.: 06.

[6] OECD (2012). *Good Practices in Survey Design Step-by-Step, In Measuring Regulatory Performance: A Practitioner's Guide to Perception Surveys*, OECD Publishing, Paris.

[7] Johansen, R. (1988). *Groupware: Computer support for business teams*, New York: The Free Press.

[8] Andriessen, J. H. E. (2003). *Working with groupware. Understanding and Evaluation Collaboration Technology*, Springer. https://doi.org/10.1007/978-1-4471-0067-6

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Preliminary communication

Statistical Evaluation of Semi-Analytical, Analytical, and Numerical Models of the Serial Production Lines

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Abstract: Production lines are the backbone of the manufacturing industry. To gain the best profit out of a line it is necessary to design each line using the production system engineering. Therefore, three approaches can be used, the numerical, the analytical, and the semi-analytical approach. The aggregation method, finite state method, and the numerical approach are statistically compared concerning the analytical approach using the STATISTICA software. We analyzed the interaction between the input data and the output data for the finite state method in an illustrative example, using a full factorial design and the Design Expert software.

Keywords: analytical approach; Design Expert; production lines; production system engineering; STATISTICA

1 INTRODUCTION

The production industry has a big influence on the economic growth of a country, [1]. One job in the production industry generates five to seven jobs in the rest of the economy, [2]. To increase such benefits, it is important to take care of the production facilities, for example, the serial production lines, which are the backbone of the manufacturing industry.

The serial production line consists of machines and buffers which are placed in a line. Such lines can be short or long, depending on the product type. The amount of the required products determines the level of automatization. The combination of the machines and buffer capacities influences productivity. For this reason, designing such lines is getting more and more attention.

Therefore, two different approaches can be used, the heuristic approach and the systematic approach which is known as the production system engineering (PSE). The heuristic approach is based on trial-and-error experiments, which generate unpredictable results. The systematic approach was developed in the past five decades mainly in the automobile industry. The PSE is suitable for designing new production lines or improving existing ones, [3]. With such an approach the designer can predict the costs, the energy consumption, [4], or evaluate the impact of production on the environment, [5]. The PSE determines the key parameters of a production line, which can be used to identify bottlenecks or to achieve a leaner production line reducing the buffer capacities without losing the target performance, [6].

To calculate the key parameters the following three models can be used: the numerical, the semi-analytical and the analytical approach.

2 BRIEF LITERATURE REVIEW

In the Year 1962 Sevest`yanov published the analytical solution for a two-machine single buffer line in the steady-state response, [7] called the serial Bernoulli production line. For longer serial lines with more machines and buffers, this approach was not suitable except for a three-machine line under specific circumstances, [8].

To calculate longer production lines, semi-analytical methods were introduced, the decomposition method, the aggregation method, and the finite state method. The decomposition method was published 1986, [9]. Since then the algorithm was enhanced twice to gain higher efficiency, [10] and to be closer to the real production lines, [11]. The aggregation method was published 1990 based on an iterative solution, [12]. The aggregation method uses a series of forward and backward aggregations of the whole line into a single machine, until the convergence of results. The finite state method was developed recently based on the analytical approach valid for an arbitrary number of machines and buffers, [13]. This new analytical approach is based on the constitutive matrixes, which generate the transition matrix for the whole line. This approach is exact but very time-consuming and therefore the finite state method was developed, [14].

The numerical approach is a common way today but needs 1-3 months of preparations before some valuable results can be generated, [15]. Therefore, the designers must be well skilled and trained in the usage of the simulation software.

The aggregation method, finite state method, and numerical approach were never statistically compared by the analytical approach. Therefore, the data from the supplement of the paper [16] and the software STATISTICA will be used in this work to fill the gap. To get an overview of the interaction between the input data and the output data a design of experiment approach with the software Design Expert is used on an illustrative example.

3 THE KEY PARAMETERS

Here we provide a summary of the key parameters. More details can be found in the paper [16].

Bernoulli serial line consists of machines, buffers and conveyors which can be shown as circles, rectangles and arrows, Fig. 1.

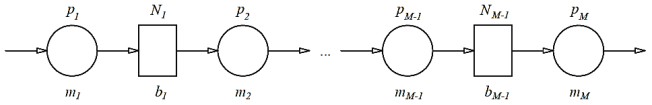

Figure 1 Bernoulli serial line, recreated according to [13]

Every approach calculates the key parameters production rate *PR*, the work-in-process, *WIP*, the probability of blockage, *BL*, and the probability of starvation, *ST*.

The production rate of the whole line, *PR*, is the intersection between the probability that the last machine is up and the probability that the previous buffer is not empty, therefore it is expressed as:

$$PR = P\left[\{\text{machine } m_M \text{ is up}\} \cap \{\text{buffer } N_{M-1} \text{ is not empty}\}\right]. \quad (1)$$

The work-in-process, WIP_i, describes the average number of semi-products in each buffer and can be defined with following expression:

$$WIP_i = \sum_{h_1=0}^{N_1} \sum_{h_2=0}^{N_2} \cdots \sum_{h_{M-1}=0}^{N_{M-1}} h_i P_{h_1 h_2 h_3 \cdots h_{M-1}}, \quad (2)$$

where h_i express the number of semi-products and $P_{h_1 h_2 h_3 \cdots h_{M-1}}$ the steady-state probability of the system. For the whole line, the work-in-process can be calculated as follows:

$$WIP = \sum_{i=1}^{M-1} WIP_i. \quad (3)$$

The probability of blockage for the penultimate machine, BL_{M-1}, is expressed by the following intersection of probabilities:

$$BL_{M-1} = P\left[\{m_{M-1} \text{ is up}\} \cap \{b_{M-1} \text{ is full}\} \cap \{m_M \text{ is down}\}\right]. \quad (4)$$

The probability of blockage for the previous machines, BL_i, can be defined with the following expression:

$$BL_i = P\left[\{m_i \text{ is up}\} \cap \{b_i \text{ is full}\} \cap \{m_{i+1} \text{ is down}\} \cup \cup \{m_i \text{ is up}\} \cap \{b_i \text{ is full}\} \cap \{b_{i+1} \text{ is blocked}\}\right]. \quad (5)$$

The probability of starvation of the i^{th} machine is the intersection between the probability that the buffer $i - 1$ is empty and that the probability of the machine i is up, therefore it is expressed as:

$$ST_i = P\left[\{b_{i-1} \text{ is empty}\} \cap \{m_i \text{ is up}\}\right], \; i = 2, 3, ..., M. \quad (6)$$

4 THE STATISTICAL COMPARISON

The main goal of this paper is to compare the different approaches and methods by using the test dependent sample approach. Therefore, the software tool STATISTICA will be used to compare the key parameters (*PR*, WIP_i, *WIP*, BL_i, and ST_i) of the aggregation method, finite state method, numerical approach with the key parameters of the analytical approach. Such comparison will be done for 12 lines in 4 cases with 3, 4, 5 and 6 machines. The data generated in [16] will be used. Longer production lines with more than 6 machines in a line are not considered because the CPU demand for the analytical approach is too high to get results in a reasonable time.

The 12 production lines for each case are getting out of 200 randomly generated production lines. To sample out the 12 lines, the performance measures by the analytical approach for each case will be the base for the application of the following criteria's, [16]:

Line 1: line with the smallest *PR*
Line 2: line with the largest *PR*
Line 3: line with the *PR* in between production rates of lines 1 and 2
Line 4: line with the smallest *WIP*
Line 5: line with the largest *WIP*
Line 6: line with the *WIP* in between the work-in-process of lines 4 and 5
Line 7: line with the smallest BL_{M-1}
Line 8: line with the largest BL_{M-1}
Line 9: line with the BL_{M-1} in between the probability of blockage of lines 7 and 8
Line 10: line with the smallest ST_M
Line 11: line with the largest ST_M
Line 12: line with the ST_M in between the probability of starvation of lines 10 and 11.

4.1 The Results

The statistical test (the differences in mean between dependent samples) approach using significance level of 1% to compare the key parameters of the aggregation method, the finite state method, the numerical approach with the analytical approach. The comparison of the key parameters in the case of a 3-machine line shows no significant differences according to the analytical approach. Except for the WIP_2 of the numerical approach is higher than the WIP_2 of the analytical approach. This deviation is still less than 5%. The comparison of the key parameters in the case of a 4-machine line shows no deviations for all key parameters. The comparison of the key parameters in the case of a 5-machine line shows no deviations in the major key parameters, except the following:

- The *PR* of the numerical approach is higher than the *PR* of the analytical approach.
- The BL_1 of the aggregation method shows significantly lower values than the BL_1 of the analytical approach.
- The BL_1 of the numerical approach shows significantly lower values than the BL_1 of the analytical approach.
- The BL_2 of the numerical approach shows significantly lower values than the BL_2 of the analytical approach.
- The ST_5 of the numerical approach shows significantly lower values than the ST_5 of the analytical approach.

The comparation of the key parameters in the case of a 6-machine line shows no deviations of all parameters except the BL_1 and ST_6. These parameters are in the numerical approach less than in the analytical approach but still in an error range of 5%.

In general, all methods generate the same results as the analytical approach, except the numerical approach for some parameters of longer lines. In such cases, the numerical approach generates smaller values for some parameters as the *BL* and the *ST*.

5 THE DESIGN OF EXPERIMENTS

To design an experiment there can be used a wide spectrum of techniques. The Trial and Error approach is maybe the oldest technique to solve experiments. This technique is not searching for the best solution to a problem, it is search for just a solution. Such a technique is useless when it is not allowed to make errors in the experiment. This Technique can be applied in a wide range, from mathematical to sociology experiments, [17].

The one factor at the time (OFAT) technique is not the best practice to analyses experiments but because of its simplicity, it is still in use. One factor is changing while the rest is fixed, if the measured output is better than before the next experiment will use this changed value and change another factor. Comparing to the factorial design, more runs are needed. Further, OFAT is not taking care of the interactions of factors or about the optimal settings of factors.

The 2^k full factorial design technique takes k factors at two levels, a high level, and a low level into consideration. This means if there are $k = 3$ factors, there will be $2 \times 2 \times 2 = 8$ experiments needed to discover all possible combinations. The goal of this technique is to discover the effect of each factor and their interactions on the response variable of the experiment. If the number of factors increases the number of experiments will exponentially increase, which makes the method suitable for up to 4 or 5 factors. Expectations can be done in computational experiments.

The fraction factorial design technique is widely used because the exponential disadvantage of the full factorial design is compensated by taking a fraction like 1/2, 1/4, etc. of the full factorial design. Such a technique is useful in the early stage of a project to define the main factors with the biggest impact. There are three main ideas on which this technique is based, [18]:

1) The system with several variables is driven by the main effects and low-order interactions.
2) It is possible to project the fractional factorial design into larger designs
3) It is possible to combine the runs of two (or more) fractional factorials to assemble sequentially a larger design.

The second main goal of this paper is an identification of the relation between the input data and the output data. Therefore, 2^k full factorial design approach with the software Design Expert is used on an illustrative example to identify the main effects and their interactions.

5.1 The Illustrative Example

The illustrative example is a plate prefabrication line, which is part of every shipyard. Such a line is built up by five machines, flattening, drying, blasting preserving and marking, Fig. 2. The machines are characterized by the operational probability p_i, where i is the number of the machine in the line. The plates are moving on a conveyor from machine to machine. The space between the machines defines the buffer capacity, N_j, where j is the number of the buffer in the line. In this example, we assume that there will be just one dimension of plates, which are passing through the production line. The prefabrication line is defined by 5 variable operational probabilities (p_1, p_2, p_3, p_4, p_5) and 4 variable buffer capacities (N_1, N_2, N_3, N_4). These 9 factors generate 14 output key parameters, the production rate *PR*, the work in process WIP_1, WIP_2, WIP_3, WIP_4, *WIP*, the blockade BL_1, BL_2, BL_3, BL_4, and the starvation ST_2, ST_3, ST_4, ST_5.

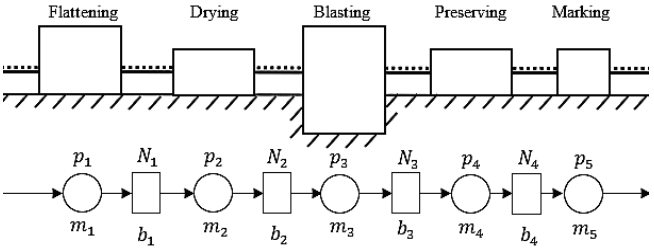

Figure 2 Plate prefabrication line and mathematical model, recreated according to [13]

The full factorial design of experiment is taken these 9 factors into consideration. Each factor has two levels, a high level and a low level, see Tab. 1. Therefore, $2^9 = 512$ experiments will be needed to discover all possible combinations.

Table 1 Input data for the full factorial design experiment

	$p_{1\text{-}5}$	$N_{1\text{-}4}$
low level	0.6	1
high level	0.9	5

To generate such an amount of experiments we decided to use the fast finite state method as the statistical comparison shows that it generates very similar key parameters within an Error-range of 1%, according to the analytical approach.

5.2 The Results

The full factorial design of experiments is run by the software Design Experts. Analyzing each key parameter in correlation with the factors, we get plots that visualize the trend of changing. Fig. 3 illustrates the trend of changing of the key parameter production rate, *PR*, by changing each factor according to Tab. 1. The results of the largest two main effects are listed in Tab. 2. Each key parameter will on average increase or decrease depending by the largest two main effects.

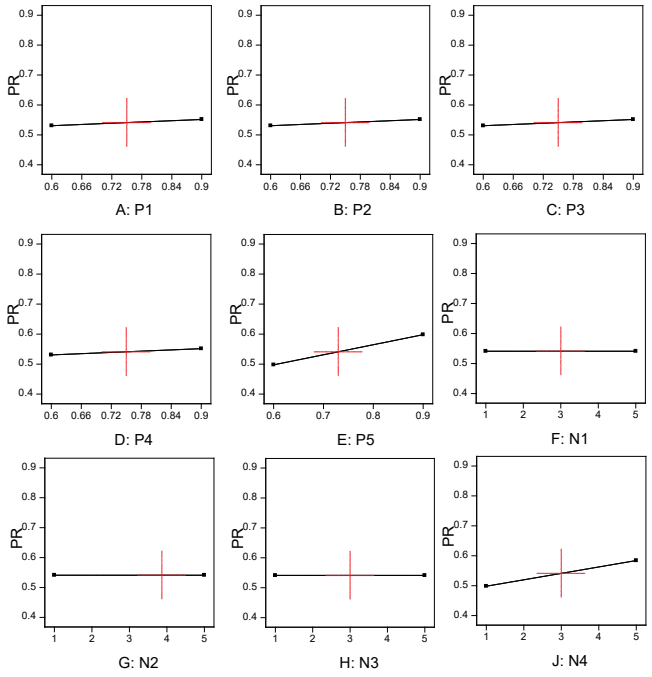

Figure 3 Effects related to the production rate

Table 2 Largest main effects according to the output parameters

Output key parameters	Largest main effects		
PR	N_4	0.10	pc/cycle time
	p_5	0.08	
WIP_1	N_1	2.44	pc
	p_1	1.58	
WIP_2	N_2	1.74	pc
	p_3	–0.84	
WIP_3	N_3	1.40	pc
	p_4	–0.96	
WIP_4	N_4	1.24	pc
	p_5	–1.02	
WIP	N_1	2.44	pc
	p_1	2.84	
BL_1	N_1	–0.08	probability
	p_1	0.28	
BL_2	N_2	–0.12	probability
	p_2	0.15	
BL_3	N_3	–0.12	probability
	p_4	–0.11	
BL_4	N_4	–0.10	probability
	p_5	–0.12	
ST_2	p_1	–0.19	probability
	p_2	0.11	
ST_3	p_3	0.16	probability
	p_2	–0.09	
	p_1	–0.09	
ST_4	N_3	–0.08	probability
	p_4	0.19	
ST_5	N_4	–0.08	probability
	p_5	0.20	

The production rate mainly depends on the last buffer and machine in the line. When the buffer capacity N_4 is increasing from 1 to 5, the production rate, PR, will increase on average 0.1 pieces per cycle time. The change of the operational probability of the fifth machine, p_5, from 0.6 to 0.9 will result that the PR increase on average 0.08 pieces per cycle time. The work in process, WIP_j, depends on the capacity N_j of the j^{th} buffers in the production line. If the capacity increase on average from 1 to 5 the WIP_j will increase between 1.4 pieces and 2.44 pieces. The work in process all, WIP, mainly depends on the buffer capacity N_4 and on the operational probability of the first machine, p_1. Among the probability of blockade factors, the BL_1 has the biggest main effect. When the operational probability of the first machine, p_1, is changing from 0.6 to 0.9 the key parameter BL_1 will on average increase by 0.28. The probability of starvation of the third machine, ST_3, has three dominant main effects. The biggest change is caused by the increase of the operational probability of the fifth machine, p_5.

6 CONCLUSION

The statistical comparison shows that the numerical approach generates some higher values than the analytical approach, but the results are still good enough. The aggregation method and the finite state method are very accurate according to the analytical approach.

The design of experiment shows the interaction between the key parameters and the input parameters (factors). Analyzing the data, we can conclude that if we want to increase the production rate of the production line in the illustrative example, that increasing the buffer capacity N_4 and the operational probability of the fifth machine, p_5 will be the best choice. Further researches could be to run a Central Composite Face (CCF) centered design technique with three levels, which would better approximate the changing of the output key parameters. In this case, the user could change the factors within the range of the model and simulate different scenarios of the production line.

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7 REFERENCES

[1] Kurfess, T. (2013). Why Manufacturing Matters. *Mechanical Engineering, 135*(11), 32-35. https://doi.org/10.1115/1.2013-NOV-1

[2] Bivens, J. (2019). *Updated employment multipliers for the U.S. economy*. Economic Policy Institute, Washington DC.

[3] Wang, Z. & Gershwin, S. B. (2015) Heuristic production and sale policy for a two-product-type manufacturing system with

downward substitution. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 929-942. https://doi.org/10.1109/TSMC.2014.2371876

[4] Jia, Z., Zhang L., Arinez, J., & Xiao, G. (2016). Performance analysis for serial production lines with Bernoulli Machines and Real-time WIP-based Machine switch-on/off control. *International Journal of Production Research, 54*(21), 6285-6301. https://doi.org/10.1080/00207543.2016.1197438

[5] Zhou, W., Wang, J., & Zhu, X. (2019). Research on Environmental Assessment Model of Shipyard Workshop Based on Green Manufacturing. *Journal of Coastal Research*, 16-20. https://doi.org/10.2112/SI94-004.1

[6] Hadžić, N., Ložar, V., Opetuk, T., & Andrić, J. (2021). A Finite State Method in improvement and design of lean Bernoulli serial production lines. *Computers & Industrial Engineering, 159*, 107449. https://doi.org/10.1016/j.cie.2021.107449

[7] Sevast'yanov, B. A. (1962). Influence of Storage Bi Capacity on the Average Standstill Time of Production Line. *Theory of Probability Applications*, 429-438. https://doi.org/10.1137/1107040

[8] Li, J. & Meerkov, S. M. (2009). *Production System Engineering*, Springer, New York. https://doi.org/10.1007/978-0-387-75579-3

[9] Gershwin, S. B. (1986). An efficient decomposition method for the approximate evaluation of tandem queues with finite storage space and blocking. *Operation Research, 35*(2), 291-305. https://doi.org/10.1287/opre.35.2.291

[10] Dallery, Y., David, R., & Xie, X. L. (1988). An efficient algorithm for analysis of transfer lines with unreliable machines and finite buffers. IIE Transactions, 20(3), 280-283, https://doi.org/10.1080/07408178808966181

[11] Dallery, Y. & Bihan, H. L E. (1999). An improved decomposition method for the analysis of production lines with unreliable machines and finite buffers. International Journal of Production Research, 37:5, 1093-1117 https://doi.org/10.1080/002075499191427

[12] Lim, J.-T., Meerkov, S., & Top, F. (1990). Homogeneous asymptotically reliable serial production lines: Theory and a case study. *IEEE Trans. Autom. Control., 35*(5), 524-534. https://doi.org/10.1109/9.53518

[13] Hadžić, N. (2019). Analytical solution of the serial Bernoulli production line steady-state performance and its application in the shipbuilding process. International Journal of Production Research 57(4), 1052-1065. https://doi.org/10.1080/00207543.2018.1500042

[14] Hadžić, N., Ložar, V., & Abdulaj, F. (2020). A Finite State Method in the performance evaluation of the Bernoulli serial production lines. *Applied sciences, 10*(18), 6602. https://doi.org/10.3390/app10186602

[15] Václav, Š. & Lecký, Š. (2017). Impact of computer-aided assembly technologies and simulation. International Scientific Journal "INDUSTRY 4.0", II(1), 9-12.

[16] Ložar, V., Hadžić, N., Opetuk, T., & Slapničar, V. (2021). Accuracy evaluation of the semi-analytical and numerical methods in the production engineering, *Mathematics,* 9(13), 1461. https://doi.org/10.3390/math9131461

[17] Cowles, H. M. (2015). Hypothesis Bound: Trial and Error in the Nineteenth Century. *Isis, 106*(3), 635-645. https://doi.org/10.1086/683528

[18] Montgomery, D. C. (2001). *Design and analysis of experiments*. 5th ed. New York: John Wiley.

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Subject review

Corporate Responsibility in the Context of Digitalization

Patricia Girrbach

Abstract: Corporate Responsibility focuses on economic performance, the protection of the natural foundations of life and social responsibility. In this context it is important to deal carefully with the limited resources available to take care of inter- and intragenerational justice by preserving the resource base. Due to the fact, that digitalization changes whole industry, a change in detail a more holistic view on responsibility is necessary. Corporate Responsibility must be enhanced to Corporate Digital Responsibility in terms of digital aspects. In this context this paper provides insights into Corporate Digital Responsibility from the perspective of blockchain usage in supply chain management.

Keywords: blockchain technology; Corporate Digital Responsibility; resource efficiency in a broader sense

1 INTRODUCTION

It is well-known that the term digitization refers to the transfer of any kind of information from a conventional old fashioned analogue kind of storage to a digital one [1, 2]. Consequently, information is nowadays available converted digitally as zeros and ones such as in the case of digital photos. Beside that the term digitization addresses also that tasks taken over by human craft in former times nowadays are carried out by computers which fulfills these tasks even more efficient than any human ever could. Hereby, digitization is the prerequisite for any kind of digitalization which can also be interpreted as automation which is based on information technologies [1, 2]. In this context new technologies enable not only a new level of production and a total transformation of processes along the entire value chain but also a new level of consumption in general. These new technologies include well-known and often used technologies such as Internet of Things, Cloud based Manufacturing, Cyber Physical Systems or also Information and Communications Technology which are essential for nowadays industry [1, 2]. Thus, these new technologies are important starting points for industry 4.0 paving the way to a new level of production initiating a new technological age which transforms production processes all over the world and whole value chains in an incremental way. In this context Corporate Digital Responsibility comes into play [1, 10]. If there is a change of whole industries, it is a necessity that companies rethink previous old fashioned organizational concepts. Therefore, this paper provides insights into Corporate Digital Responsibility from the perspective of blockchain usage in supply chain management (Fig. 1).

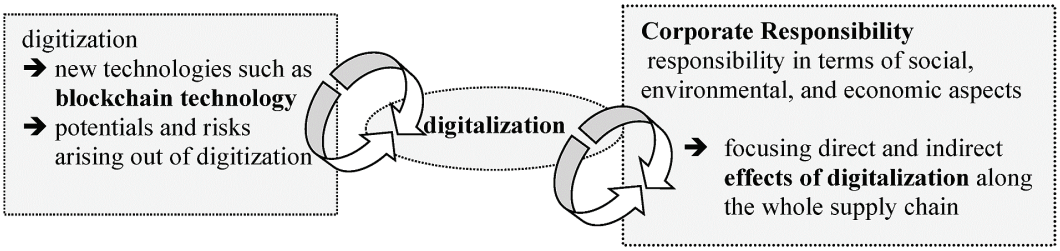

Figure 1 Corporate Responsibility in the context of digitalization (own figure)

2 CORPORATE DIGITAL RESPONSIBILITY

The term Corporate Responsibility operationalizes the company's assumption of responsibility for the effects of its decisions and activities in terms of society on the one hand as well as on the environment on the other hand [3]. Hereby, it is important to focus on sustainable development serving as vision guiding organisational behaviour in a long-term view. In this context sustainable development is a development that meets the needs of the present taking care that generations in the future will also be able to meet their own needs [1]. Therefore, Corporate Responsibility is based on the three pillars of sustainability, including in detail economy, environment, and society [1, 4]. Consequently, sustainable corporate management combines economic performance, social responsibility and finally the protection of the natural foundations of life [4]. Accordingly, it is important to take care of the limited resources available and not to live at the expense of people from other regions of the world or future generations [3]. Only then companies can promote inter- and intra-generational justice by maintaining the resource base not only for todays but also for further generations [3]. So, we can state that Corporate Responsibility as a holistic concept operationalizes the company's responsibility for the impact of its decisions and activities on society and the environment in a holistic view [3, 4]. Thus, Corporate Responsibility must be implemented in the organization processes along the entire supply chain

also affecting suppliers, partners, and customers. Therefore, a vertically and horizontally implementation is needed [5]. There are three organizational layers, Corporate Responsibility must be anchored [6]. At the normative long-term level, the principle of sustainability must be anchored as a starting point and as a vision guiding companies in such a way that they meet the needs of customers and today's society without endangering future generations to meet their own needs and choose the lifestyle they want. For this reason, sustainable strategies for production must be implemented at the strategic medium-term level. In this context sustainability strategies come into play such as consistency, sufficiency, or efficiency strategy. Starting points for fulfilling these strategies are at the operational level e.g., all measures for a more efficient supply chain management to reduce the ecological footprint or emissions and to achieve time and cost reductions. This refers directly to ecological and economic issues and indirectly to social aspects. For sustainable value creation, it is important to take a holistic view of the value chain and to look at suppliers as well as customers. The aim is to bear economic, social, and ecological responsibility for the total consequences of organizational activities along the entire supply chain. Hereby organizational responsibility goes far beyond the legal requirements for the sake of a more holistic view of responsibility [4]. This is caused in the reason that especially in the context of digitalization responsibility must be expanded. Due to that companies are responsible also for the use and consequences of new technologies arising out of digitization along the entire value chain [5, 7]. Moreover, they should use the possibilities arising out of new technologies to reach sustainable objectives since digitalization is renewing the way companies can create value. The future perspective of the digital value chain includes leaner production that meets requirements for an efficient resource-saving economy [1, 8]. Hereby, information is used on the one hand to focus and reduce material and energy flows and on the other hand to avoid rejects, material waste as well as overproduction. Consequently, processes become more efficient through digitalization as important part of Corporate Digital Responsibility (Fig. 2).

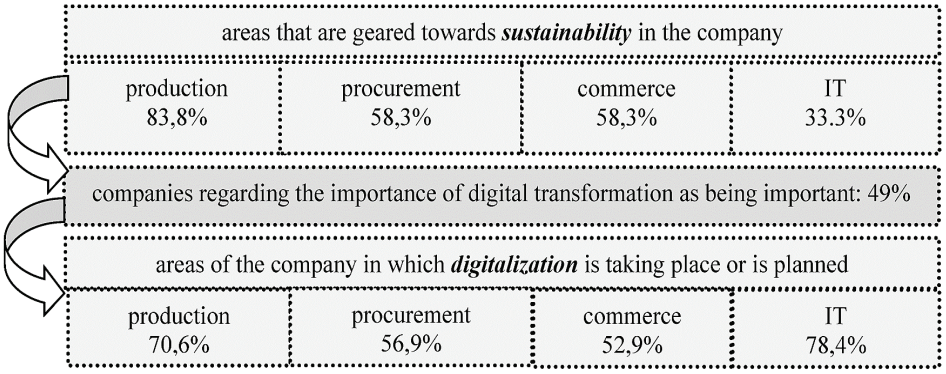

Figure 2 Responsibility and digitalization (translated based on 8)

To remain competitive, companies must take advantage of the opportunities created in the context of industry 4.0 to achieve and enhance various strategic competitive advantages [1, 9, 10]. In this regard, the future success of a company will increasingly depend on implementing digitized processes along the entire supply chain for the sake of efficiency. In this context digitalization relates to responsibility goals such as ecological, economic but also social aspects within the framework of Corporate Responsibility so efficient supply chain management is needed. Moreover, it is important not to focus only reducing costs but also mitigating risks on the other side. Digitalization enables significant improvements due to automated processes and real-time information. Moreover, digitalization permits optimized energy efficiency. Improved energy efficiency is important for sustainable management in terms of the ecological and social responsibility of companies [14]. To minimize the ecological footprint of an organization, a continuous improvement in efficiency is recommended, especially regarding energy requirements [13]. In this context companies must determine first how high the actual energy consumption in detail is and in which areas it is particularly high. This investigation serves as a starting point for improvements and specific measurements. Afterwards due to always limited organizational resources (manpower, time, money) the company must select and decide at which point in the value chain an efficiency improvement using new technologies is most promising.

As mentioned before Corporate Digital Responsibility is based on the concept of sustainability by assuming responsibility for economic, social, and ecological as well as digital aspects focusing on the chances for sustainable issues arising out of digitalization [1, 10]. This implies that Corporate Responsibility is expanded to Corporate Digital Responsibility in the context of digitalization. Thus, Corporate Digital Responsibility includes more comprehensive corporate responsibility in an increasingly digitalized economy and society [1, 10, 11]. In the context of digitalization organizational activities do not only focus on legal requirements but try to shape the digital world for the benefits of society and for the sake of sustainability in a more holistic and enhanced view. External effects of digital corporate activities can arise in the areas of the environment as well as labor, human rights, and other aspects such as social issues [1]. Therefore, Corporate Digital Responsibility focuses not only on social, economic, and ecological effects

of digital corporate activities along the entire supply chain but also seizes any kind of opportunities that arise for sustainable goals in the context of digitalization [10, 12] (Fig. 3). In this context sustainable goals contain any kind of value creation for companies or any stakeholder group, e.g., customers [1]. The creation of value can address economic, environmental, and social aspects. It can be sate that any technology that contributes to the well-being of people, the protection of the planet or increased profit can be considered as value-adding. Hereby, sustainability and its three dimensions serve as indicator if value is created. The social dimension focuses on people including not only employees but also external stakeholders such as customers, suppliers, or the society in general. Concerning the economic dimension new technologies should reduce costs by saving materials, time, or energy. Obviously, due to the reduction of energy and material this influences the ecological dimension in a positive way, too [1]. Advantages concerning the social dimension include improved well-being or better situations for stakeholders due to saving time or human effort. Environmental objectives focus on the protection of natural resources and the maintenance of the planet in general. This addresses the intra- and intergenerational equity. This is caused in the reason that currently climate change is one of the most pressing environmental issues. It is well known that we are using too many resources. Our ecological footprint increases. In this context the ecological footprint is a criterion for human demand for natural capital that compares on the one hand how much bio capacity is used by human activities and on the other hand how much bio capacity is available on a sustainable basis [21]. Consequently, it can be regarded as one criterion for environmental sustainability. Obviously, one important starting point for reducing our ecological debt is for example using less materials and energy in logistical processes.

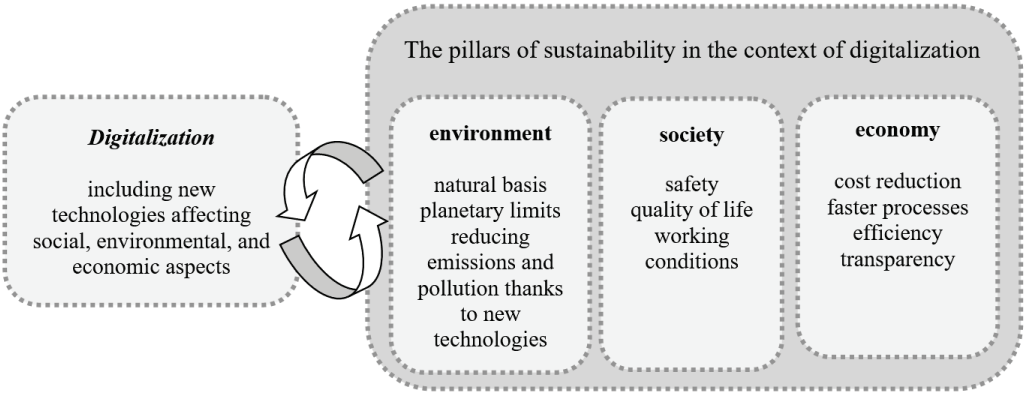

Figure 3 Responsibility in the age of digitalization (own figure based on [1])

To prove if sustainable objectives are reached the concept of resource efficiency in a broader sense is useful that can also be adapted to logistical processes [22]. Resource efficiency in the broader sense is based on the concept of resource efficiency including the number of resources contained in a product in relation to the resources required for its manufacturing or transportation and in consequence, resource efficiency can be raised by using fewer resources, e.g., in logistical processes. To concretize resource efficiency in a broader sense, resources should be differentiated. Sustainability focuses normally on resources in a more specific kind of view including only energy and material. The concept of resource efficiency in a broader sense enhances this view. In this context resources also contain e.g., time, capital, and human effort. It could be increased by a positive reducing effect on the required input factors. This refers in terms of economic aspects a reduction of time or costs, concerning environmental issues a decrease of materials, energy and waste and concerning social aspects a reduction of time or human effort (Fig. 4).

In terms of digitalization the author enhances the well-known concept of resource efficiency in a broader sense to resource efficiency 4.0 for pointing out chances as well as risks raising out of digitalization due to new technologies. Moreover, the concept is enhanced to further input and output factors which become relevant in the context of digitalization such as increased trust through documented transparency in terms of social (e.g., the protection of privacy, working conditions) and environmental (e.g., ecological footprint) aspects of a product or service. In terms of the output this contributes to the sustainability-orientation of products and services as important value-adding element for customers. Hereby, resource efficiency 4.0 doesn´t aim bringing out exact figures because this is impossible since various direct and indirect influences and interdependencies exist in the process of manufacturing. Rather resource efficiency 4.0 aims to deliver an awareness of the impact of new technologies in terms of further aspects using resource efficiency as a well-established basis term that companies are used to handle. This is important since many companies are often not aware of the fact that they can influence not only environmental aspects, but also further social aspects such as the privacy or safety (better working conditions) of people by using new technologies. Therefore, companies should pay attention to all advantages of new technologies by focusing further input factors, including not only saving time, capital, emissions, or materials, but also the option of averting exploitation of people and environment due to more transparency along the entire manufacturing process (Fig. 4).

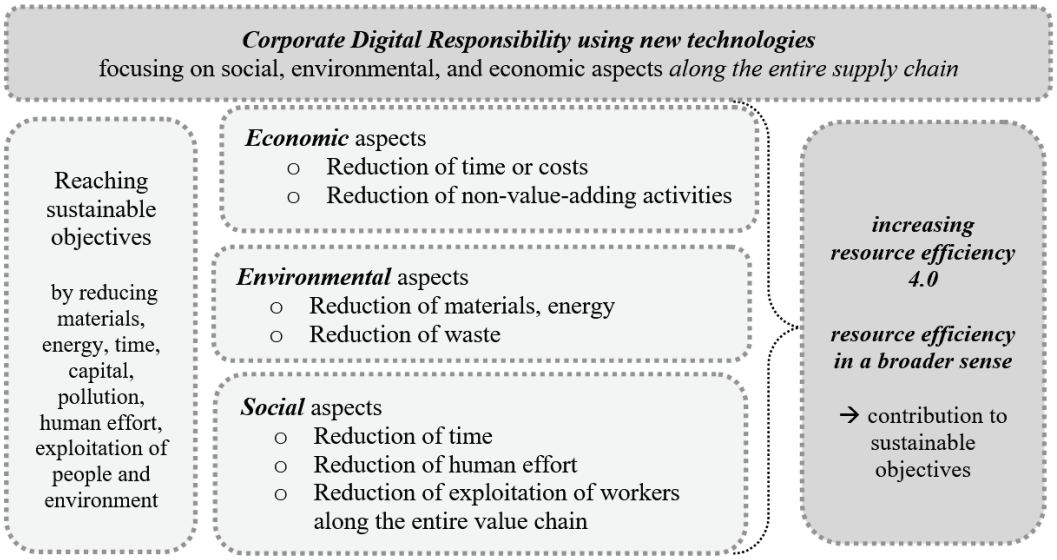

Figure 4 Reaching sustainable objectives by increasing resource efficiency 4.0 (own figure)

Therefore, based on the concept of resource efficiency 4.0 Corporate Digital Responsibility can contribute to sustainable objectives using digitalization [1, 8, 13]. In this context especially logistic processes offer a high potential for increasing resource efficiency along the entire supply chain focusing on ecological, economic, and social aspects. Figure 4 shows possible advantages arising out of new technologies. In the following it will be shown that blockchain technology has the potential to optimize not only energy management processes in almost all stages of the value chain but also to contribute to economic, environmental, and social objectives based on a sustainable supply chain management.

3 THE CONTRIBUTION OF BLOCKCHAIN TO RESOURCE EFFICIENCY 4.0

Sustainable-oriented companies taking responsibility for ecological and social issues are challenged to create transparency and traceability for the end customer along the entire supply chain [16]. This is caused in the reason that transparency and resulting trust are the basis of economic cooperation in all stages of the entire value chain. In this context on the one side companies and retailers must trust suppliers delivering the guaranteed quality produced in accordance with specific quality standards in terms of working conditions or environmental issues and on the other side consumers must trust that the promised quality in terms of sustainable aspects have been adhered to at all processes and stages of the value chain. Hereby, Corporate Responsibility requires a credible proof of ethically correct economic activity in terms of materials or production methods based on transparency due to permanent available detailed documentation along the entire process [16]. In this context blockchain technology (BC) comes into play which creates trust by a complete and non-changeable history of transactions [16, 17, 19]. Normally there is a need to check the authenticity of a document, a banknote, a contract or a product by banks, notaries, or lawyers. There are also numerous wholesalers, retailers, and online shops along the supply chain as well as the mentioned authentication instances increasing the final price for customers. Moreover, inefficient transportation processes cause emissions and pollution along the whole supply chain. Beside those aspects deliveries are often too late or the security in terms of data exchange or transparency in terms of the delivery is not given. Furthermore, there is no guarantee that products and services have been produced in a socially acceptable and environmentally friendly manner as promised.

In this context blockchain offers many chances in terms of sustainable goals such as economic, social, and environmental aspects since blockchain technology creates a totally new quality of any kind of transactions [17, 19]. In simplified terms, blockchains can be described as distributed databases organized by the participants in the network [15, 16, 17]. First, every transaction (e.g., loading of goods), is generated by a sender, and digitally signed. This transaction is distributed to the participants (so-called nodes). The nodes of the network check the validity of the transaction and try to find a consensus. Relevant consensus models are Proof of Work, Proof of Stake and Proof of Authority (authentication nodes). Verified transactions are stored in a block using hash functions which represents transactions uniquely [16, 17]. A block contains the transaction data such as time stamp, digital fingerprint, and data from the previous blocks. This coding is secure against manipulation. Blocks are linked to the existing blocks by chaining, so that a chain is created. Since blockchain uses distributed ledger technology thus data is stored on each node [15, 16, 17]. Changes to the database are not possible due to the large number of copies. This makes blockchain a secure booking system for any form of digital property rights that no longer needs a central authority (e.g., notary or bank) caused in the reason that every raw material, and process step, as well as every transport and transaction can be stored in a tamper-proof manner [16]. This ensures transparency along the entire value chain for all stakeholders (partners, customers, and suppliers). Hereby smart contracts

as part of the blockchain technology carry out transactions automatically as soon as a transaction has taken place (e.g., receipt of money due to the payment of a customer) [15, 16, 17]. Consequently, blockchain creates transparency and trust with increased security against fraudulent manipulation.

The following practical example shows how well the blockchain technology works regarding sustainable goals increasing resource efficiency in a broader sense. IBM and Maersk (shipping company) started a pilot project whereby containers were shipped to Hamburg from abroad replacing all necessary papers by blockchain [18]. According to Maersk, at least 200 or more individual operations must be issued per container in former times. That means that without blockchain at least 30 office workers are employed, and hundreds of documents must be printed for each container. Concerning transportation often inefficient processes take place due to the reason of inefficient route planning or traffic jam. In that context IBM and MAERSK aim to increase efficiency in terms of processes, materials (paperless processes), and transportation using blockchain taking over the role of the digital delivery note in the supply chain available for all participants. Inventory control, warehouse processing, and object tracking based on RFID-chips is possible in real-time.

Thanks to location data, smart contracts introduce following activities autonomously, e.g., when the required goods reach the port, the container is automatically unloaded and afterwards loaded onto the truck [15, 16, 17]. Based on new technologies (embedded systems, internet of things), vehicles are advancing into self-communicating units taking on driving tasks or automatically adapting routes (e.g., based on traffic jam information). In this context helpful methods such as predictive analytics are used optimizing route planning for all vehicles. Hereby, blockchain enables complete transparency and permanent documentation of all transactions along the entire supply chain [15, 16, 17].

This practical example shows, that due to blockchain all necessary papers have been replaced by blockchain technology [18]. This leads on the one hand to paperless digitized documents (better data handling), automated contract execution possible due to smart contracts and on the other hand to faster and error-free processes) [15, 16, 17]. Decentralized authentication saves a lot of time and money while increasing security against fraudulent manipulation. There are low contract, enforcement and monitoring costs compared to regular contracts. Increased transparency is achieved through real-time information relating to goods and participating actors. Thanks to blockchain MAERSK deliveries are safer, cheaper, faster, and eco-friendly since materials (paper) as well as emissions (transport) can be reduced through digitalized, optimized processes. Moreover, it contributes to social aspect of sustainability since transactions are safer for everyone involved. Additionally, the service quality for customer increases (Fig. 5).

Concerning the blockchain technology in general participants are in direct contact and have direct access to digitized documents [15, 16, 17]. Results are, intermediaries are left out, transaction costs fall, and processes become more efficient. Blockchain ensures security since it enables detailed access control. In addition, it is tamper-proof thanks to cryptography. The decentralized structure enables permanent data storage in the entire network for the sake of data backup. The blockchain technology contributes to sustainable objectives in several ways: Automatous processes along the whole supply chain containing digitalized documents are established [15, 16, 17]. The supply chain is logistically optimized (e.g., automatic determination of the best route using real-time data). Besides that, transactions with suppliers, partners and customers are simplified, improved, and automated. Processes are faster, cheaper, error-free, optimized with increased service quality and security (benefits for partners and customers). Stakeholders save time and money. In terms of ecological goals, blockchain reduces the ecological footprint through optimized transport, reduced emissions, and paperless processes. The following figure shows some of the positive effects of the blockchain technology on sustainable objectives (Fig. 5).

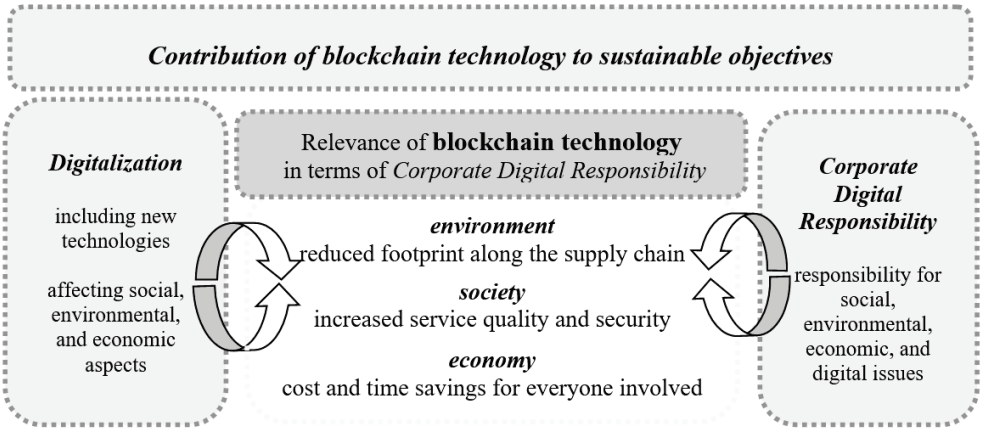

Figure 5 Blockchain and its positive effects on sustainable objective (own figure)

Another important advantage concerning social issues is that participants are in direct contact and have direct access to digitized documents and party-specific information is possible [16]. In this context blockchain technology enables manufacturers to oblige their suppliers to document production steps with images and text. Customers can then,

for example, call up the entire value creation of a particular product on a product detail view. Thus, companies can offer their customers more transparency by making the entire value chain and the ecological footprint visible in online stores. Especially in terms of sustainable aspects it is important that the composition of products or the production process (e.g., working conditions) can be retrieved from the blockchain. Customers who value sustainable production thus gain more security through traceability. Consequently, blockchain creates transparency and trust due to increased security against fraudulent manipulation by creating a complete and non-changeable history of transactions [16, 17]. In summary, blockchain enables cost and time savings for everyone involved (economy) as well as a reduction in the ecological footprint (ecology). Moreover, it enhances service quality, creates trust and transparency concerning working conditions and can consequently reduce the exploitation of workers (social) along the entire supply chain [16]. So, Corporate Digital Responsibility can make a significant contribution enhancing resource efficiency 4,0 using new technologies such as blockchain [1, 2, 20] (Fig. 6 and 7).

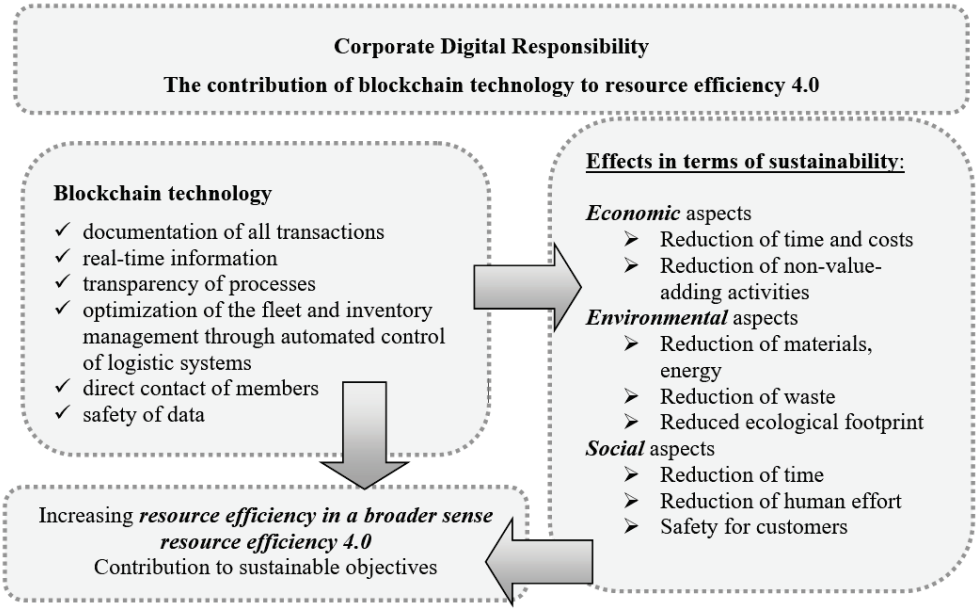

Figure 6 Relevance of blockchain technology in terms of Resource efficiency 4.0 [own figure]

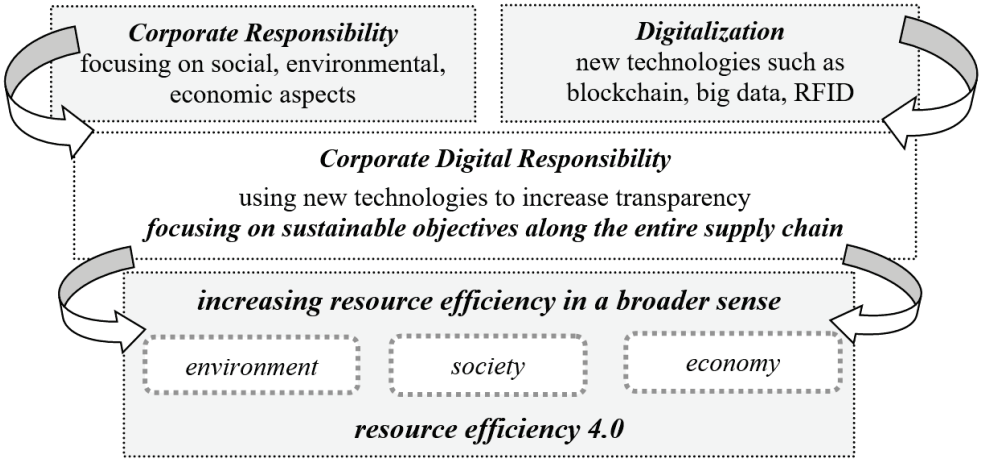

Figure 7 Corporate Digital Responsibility as a starting point for enhancing resource efficiency 4.0 [own figure]

4 CONCLUSION

This paper provides insights into Corporate Digital Responsibility from the perspective of blockchain usage in supply chain management using the concept of resource efficiency in a broader sense, in detail resource efficiency 4.0 as starting point. Regarding Corporate Digital Responsibility, digitalization, especially blockchain, offers social as well as ecological and economic potential benefits that companies should take advantage of. Only then can responsibility-oriented companies meet their responsibility regarding ecological, economic, and social aspects in the digital age, e.g., by offering customers more security, protection, and cost savings regarding goods received, but also by reducing the organizational ecological footprint along the entire supply chain. Therefore, the blockchain technology

fulfills current requirements for contemporary sustainable corporate management and process control along the entire supply chain as part of Supply Chain Management 4.0 [16]. This is caused in the reason that blockchain technology creates a new quality of transactions contributing to the concept of resource efficiency 4.0 in a significant way.

Notice

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5 REFERENCES

[1] Dörr, S. (2020). Praxisleitfaden Corporate Digital Responsibility: Unternehmerische Verantwortung und Nachhaltigkeitsmanagement im Digitalzeitalter, Springer, Berlin. (in German) https://doi.org/10.1007/978-3-662-60592-9

[2] Neugebauer, R. (2018). *Digitalisierung: Schlüsseltechnologien für Wirtschaft & Gesellschaft*, Springer, München. (in German) https://doi.org/10.1007/978-3-662-55890-4

[3] Müller-Christ, G. & Giesenbauer, B. (2019). Integrales Ressourcenmanagement. Leitplanken einer nachhaltigkeits-bezogenen Möglichkeitswissenschaft. In: Hochmann, L. et al., *Möglichkeitswissenschaften. Ökonomie mit Möglichkeitssinn*, 307-332. (in German)

[4] Kreipl, C. (2020). *Verantwortungsvolle Unternehmens-führung: Corporate Governance, Compliance Management und Corporate Social Responsibility*, Springer, Wiesbaden. (in German) https://doi.org/10.1007/978-3-658-28140-3

[5] Müller-Christ, G. (2020). Eine systemische Erzählung über die Integration von Nachhaltigkeit in unternehmerische Entscheidungen. In: Butzer-Strothmann, K., Ahler, F. *Integrierte nachhaltige Unternehmensführung. Konzepte – Praxisbeispiele – Perspektiven*, 27-48. https://doi.org/10.1007/978-3-662-61168-5_3

[6] Kaminski-Nissen, M. (2020). *Die SDGs: Leitplanken, Ideengeber und Werkzeug für mehr gelebte Nachhaltigkeit in Unternehmen*, www.baumev.de/News/9127/Sustainable DevelopementGoalsSDGs.html, 10-01-2020 (in German)

[7] Knaut, A. (2017). Corporate Social Responsibility verpasst die Digitalisierung. In: Hildebrandt A., Landhäußer, W.: *CSR und Digitalisierung*, 51-59. (in German) https://doi.org/10.1007/978-3-662-53202-7_3

[8] Ilg-Müller, C. (2019). Transformation im Mittelstand - Digitalisierung als Handlungsfeld nachhaltiger Unternehmensführung. *Ökologisches Wirtschaften, 34*. (in German) https://doi.org/10.14512/OEW340342

[9] Hasselbalch, G. & Tranberg, P. (2017). Datenethik: Eine neue Geschäftsethik entwickeln. *Die Ethik der digitalen Zeit*, 186-196. (in German)

[10] Esselmann, F. & Brink, A. (2016). Corporate Digital Responsibility: Den digitalen Wandel von Unternehmen und Gesellschaft erfolgreich gestalten. *Spektrum, 12*, 38-41. (in German)

[11] Hildebrandt, A. & Landhäußer, W. (2017) (eds) *CSR und Digitalisierung. Management-Reihe Corporate Social Responsibility*. Springer Gabler, Berlin, Heidelberg. (in German) https://doi.org/10.1007/978-3-662-53202-7_3

[12] Thorun, C. et al. (2018). Ethik in der Digitalisierung - Der Bedarf für eine Corporate Digital Responsibility. *WISO direkt*. Friedrich-Ebert-Stiftung, Bonn, http://library. fes.de/pdf-fles/wiso/14691.pdf (Accessed on 01-02-2018) (in German)

[13] Dürr, H. (2016) Corporate Social Responsibility und Energiewende. In: Hildebrandt, A., Landhäußer, W. (eds) *CSR und Energiewirtschaft. Management-Reihe Corporate Social Responsibility*. Springer Gabler, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-46583-7_20 (in German)

[14] Hellmann, K. U., Nehm, F., & Grimm, O. (2017) Digitalisierung, Energieeffizienz und Corporate Social Responsibility. In: Hildebrandt, A., Landhäußer, W. (eds) *CSR und Digitalisierung. Management-Reihe Corporate Social Responsibility*. Springer Gabler, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-53202-7_18 (in German)

[15] Schütte, J. et al. (2017). Blockchain und smart contracts, https://www.fraunhofer.de/content/dam/zv/de/forschung/artikel/2017/Fraunhofer-Positionspapier_Blockchain-und-Smart-Contracts_v151.pdf. (in German) (Accessed on 03-11-2018).

[16] Düring, T. & Fisbeck, H. (2017) Einsatz der Blockchain-Technologie für eine transparente Wertschöpfungskette. In: Hildebrandt A., Landhäußer W. (eds) *CSR und Digitalisierung. Management-Reihe Corporate Social Responsibility*. Springer Gabler, Berlin, Heidelberg. (in German) https://doi.org/10.1007/978-3-662-53202-7_33

[17] Neugebauer, R. (2018). *Digitalisierung Schlüsseltechnologien für Wirtschaft und Gesellschaft*, Springer, Berlin. (in German) https://doi.org/10.1007/978-3-662-55890-4

[18] IBM (2018). Supply Chain: Digitizing Global Trade with Maersk and IBM, https://www.ibm.com/blogs/blockchain/2018/01/digitizing-global-trade-maersk-ibm/ (Accessed on 01-06-2021)

[19] Adam, K. (2020). *Blockchain-Technologie für Unternehmens-prozesse: Sinnvolle Anwendung der neuen Technologie in Unternehmen*. Springer, Berlin. (in German) https://doi.org/10.1007/978-3-662-60719-0

[20] Federal Ministry of Justice and Consumer Protection (2019). Blockchain-Strategie der Bundesregierung - Wir stellen die Weichen für die Token-Ökonomie, https://www.bmwi.de/Redaktion/DE/Publikationen/Digitale-Welt/blockchain-strategie.html (Accessed on 01-06-2021) (in German)

[21] Federal Environment Agency (ed.) (2007). Environmental research of the federal ministry of the environment, nature conservation and nuclear safety. *Research report. Scientific assessment and evaluation of the indicator ecological footprint*, Berlin.

[22] Girrbach, P. (2015). How can we use lean production methods for increasing resource efficiency in a broader sense? *Proceedings of MOTSP 2015*.

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Subject review

Current State of Dynamic Vehicle Routing Problems Solved by Ant Colony Optimization Algorithm

Luka Olivari*, Goran Đukić

Abstract: Dynamic Vehicle Routing Problem is a more complex version of Vehicle Routing Problem, closer to the present, real-world problems. Heuristic methods are used to solve the problem as Vehicle Routing Problem is NP-hard. Among many different solution methods, the Ant Colony Optimization algorithm is proven to be the efficient solution when dealing with the dynamic version of the problem. Even though this problem is known to the scientific community for decades, the field is extremely active due to technological advancements and the current relevance of the problem. As various sub-types of routing problems and solution methods exist, there is a great number of possible problem-solution combinations and research directions. This paper aims to make a focused review of the current state in the field of Dynamic Vehicle Routing Problems solved by Ant Colony Optimization algorithm, to establish current trends in the field.

Keywords: Ant Colony Optimization; Dynamic Vehicle Routing Problem; overview

1 INTRODUCTION

Vehicle Routing Problem (VRP) was first introduced in 1959 by [1], its goal is to construct an optimal solution, i.e. find routs with minimal cost, travel time, or environmental impact, for multiple vehicles that are visiting n number of nodes (also called locations or customers). If the problem is reduced to one vehicle, it is called the Traveling Salesmen Problem (TSP). VRP is considered a static problem as all information is known before route planning. In contrast with VRP, in the Dynamic Vehicle Routing Problem (DVRP) all relevant information is not known before the planning process begins, and information can change after initial routes have been planned. Dynamic elements include dynamic demand (new customers, canceling orders, changing node location or time window, etc.), dynamic road time (real-time traffic conditions may change vehicle speed). In [2] DVRP is classified by dynamic elements and their characteristics into three categories. Dynamic Demand based VRP (DDVRP), Real-time traffic information based VRP (RTVRP), and Dynamic demand and real-time traffic information based VRP (DDRTVRP) as the most complex problem of DVRP.

DVRP was first introduced in 1980 in [3], and since then it has been a topic of scientific interest, as it is closer to real-world problems than VRP. Between 2000 and 2015 number of scientific papers in the field of DVRP has rapidly grown due to the development of information and communication technologies. [4] Scientific interest continued to this day, as scientists tackle different aspects of VRP and DVRP. Although it may be that the VRP field was never more active there is still much work to do.

Logistics 4.0, supply chain 4.0, as well as the technologies that support them, are rapidly evolving as part of the fourth industrial revolution. Industry 4.0 is defined by digitalization, networking, and a higher level of automation in order to achieve better productivity and efficiency. It is expected that in the near future the level of digitalization will rise even higher and that companies, suppliers, and users will work together in a fully digital environment. [5] The dynamic vehicle routing problem is being taken to a new level, as information can be collected in real-time, processed a decentralized way, and in the cloud. All that makes DVRP a very attractive topic for both academic and industrial circles.

VRP is considered an NP-hard problem, so DVRP is also considered to be an NP-hard problem. Computational problems are grouped into classes how complex they are, or how much computational time is consumed to solve specific problems. If n represents the size of the problem, in VRP case number of nodes, P class of problems can be solved in polynomial time (i.e. n^2), and NP class of problem can be solved in nondeterministic polynomial time (i.e. 2^n). The computational time of the NP problem increases much faster with the size of the problem than the P problem. NP-complete class of problems is the hardest class of NP problems, and NP-hard class of problems are problems that are at least hard as NP-complete problems. Considering that VRP is an NP-hard problem, it means that optimal solution cannot be calculated in a time acceptable for practical use by exact algorithms [6]. Because of that, finding an optimal solution for both problems often requires the use of heuristic algorithms. Common solution methods include Tabu Search, different Neighborhood Search approaches (such as Adaptive Neighborhood Search, Variable Neighborhood Search, Large Neighborhood Search), Insertion Methods, Nearest Neighbor, Column Generation, Genetic Algorithms, Particle Swarm Optimization, Waiting-Relocating Strategies, Markov Decision Processes, Dynamic Programming-Based Approach (such as adaptive dynamic programming, approximate dynamic programming, and neuro-dynamic programming), etc. Some methods are used individually and /or as a hybrid variant with other methods. [4]

Among lots of different heuristics approaches Ant Colony Optimization (ACO) algorithm or its variants is considered by many authors to be a reliable, efficient, and overall good choice for solving DVRP, due to its ability to adapt to dynamic changes. This is because of its inherent

ability to memorize past optimal solutions via its artificial pheromone model. [7]

Ant Colony Optimization is a sub-type of Swarm Intelligence (SI). The first ACO algorithm, called Ant System (AS) was introduced by M. Dorigo in 1996., it was applied to classical TSP. AS was inspired by real ants which use pheromone trail as a communication method. [8] ACO or any of its variants, mimics the self-organizing behavior of ants searching for food. Real ants lay pheromones to mark their path from the nest to the food source and back. If there is more than one way to reach food, ants will randomly choose a path. A shorter path will have a stronger pheromone trail due to the fact there was less time for pheromones to evaporate. The next ant, when confronted with the possibility to choose between two different paths, will have a higher chance of choosing a path with a stronger pheromone trail. In ACO, artificial ants can solve complex combinatorial problems with high-quality solutions. ACO algorithm was designed with static combinatorial optimization problems in mind, but it turned out to be well suited for dynamic problems as well, especially because dynamic problems may be considered series of static problems if the working day is sliced into a number of time intervals. [7]

As the scientific field is decades old and very active, there is a great number of research directions, possible combinations of dynamic vehicle problems, and solution methods. The very active scientific field is making it inconvenient to accurately overview current advances, trends, and the possibility of further research. Extensive research is needed to determine current trends, research directions, and the best possible method for a given problem. To reduce the complexity of the problem, this paper will focus on one solving method of dynamic routing problems.

The goal of this paper is to make a focused review of the current state in the field of Dynamic Vehicle Routing Problems solved by some variant of Ant Colony Optimization algorithm, to establish current trends and best solution method for given problems. As the field is very active, to establish the latest trends, papers published since 2018 were reviewed and categorized into several categories. Each paper was analyzed to determine what type of DVRP was the subject of the paper, if the authors introduced a new version of the routing problem, what method was used to solve the named problem (i.e. was basic ACO algorithm used or a new variant of the algorithm was developed), was the problem solved by using the ACO algorithm alone or if it was combined with some other method (hybrid approach), were Industry 4.0 (I4.0) technologies integrated into the problem, if the authors considered the environmental impact, and if the authors proposed innovation in the evaluation system for DVRP.

In section 2, relevant literature is reviewed, the first part consists of review articles and in the second part are original scientific articles published since 2018 in chronological order. In section 3, the categorization of reviewed literature is visually represented in table form, and current trends are discussed. In section 4 concluding remarks are presented.

2 LITERATURE REVIEW

As VRP and DVRP are problems decades old, there was a great number of review articles, some more important are listed below.

In [9] authors classified routing problems, introduce the concept of degree of dynamism, and reviewed applications and solution methods for DVRP. As most researched problems are theoretical, simplified routing problems, so-called Rich Vehicle Routing Problems (RVRP) have emerged. RVRP tends to simulate real-life objectives and constraints, but the true definition of RVRP remains somewhat vague. To tackle that problem, in [10] authors provide generic taxonomy of RVRP literature and propose the definition of RVRP. In [4] authors made a taxonomy of DVRP papers according to the eleven criteria, analyzed the influence of advances in information and communication technology on DVRP. In [7] authors analyzed the behavior of ACO algorithms specifically designed for dynamic combinatorial optimization problems. A case study of using these algorithms on dynamic traveling salesman problems is conducted to investigate the effect of different features in dynamic situations. In [2] authors classified VRPs, (among which is DVRP), a mathematical model for each type is presented as well as an analysis of the solution methods.

To the author's knowledge, a focused review of dynamic vehicle routing problems solved exclusively with a variant of the Ant Colony Optimization algorithm has not yet been conducted.

For finding relevant literature, i.e. original scientific articles published since 2018., Web of Science, Scopus, Springer, and Scient Direct databases was searched as well as general search using Google Scholar. The search was conducted with different combinations of keywords: *dynamic*, *vehicle*, *routing*, *problem*, the Boolean operator AND, and keywords: *ant*, *colony*, *optimization, system*.

Papers are ordered chronologically by year they are published, but it should be noted that the month of publication was not considered.

In [11] authors solve classic DVRP with the new variant of ACO algorithm called enhanced Ant Colony Optimization (E-ACO). The primary goal of E-ACO is to avoid falling into local search prematurely by improving the degree of randomization. ACO is modified in three ways by combining ACO with K-means, crossover operation, and 2-Opt. First, using the K-means algorithm to divide the whole problem into smaller, compact regions. Then ACO is used to solve each region separately. The initial solution is mutated with a crossover operation, that originates from the Genetic Algorithm (GA), in order to avoid falling in the local optimum. Finally, a 2-Opt local search heuristic is applied to optimize routes and as another way to avoid falling into the local optimum. The second contribution of this paper is the design of a mfair and impartial estimation for DVRP by adding t-test to the evaluation system.

In [12] authors solve the Dynamic Multidepot Vehicle Routing Problem (DMDVRP) with Hybrid Ant Colony Optimization (HACO). The goal of HACO is to improve randomization to avoid falling into the local optimum

prematurely. ACO is modified in three steps: first by dividing DMDRP with clustering algorithm into smaller scale DVRPs. After the ACO algorithm is used to generate the initial solution, mutation operation (derived from GA) is applied to randomize the solution to avoid falling into the local optimum. The 2-Opt heuristic is finally applied to improve the route. To deal with new customer requests authors split working day into 24 same time intervals. In each time interval, new customers are added to the nearest existing route, after which routs are reoptimized.

In [13] authors introduce a new variant of the routing problem called Dynamic Green Vehicle Routing Problem (DGVRP). In the dynamic environment, authors try to reduce greenhouse gas emissions, produced by a set of vehicles. The problem is solved by the hybrid ACO and Large Neighborhood Search (LNS) algorithm.

In [14] authors present a mathematical model of a new variant of the routing problem the multi-tours DVRP with overtime. The problem is solved with a hybrid approach. After a solution is created by Ant Colony System (ACS), the best solution is optimized with a local search algorithm. Finally, new data sets for testing algorithms are proposed.

In [15] authors solve Asymmetric Dynamic Traveling Salesman Problem with the proposed MAX-MIN Ant System (MMAS) algorithm with a build-in short-term memory. Improvement in the algorithm is used to accelerate the convergence of a best so far solution.

In [16] authors exchanged framework of population-based Ant Colony Algorithm (P-ACO) with Adaptive Large Neighborhood Search (ALNS) to solve classic Dynamic Traveling Salesman Problem (DTSP). A hybrid algorithm is then tested on the real-life problem of surveying deer with drones.

In [17] authors introduce a more complex variant of DTSP in which existing nodes are replaced with new ones. Also, the authors propose two novel restart strategies, local random restart strategy (LRRS) and local restart strategy (LRS) in combination with hyper populated ant systems to solve the named problem. The new variant of the ACO algorithm has shown increased practical efficiency in solving dynamic problems.

In [18] authors analyze the performance of MAX-MIN Ant System combined with unstringing-stringing (US) local search and 3-opt local search, to solve Asymmetric and Dynamic Travelling Salesman Problem with Moving Vehicle (ADTSPMV). The authors state that MMAS-US is the best algorithm for solving ADTSP, but for moving vehicle variant MMAS-3opt is better.

In [19] authors propose a new demand coverage diversity adaptation method abbreviated ACO-CD because it is based on the ACO framework. A new metaheuristic is used to effectively respond to the new customers in the classic DVRP while keeping low traveling costs. This is achieved by maintaining a diversity of customers which ensures that there is always an existing customer next to the new one without knowing the location of the new customer in advance. The effectiveness of ACO-CD is verified by comparing solution results with the basic version of the ACO algorithm.

In [20] authors take into account steep and slow roads (information about roads is obtained using Google Maps) while searching for an optimal solution via ACO for Dynamic Capacitated Vehicle Routing Problem (DCVRP) in order to reduce CO_2 emissions. The routing model is developed primarily with Latin America in mind where the population, the topography of big cities, and height above sea level are higher than average, but model usefulness is not limited to that area only.

In [21] authors consider multi-source multi-destination traffic routing problem (MSMD traffic routing problem) in the Internet of Vehicle (IoV) environment. Specific to this problem is that individual vehicles randomly enter road networks while having their unique source-destination combination. The problem is solved by a new ACO variant where the algorithm is improved by considering path distance, vehicle density on the paths, and travel time of the vehicles.

In [22] authors propose a hybrid algorithm named BSO-DVRP to solve classic DVRP. Brain Storm Optimization in objective space (BSO-OS) is used to decide between ACS and ALNS algorithms to create new solutions. BSO-OS randomly chooses one or two existing solutions. If one solution is chosen, then ALNS is applied to generate a new solution. If two solutions are chosen, they are used by ACS as the initial solution to update pheromones and create a new solution.

In [23] authors propose how to heuristically repair the solution given by MMAS when dynamic change occurs on classic DVRP. Ant System has the inherent ability to memorize past solutions via pheromone trail, but if the dynamic environment drastically changes it could be better to reinitialize the pheromone trail rather than transfer knowledge from the previous optimal solution. After the dynamic change occurs, the unstring-string heuristic is used to repair past optimal solutions to remove affected nodes from the solution and add new nodes.

In [24] authors propose the integration of Game Theory (GT) into the ACO algorithm in order to improve performance when dealing with classic DVRP. After the dynamic problem is reduced into series of static problems by dividing the workday into time slices and acquiring all data related to the nodes, GT and ACS are used to decide which node will be visited next.

In [25] authors make use of the Internet of Things technology to determine which waste collection bins are full and need to be visited. New nodes (waste bins) appear dynamically, and the problem is solved by the classic ACO algorithm.

In [26] authors propose pairwise proximity learning-based ant colony algorithm (PPL-ACO) which predicts the customers' orders to get optimal routes before change happens. This approach needs fewer computing resources and enables solving large-scale DVRPs. The effectiveness of the proposed algorithm is greater on large-scale DVRPs because it cannot achieve high learning accuracy on small-scale problems.

In [27] authors propose and validate a framework to solve DVRP with time windows (DVRPTW). Among seven

algorithm variables used to validate the framework, a hybrid version that combines multiple ant colony systems with random variable neighborhood descent is proven to have the best performance based on test results.

3 DISCUSSION

Reviewed papers were categorized into eight categories defined below. Papers included in categorization are [11] - [27]. All of those are original scientific articles published since 2018, written in the English language, that solves DVRP with some variant of the ACO algorithm. Subject review, books, and dissertations were omitted from categorization as well as papers that deal with a static variant of the problem (VRP).

Categories:

a) In this category it is stated what type of DVRP paper tackles.
b) Papers in this category introduce a new, previously unmentioned, variant of DVRP.
c) Papers in this category developed and applied a new variant of the ACO algorithm to solve DVRP.
d) Papers in this category used a hybrid approach i.e., used ACO in combination with other methods to solve the problem.
e) Papers in this category integrate I4.0 technologies in DVRP.
f) Papers in this category used the ACO algorithm on DVRP in order to reduce environmental impact.
g) Papers in this category proposed innovation in the evaluation system for DVRP.

To facilitate an overview of the current state of Dynamic Vehicle Routing Problems solved by the variant of the Ant Colony Optimization algorithm, the results of categorization are visually shown in Tab. 1.

Most authors deal with a known variant of DVRPs, classic DVRP is dominant through papers. Several new variants of the problem were introduced, namely Dynamic Green Vehicle Routing Problem [13], multi-tours DVRP with overtime [14], and the new variant of DTSP which replaces existing nodes with new ones [17]. Because the academic community is often interested in solving theoretical problems, they mostly deal with idealized models. Technological advancement in the last two decades has led to an increased number of papers that deal with RVRP that try to simulate the complexity of real-life problems. [10] The absence of real-life, rich routing problems solved by ACO is noticeable.

Papers published in 2018 and 2019 often use a hybrid approach i.e., combine ACO algorithm with other algorithms and mathematical models like Genetic Algorithm, Large Neighbourhood Search, 2-Opt, 3-Opt, and Game Theory for solving DVRP. After 2019 lots of papers are focused on the development of new variants of ACO algorithms.

Although the fourth industrial revolution is in full swing, and there are mentions of the fifth industrial revolution, only [21] and [25] include possibilities offered by I4.0 technologies in DVRP. I4.0 technologies (i.e. real-time tracking of the vehicles and road conditions, communication between vehicles, and predictive analysis) could enable the creation of more realistic RVRP by integrating previously unavailable information in the problem.

Table 1 Overview of paper categorization

Ref.	a	b	c	d	e	f	g
[11]	classic DVRP			●			●
[12]	DMDVRP			●			
[13]	DGVRP	●		●		●	
[14]	multi-tours DVRP with overtime	●		●			●
[15]	ADTSP		●				
[16]	DTSP		●	●			
[17]	new variant DTSP	●	●				
[18]	ADTSPMV			●			
[19]	classic DVRP		●				
[20]	DCVRP					●	
[21]	MSMD DVRP		●		●		
[22]	classic DVRP			●			
[23]	classic DVRP		●				
[24]	classic DVRP		●				
[25]	classic DVRP				●		
[26]	classic DVRP		●				
[27]	DVRPTW			●			

Two papers, [13] and [20] are trying to reduce environmental impact using ACO algorithms on DVRP.

The effectiveness of newly proposed solving methods is superior when compared with other methods in the field, but they are usually compared with basic variants of other methods. While some papers are introducing innovation in evaluation systems, [11] is trying to design a more equitable evaluation system for DVRP, while [14] propose new data sets to test the algorithms, but it seems that a universal evaluation system has not yet been crated.

The ACO algorithm has proven to be an efficient solution for many different dynamic vehicle routing problems. Even though the review was focused, due to many different combinations of problems and solutions, and the nonexistence of a universal evaluation system, it is difficult to conclude which variant of the ACO algorithm is best for solving a particular variant of the dynamic problem. Similarly, universally best variant of the ACO algorithm, even if there is one, is still not possible to determine.

Regarding future research authors of reviewed literature mostly suggest further improvements on algorithms, testing other heuristics on the same problem, tackling more complex dynamic problems, and applying proposed algorithms on real-world problems.

4 CONCLUSION

This paper offers a focused review of the Dynamic Vehicle Routing Problem solved by the Ant Colony Optimization algorithm. Papers published since 2018 have been categorized to determine current trends in this field. Most of the papers deal with classic DVRPs, but some new variants of the problem are being introduced. Hybridization and improvement of the ACO algorithm are very popular, and results are promising when compared with basic versions of other solving methods.

The absence of a universal evaluation system is making it difficult to accurately evaluate and rank solution methods. The best solution method is not possible to determine until there is a universal evaluation system, at least for a single variant of a given problem. Also, there is no comparison of the solution given by the proposed algorithm and the best possible solution.

Environmental impact and integration of industry 4.0 technologies are not discussed in many papers.

Possible future research could be even more focused i.e., finding the best possible solution method for a specific type of dynamic problem. But to accomplish that, a universal (at least for a specific type of problem) evaluation system needs to be established. Integrating new possibilities offered by I4.0 technologies could lead to the creation of more complex DVRPs similar to real-life problems.

Notice

The paper was presented at MOTSP 2021 – 12th International Conference Management of Technology – Step to Sustainable Production, which took place in Poreč/Porenzo, Istria (Croatia), on September 8–10, 2021. The paper will not be published anywhere else.

5 REFERENCES

[1] Dantzig, G. B. & Ramser, J. H. (1959). The Truck Dispatching Problem. *Manage. Sci.*, 6(1), 80-91. https://doi.org/10.1287/mnsc.6.1.80

[2] Zhang, H., Ge, H., Yang, J., & Tong, Y. (2021). Review of Vehicle Routing Problems: Models, Classification and Solving Algorithms. *Arch. Comput. Methods Eng.*, no. 0123456789. https://doi.org/10.1007/s11831-021-09574-x

[3] Psaraftis, H. N. (1980). A Dynamic Programming Solution to the Single Vehicle Many-to-Many Immediate Request Dial-a-Ride Problem. *Transp. Sci.*, 14(2), 130-154.

[4] Psaraftis, H. N., Wen, M., & Kontovas, C. A. (2016). Dynamic Vehicle Routing Problems: Three Decades and Counting," *Networks, 67*(1), 3-31. https://doi.org/10.1002/net.21628

[5] Alcácer, V. & Cruz-Machado, V. (2019). Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems. *Eng. Sci. Technol. an Int. J., 22*(3), 899-919. https://doi.org/10.1016/j.jestch.2019.01.006

[6] Kłodawski, M., Jacyna, M., Vasek, R., Klimek, P., Jachimowski, R., Szczepański, E., & Lewczuk, K. (2020). Route Planning with Dynamic Information from the EPLOS System. *Tehnički glasnik, 14*(3), 332-337. https://doi.org/10.31803/tg-20200710130158

[7] Mavrovouniotis, M., Yang, S., Van, M., Li, C., & Polycarpou, M. (2020). Ant colony optimization algorithms for dynamic optimization: A case study of the dynamic travelling salesperson problem [Research Frontier]. *IEEE Comput. Intell. Mag.*, 15(1), 52-63. https://doi.org/10.1109/MCI.2019.2954644

[8] Dorigo, M., Maniezzo, V., & Colorni, A. (1996). Ant system: Optimization by a colony of cooperating agents. *IEEE Trans. Syst. Man, Cybern. Part B Cybern.*, 26(1), 29-41. https://doi.org/10.1109/3477.484436

[9] Pillac, V., Gendreau, M., Guéret, C., & Medaglia, A. L. (2013). A review of dynamic vehicle routing problems. *Eur. J. Oper. Res.*, 225(1), 1-11. https://doi.org/10.1016/j.ejor.2012.08.015

[10] Lahyani, R., Khemakhem, M., & Semet, F. (2015). Rich vehicle routing problems: From a taxonomy to a definition. *Eur. J. Oper. Res., 241*(1), 1-14. https://doi.org/10.1016/j.ejor.2014.07.048

[11] Xu, H., Pu, P., & Duan, F. (2018). Dynamic Vehicle Routing Problems with Enhanced Ant Colony Optimization. *Discret. Dyn. Nat. Soc., vol. 2018*, 1-13. https://doi.org/10.1155/2018/1295485

[12] Xu, H. (2018). A Hybrid Ant Colony Optimization for Dynamic Multidepot. *Discret. Dyn. Nat. Soc., vol. 2018*, 1-10. https://doi.org/10.1155/2018/3624728

[13] Messaoud, E., El Bouzekri El Idrissi, A., & Alaoui, A. E. (2018). The green dynamic vehicle routing problem in sustainable transport. *Proc. - GOL 2018 4th IEEE Int. Conf. Logist. Oper. Manag.*, 1-6. https://doi.org/10.1109/GOL.2018.8378096

[14] K. Ouaddi, Y. Benadada, and F. Z. Mhada, 2018,"Ant colony system for dynamic vehicle routing problem with overtime," *Int. J. Adv. Comput. Sci. Appl.*, 9(6)306-315, https://doi.org/10.14569/IJACSA.2018.090644.

[15] Schmitt, J. P., Baldo, F., & Parpinelli, R. S. (2018). A MAX-MIN ant system with short-term memory applied to the dynamic and asymmetric traveling salesman problem. *Proc. - Brazilian Conf. Intell. Syst. BRACIS 2018*, 1.6. https://doi.org/10.1109/BRACIS.2018.00009

[16] Chowdhury, S., Marufuzzaman, M., Tunc, H., Bian, L., & Bullington, W. (2019). A modified Ant Colony Optimization algorithm to solve a dynamic traveling salesman problem: A case study with drones for wildlife surveillance. *J. Comput. Des. Eng., 6*(3), 368-386. https://doi.org/10.1016/j.jcde.2018.10.004

[17] Prakasam, A. & Savarimuthu, N. (2019). Novel local restart strategies with hyper-populated ant colonies for dynamic optimization problems. *Neural Comput. Appl., 31*, 63-76. https://doi.org/10.1007/s00521-018-3638-3

[18] Schmitt, J. P., Parpinelli, R. S., & Baldo, F. (2019). Analysis of Max-Min Ant System with Local Search Applied to the Asymmetric and Dynamic Travelling Salesman Problem with Moving Vehicle. *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 11544 LNCS, 202-218. https://doi.org/10.1007/978-3-030-34029-2_14

[19] Xiang, X., Qiu, J., Xiao, J., & Zhang, X. (2020). Demand coverage diversity based ant colony optimization for dynamic vehicle routing problems. *Eng. Appl. Artif. Intell.*, 91, p. 103582. https://doi.org/10.1016/j.engappai.2020.103582

[20] Khakifirooz, M., Menezes, B., Fathi, M., & Monterrey, D. (2020). CO_2 Emission through Road Gradient and Real-Time Traffic Monitoring for Vehicle Routing Problems. *Conference: 12th International Exergy, Energy and Environment Symposium (IEEES-12)*, March 22-26, Doha, Qatar. 1, 3-6.

[21] Nguyen, T. H. & Jung, J. J. (2020). Multiple ACO-based method for solving dynamic MSMD traffic routing problem in connected vehicles. *Neural Comput. Appl., 8*. https://doi.org/10.1007/s00521-020-05402-8

[22] Liu, M., Shen, Y., & Shi, Y. (2020). *A Hybrid Brain Storm Optimization Algorithm for Dynamic Vehicle Routing Problem*, vol. 12145 LNCS. Springer International Publishing.

[23] Bonilha, I. S., Mavrovouniotis, M., Muller, F. M., Ellinas, G., & Polycarpou, M. (2020). Ant Colony optimization with Heuristic Repair for the Dynamic Vehicle Routing Problem. *IEEE Symp. Ser. Comput. Intell. SSCI 2020*, 313-320. https://doi.org/10.1109/SSCI47803.2020.9308156

[24] Darwish, S. M. & Abdel-Samee, B. E. (2020). *Game Theory Based Solver for Dynamic Vehicle Routing Problem*, vol. 921. Springer International Publishing.

[25] Alwabli, A., Kostanic, I., & Malky, S. (2020). Dynamic route

optimization for waste collection and monitering smart bins using ant colony algorithm. *The 2nd IEEE Int. Conf. Electron. Control. Optim. Comput. Sci. ICECOCS 2020*. https://doi.org/10.1109/ICECOCS50124.2020.9314571

[26] Xiang, X., Tian, Y., Zhang, X., Xiao, J., & Jin, Y. (2021). A Pairwise Proximity Learning-Based Ant Colony Algorithm for Dynamic Vehicle Routing Problems. *IEEE Trans. Intell. Transp. Syst.*, 1-13. https://doi.org/10.1109/TITS.2021.3052834

[27] da Silva Júnior, O. S., Leal, J. E., & Reimann, M. (2021). A multiple ant colony system with random variable neighborhood descent for the dynamic vehicle routing problem with time windows. *Soft Comput.*, 25(4), 2935-2948. https://doi.org/10.1007/s00500-020-05350-4

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Subject rieview

Application of Robots and Robotic Systems in Agriculture

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Abstract: The paper depicts agricultural robots that can perform complex tasks. Fast development and application of agricultural robotics is a result of increased development of agricultural machinery. Robots are complex and intelligent systems with a significant role in agriculture that are becoming an integral part of both the technological and scientific progress. The paper presents some important roles of robots and robotic systems in various agricultural areas and explains the deployment of new technologies supported by the examples of their application in arable farming, horticulture, and forestry. Robotics application decreases the deployment of human resources, enables significant production cost savings, and increases production capacity. The application of robotic systems facilitates high precision levels and repetition speed regarding time and space, which cannot be replicated by farmers.

Keywords: agriculture; robotic systems; robots; sensors

1 INTRODUCTION

A robot usually involves an electromechanical machine that can move, perform operations using a limb joint, feel external stimuli, and physically affect its environment [1]. The application of robotics in agriculture has resulted in an increased application of automated guided robots that minimize production losses [2]. The author argues that soon cooperative teams consisting of small autonomous agricultural robots are bound to be present in agricultural fields. During the last twenty years, the integration of many autonomous vehicles, especially agricultural robots, has been enabled based on the application of specialized sensors. Machine vision, global positioning systems – GPS, real-time kinematics, laser-based equipment, and inertial devices, actuators (hydraulic cylinder, linear and rotary electrical motors), and electronic equipment (built-in computers, industrial PC and PLC) are components of new robots in agriculuture [3-7]. The authors [8] claim that robotics improves common agricultural practices, such as yield increase, and reduces the application of environmentally hazardous chemicals. Additionally, new agricultural robotic systems are being developed to facilitate integration of different technologies as well as modularity, flexibility, and adaptability. Robotics is a new scientific and technological dimension. The progress of technology and science accompanied by the development of artificial intelligence as one of the most important factors has qualified robots to become intelligent working partners [9].

A robot is an electromechanical movable device designed to perform tasks using its axes, feel external stimuli, and to physically affect its environment [10]. Artificial intelligence and robotics have been increasingly used to perform tasks in specific workspace concepts with robots becoming increasingly humanoid (like human beings with arms and legs, a head with eyes, as well as with 'skin') [11]. The authors [12] claim that robotics integrates mechanics, electronics, computer science, information systems, and automation. Automation studies the principles and theory of automatic control systems as well as the devices that perform tasks without continuous human control.

As stated by the authors [13] the basic division of robots is the division according to the degree of independence, into industrial and autonomous mobile robots

Agricultural robots can be autonomous or semi-autonomous systems able to move through different process phases to solve complex problems. They have been successfully implemented in repetitive tasks to reduce human workload and to optimize time and cost regarding soil preparation [13], irrigation, plant protection [14-17], pruning [18], harvesting [19-22], surveillance and control [23-28], and mapping [29]. According to [30], after only a year, the introduction of robots in production processes was justified both productionally and financially. According to [31-34], automatization resulted in increased productivity of agricultural machinery arising from a higher level of efficiency, reliability and precision, and a reduction of human intervention.

Based on the structural features of objects and the environment, the authors [35] distinguish four groups of robots: 1) both the environment and objects are structured; 2) the environment is structured, whereas the objects are unstructured; 3) the environment is structured, whereas the objects are unstructured; 4) both the environment and the objects are unstructured. The domain of agriculture relates to the fourth group in which neither the environment nor the objects are structured, which poses a challenge regarding commercialization. The agricultural environment requires robots to be mobile compared to most robots used in factories or parked vehicles, whose mobility is limited. Authors [36] in their research state that a robotic system must be cost-effective, while at the same time safe and reliable for human safety, environmental protection, and crops.

The author [37] claim how robots also have their disadvantages: robots reduce the chances of employment in the industries, human labor is no longer required in farms. Robots can handle their prescribed tasks, but they can't handle unexpected situations. Robots can be a danger, this is because no one can trust a robot as it does not have a human brain that can think before doing anything, what ever is fed to the robots through chips is performed if it goes wrong. Once the machine damages, the whole farm can come into

chaos. A high cost is needed to train employees with robots, if the robots are ruling the work in many places, the labor is needed to assist them, because the whole work can't be thrown in the ability of the robots, So, the employees need training and that involves cost, So, a lot of money is involved with the installation of machines in the workplace.

2 ROBOTIC OPERATING PRINCIPLES

Robots work on the principle of mobility and sensor data collection (Fig. 1) [38]. Robot mobility is controlled by a remote-control device, which is an RF data encoding emitter. The remote- control consists of a keypad connected to the 8-bit microcontroller AT89C2051. The emitter transmits the data produced by the microcontroller. The RF receiver microcontroller 89C51 is built in the robot and it decodes the data sent by the remote-control. The whole robot is powered by a battery that produces +5V of voltage for the microcontroller, and +12V of cranking voltage [39].

A robot consists of DC motors that enable its mobility and an RF data receiver. To move smoothly, a robot requires sensors and controls, which manage its movement in unknown surroundings. It usually consists of five main parts: sensors, a controller/computer, a drive/actuator (transducer), a robotic arm, and an end-effector [40, 41].

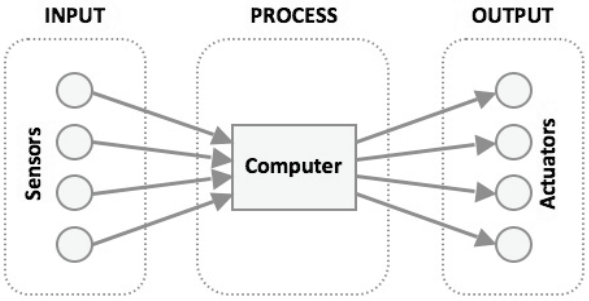

Figure 1 The principle of operation of the robot (Source: Nepalla Choudary)

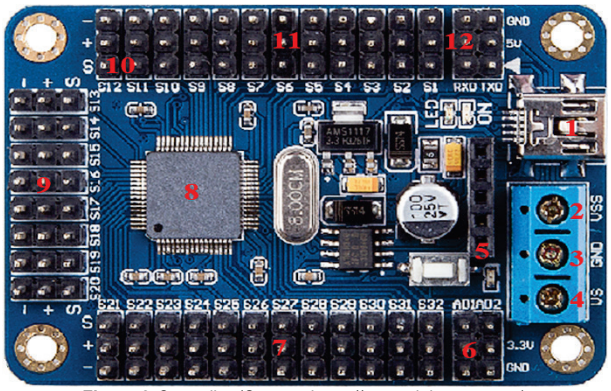

Figure 2 Controller (Source: https://www.elabpeers.com) (1-mini USB, 2-chip VCC, 3-GND, 4-servo VCC, 5-WIFI, 6-AD input, 7-channel 21-31 servo motor, 8-CPU 32 bit, 9-channel 13-20 servo motor, 10-servo controlling signal, 11-channel 1-12 servo motor, 12-UART)

Sensors send data in the format of electronic signals back to the controller. They provide the robot controller with the data from the environment. The most often built-in sensors in robots are the following: a microphone, an ultrasound sensor, an acoustic vector sensor, a camera, an infrared sensor, and a sensor for detection of specific chemicals. Robots can be transformed and programmed so that the collected data surpass the five human senses. A controller or computer, which is a term found in common use, is the robot's brain. It supports the connection between a robot and other systems so that it can cooperate with other devices, processes, or robots (Fig. 2).

An actuator is a mechanical device that produces motion. There are different types of actuators and the most often used are a hydraulic, pneumatic, DC, and servomotor as well as a stepper (Fig. 3).

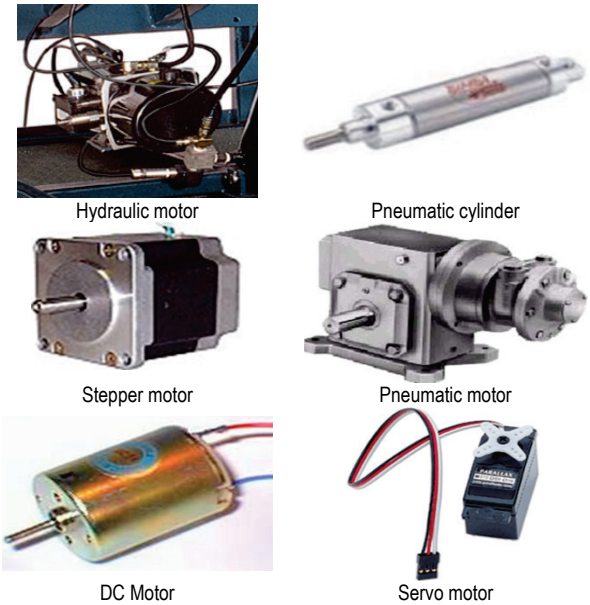

Figure 3 Actuators (Source: N.Nagarjuna Reddy)

An agrobot consists of a DC motor with an H-bridge electronic circuit that enables a change of the voltage polarity. The installation of the H-bridge results in forward and backward locomotion of the DC motor through the connection and disconnection of the S1-S4 assembly (Fig. 4). A robotic arm is a robot part that sets the end effectors and sensors to perform the tasks programmed in advance. The robotic arm looks like a human arm and it has a shoulder, an elbow, a joint, and fingers. The end effectors are the robot's last link (i.e., the end) of the robot.

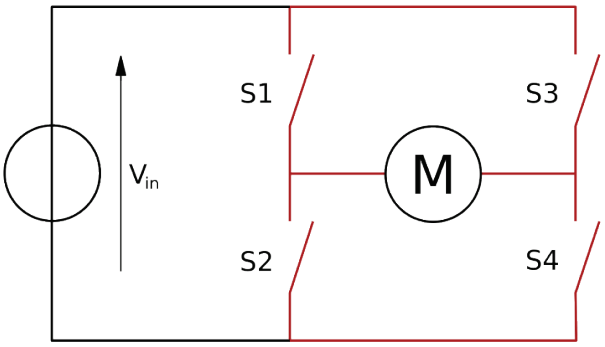

Figure 4 Structure of an H bridge (Source: http://eleccomponentz.blogspot.com)

Tools are attached to this endpoint. In a wider sense, the end-effectors can be considered a robotic part that affects the working environment. As agricultural production is concerned, the most often used effectors are a pincher (Fig. 5) which is used in research [42] and a vacuum pump (Fig. 6).

Figure 5 Grippe arm (Source: Font Davinia)

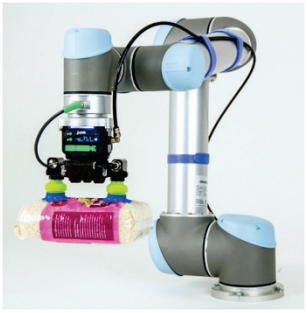

Figure 6 Vacuum pump
(Source: https://www.therobotreport.com)

Robots are increasingly used in agriculture for pest control, where it is necessary to perform plant protection following specific safety rules regarding the human operator. A robot named *Agrobot* was constructed for the research of authors [43] to protect crops and farmers' health. *Agrobot* is a remotely controlled robot used for the application of protective chemicals both indoors and outdoors (Fig. 7).

Figure 7 *Agrobot* (Source: http://robotics.ee.pusan.ac.kr/)

It consists of a keypad, a microcontroller, a battery, DC motors, an RF receiver, a pneumatic compressor, a container for air and protective chemicals, wheels, and a frame. The block diagram shows its working principle (Fig. 8) [44].

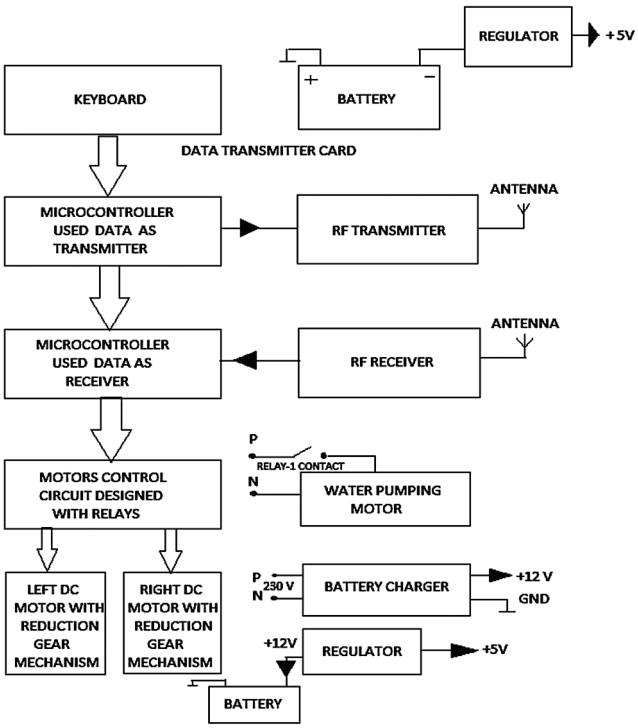

Figure 8 Block diagram of working
(Source: Ashvin Jankhaniya [43])

3 ROBOTIC SYSTEMS

Robots and robotics have facilitated the introduction of 'farms of the future', where robots perform difficult tasks once done by people (Fig. 9). Robots have been increasingly used in plant protection due to their ability to exclusively target the area affected by pest or illness, instead of the whole area. Apart from agriculture, robots have been used in forestry, protected areas, and horticulture, in which areas the use of the robotic arm is significant (Fig. 10). The robot known as *Demeter* has been increasingly used for harvesting. It has two cameras that can distinguish between the ripe crop and other plants. Additionally, it can drive, manage, and manipulate the harvester head allowing the driver to focus on other tasks. Finally, its major advantage is a high accuracy of 3 centimetres.

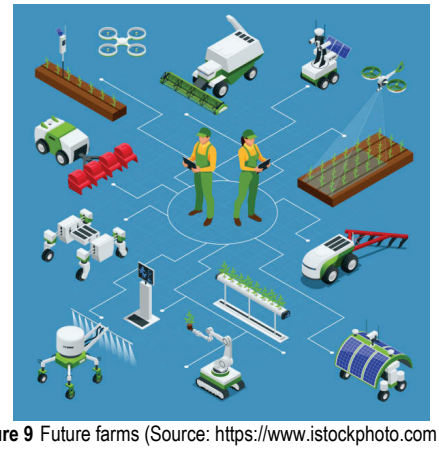

Figure 9 Future farms (Source: https://www.istockphoto.com [45])

Furthermore, weed detecting and removing robot has been widely applied. A four-wheel drive weed detecting robot was developed by the Danish Centre for Economic and Business Research. The purpose of the weeding device is to remove and destroy weed. An intelligent 'hoe' uses the vision system to detect crop rows by positioning itself precisely between them, which decreases the use of herbicides. The process itself is based on colour photography. The robot can destroy weed promptly by determining the position and the level of weed development in crops. Contactless methods have been increasingly used including laser treatments and micro sprayers, which deploy machine vision and nozzles.

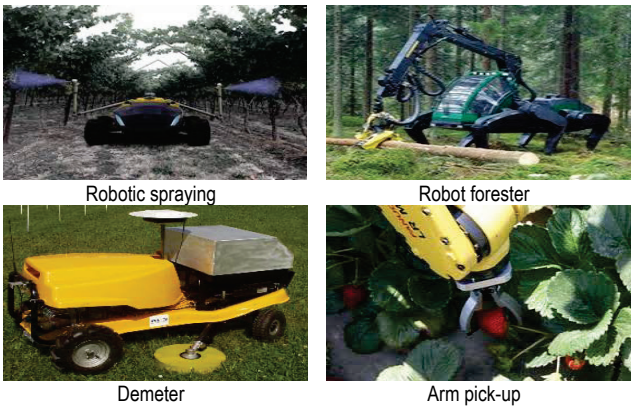

Figure 10 Robot types (Source: N.Nagarjuna Reddy)

ARA robot is a Swiss robot that with the help of artificial intelligence and solar drive (Fig. 11) can move independently through the field, detect weeds and then target it, with less use of herbicides and thus reduce the total use of herbicides by as much as 20 times on an area of 7.5 hectares per day. The *Ara* robot moves independently through the field with the help of a camera, GPS sensor, and a solar drive that allows it 12 hours of independent work. It covers the ground only by placing bearings and positioning with the help of a camera, GPS RTK, and sensors. Vision system allows to track crop rows and detect the presence and position of weeds in and between rows. Two robotic arms then apply a microdose of herbicide, systematically targeting the detected weeds [47].

Figure 11 Ara robot (Source: https://www.ecorobotix.com [47])

Apart from robots, a robotic suit has been of great help in agriculture. This latest technology connects the man to a robotic system, i.e., the man wears the suit. The robotic suit is designed for difficult agricultural tasks, such as frequent harvesting of radish. The suit has eight motors set across shoulders, elbows, back, and knees to provide the carrier with more strength. The current model weighs 26 kilograms (Fig. 12).

Figure 12 Agriculture robot suit (Source: Toyama Lab [46])

Robots substitute human labour and ensure a fast return on investment. They are increasingly useful in situations that present health and safety hazards. The research [48] cites that robotic systems must be both economically efficient as well as safe and reliable regarding people, environment, and crops. The authors [49] argue that robot application decreases human labour and increases productivity. Additionally, it decreases yield loss. It is of special importance that in cases when robots use certain programmes to create practical recommendations or when they perform specific agricultural tasks, the level of environmental protection and human safety increases.

In Frence was invented the first autonomous electric weed control robot powered by commercial farms. The *Oz* robot (Fig. 13) is designed for application in small gardens, *Dino* (Fig. 14) is used for large vegetable crops, and *Ted* (Fig. 15) for vineyards and orchards and can cover up to 10 acres per day.

Figure 13 Robot Oz (Source: www.naio-technologies.com [50])

Oz is a self-contained robot that has four 110 W electric motors and four drive wheels. With its use, weed control is significantly easier and simpler, because it has a high degree of precision, and since it works on an electric motor, it does not produce exhaust gases. *Dino* has been used on a variety of crops such as lettuce, tomatoes, garlic, cabbage, pepper and celery and in a variety of soil conditions. The *Dino* robot can work between 6 to 8 hours, depending on soil conditions and how many tools it used at the same time. The robots have

their own navigation system so that it can be used for various types of crops [50].

Figure 14 Robot Dino (Source: www.naio-technologies.com [50])

Figure 15 Robot Ted (Source: www.naio-technologies.com [50])

One of the newer smaller weed removal robots is the *Tertill*. Tertill consists of sensors, weed cutters, solar panel, speakers, robot status indicator, power button, handle, and extreme wheels (Fig. 16).

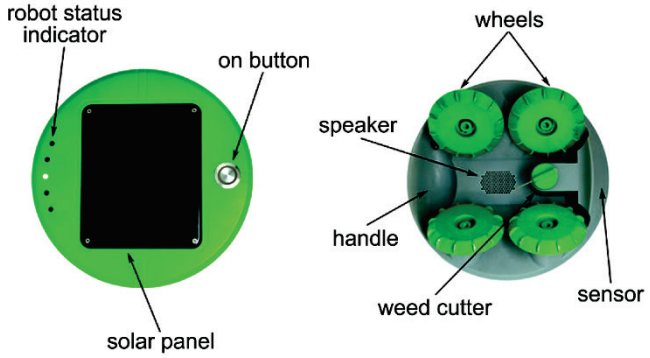

Figure 16 Tertill robot parts (Source: https://tertill.com)

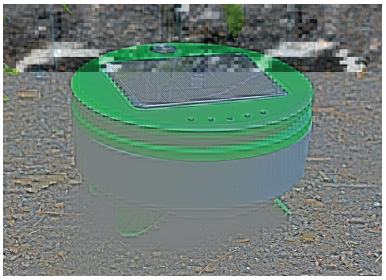

Figure 17 Robot Tertill (Source: https://agtecher.com/product/tertill-robot/)

The working principle is on the simple understanding that plants are long and weeds so anything below 2 inches is a weed. He walks through the field looking for weeds, then cuts them with a rotating nylon cutter. The solar panel and cell use sunlight for electricity and give the necessary power to the robot (Fig. 17) [51].

A pre-commercial electric robot for strawberry harvesting has been developed in Spain. It has own real time AI and integrated color and infrared depth sensors to capture harvest details. From a customizable mobile platform (Fig. 18), 24 robotic manipulators together harvest only those fruits that meet agricultural quality standards [52].

Figure 18 Robot Agrobot (Source: https://www.agrobot.com/e-series/ [52])

For harvesting sweet pepper was developed a prototype robotic harvester *Harvey* (Fig. 19). Using geometry model to get location, computer algorithms and grippers robot manage and detach pepper from plant [53]. Using very similar working principle a robot Sweeper works (Fig. 20). It has RGB-D camera, algorithm Blob detection, pixel based routine and SSD detector (Single Shot Detector) [54].

Figure 19 Robot Harvey (Source: https://research.qut.edu.au/future-farming [53])

Figure 20 Robot Sweeper (Source: http://www.sweeper-robot.eu/ [54])]

For the plant protection agricultural robot *Bonirob* has important role. *Bonirob* (Fig. 21) automates and speeds up analysis. The robot uses video and lidar (3D MEMS lidar, Nippon signal) based positioning as well as satellite navigation to find its way around the fields with RTK. All hardware is connect to main navigation control unit (Fig. 22) [55, 56].

For the thai-style dairy farms for milking is designed robot *RoboMax* (Fig. 23). It goes from cow to cow making

possible 3 milking a day at regular intervals. Robotic arm cleans the cows teats individually. Laser guided system confirms exact positioning of each teat before attachment teat. Teat cups are attached one bye one and the milk from each quarter is analyzed separately. The milk is monitored to detect contamination providiny precise results on the quantity and quality of milk produced. It has remote access so farmer can be informed on a state and performance of the robot [57].

Figure 21 Robot Bonirob (Source: https://linx-global.com [55])]

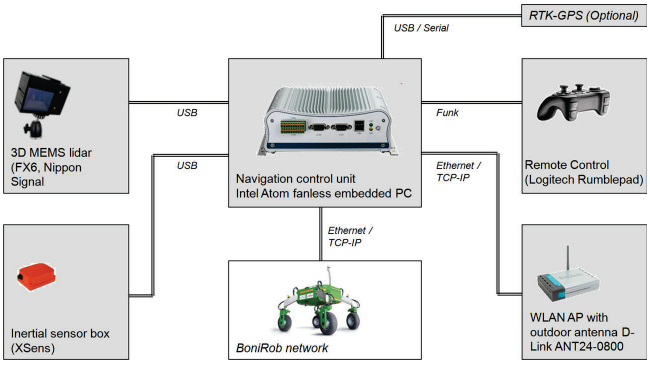

Figure 22 Navigation system hardware Bonirob (Source: https://www.cs.cmu.edu/search/site/robotics?page=1 [56])]

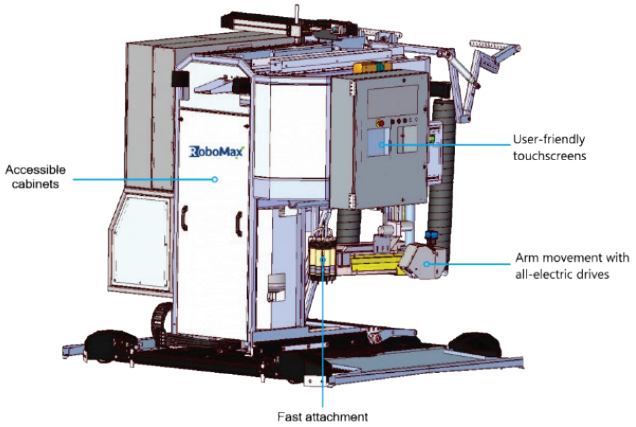

Figure 23 Robot RoboMax (Source: https://milkomax.com/en/robomax/ [57])]

4 CONCLUSIONS

The paper depicts a way in which future agricultural production can be automated. Even though the current agrotechnical operations can be performed by people, there is a growing demand for high efficiency in large production areas. The application of robots, robotic systems, and autonomous devices results in a decrease of work operations.

The development of robots has been gradual and the whole concept requires a change in the way of deployment of agricultural machinery, especially the adoption of new ways and approaches.

There are multiple advantages of robotics application in agriculture, such as control and reduction of costs, which have been high until now. Hard and hazardous agricultural tasks justify the use of robots. The rapid development of agricultural robots is based on sensors and the application of artificial intelligence. Furthermore, strenuous work, such as fast and repetitive decision making in fruit picking, can be replaced. A key advantage of robots is that they can perform in conditions in which people cannot ensure good work quality, such as in dark spaces, which can negatively affect quality, productivity, and profit. The use of robots in agriculture fulfils all economic and time management principles that people fail to accomplish.

The main disadvantages of robots are reducing the chances of employment in the industries, farms don't need human labor, robots can't manage in unexpected situations. There is always a chance for machine damages so farms can easily come under chaos. Training costs of employees to work with robots and the installation of machines in the workplace are very high.

5 REFERENCES

[1] Zutven, P., Kostic, D., & Nijmeijer, H. (2009). Modeling, identification and stability of humanoid robots. *Master thesis*, Eindhoven University of Technology. Retrieved from https://www.tudelft.nl/en/3me/about/departments/biomechanical-engineering

[2] Billingsley, J., Visala, A., & Dunn, M. (2008). Robotics in Agriculture and Forestry. In: Siciliano, B. & Khatib, O. (Eds) *Springer Handbook of Robotics*. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-30301-5_47

[3] Billingsley, J. (2000). Low Cost GPS for the Autonomous Robot Farmhand. *Proceedings of the 7th Annual Conference on Mechatronics and Machine Vision in Practice*, 119-125. Retrieved from https://eprints.usq.edu.au/5583/

[4] Åstrand, B. & Baerveldt, A. J. (2002). An agricultural mobile robot with vision-based perception for mechanical weed control. *Autonomous robots, 13*(1), 21-35. https://doi.org/10.1023/A:1015674004201

[5] Bakker, T., van Asselt K., Bontsema, J., Müller, J., & van Straten, G. (2011). Autonomous navigation using a robot platform in a sugar beet field. *Biosystems Engineering*, *109*(4), 357-368. Retrieved from https://www.sciencedirect.com/science/article/pii/S1537511011000791

[6] Li, M., Imou, K., Wakabayashi, K., & Yokoyama, S. (2009). Review of research on agricultural vehicle autonomous guidance. *International Journal of Agricultural and Biological Engineering*, *2*(3), 1-16. Retrieved from http://ijabe.org/index.php/ijabe/article/view/160

[7] Pedersen, S. M., Fountas, S., Have, H., & Blackmore, B. S. (2006). Agricultural robots—system analysis and economic feasibility. *Precision agriculture*, *7*(4), 295-308. Retrieved

from https://link.springer.com/article/10.1007/s11119-006-9014-9

[8] Stentz, A., Dima, C., Wellington, C., Herman, H., & Stager, D. (2002). A system for semi-autonomous tractor operations. *Autonomous Robots, 13*(1), 87-104. Retrieved from https://link.springer.com/article/10.1023/A:1015634322857

[9] Emmi, L., Gonzalez-de-Soto, M., Pajares, G., & Gonzalez-de-Santos, P. (2014). New trends in robotics for agriculture: integration and assessment of a real fleet of robots. *The Scientific World Journal*, 1-21. Retrieved from https://www.hindawi.com/journals/tswj/2014/404059/

[10] Raguž, R. (2019). *Application of robotics in primary school*, Pula.

[11] Zutven, P. W. M. (2009). *Modeling, identification and stability of humanoid robots with a case study on humanoid robot Tulip*, Eindhoven.

[12] Lipnjak, G. (2019). Artificial intelligence and robotics in the function of occupational health protection. *The 14th International Conference Management and safety*. Retrieved from http://www.european-safety-engineer.org

[13] Lapov Padovan, Z., Kovačević, S., & Purković, D. (2018). Curriculum development of primary school teaching of robotics, *Polytechnica: Journal of Technology Education, 2*(1), 7-34. Retrieved from https://hrcak.srce.hr/index.php?show=clanak&id_clanak_jezik=305689

[14] Zimmer, D., Jurišić, M., Plaščak, I., & Radočaj, D. (2020). Application of robots and robotic systems in agricultural practice. *Agriculture in nature and environment protection*, 356-361.

[15] Yaghoubi, S., Akbarzadeh, N. A., Bazargani, S. S., Bazargani, S. S., Bamizan, M., & Asl, M. I. (2013). Autonomous robots for agricultural tasks and farm assignment and future trends in agro robots. *International Journal of Mechanical & Mechatronics Engineering, 13*(3), 1-6. Retrieved from http://ijens.org/IJMME%20Vol%2013%20Issue%2003.html

[16] Adamides, G., Katsanos, C., Constantinou, I., Christou, G., Xenos, M., Hadzilacos, T., & Edan, Y. (2017). Design and development of a semi-autonomous agricultural vineyard sprayer: Human–robot interaction aspects. *Journal of Field Robotics, 34*(8), 1407-1426. Retrieved from https://onlinelibrary.wiley.com/doi/full/10.1002/rob.21721

[17] Adamides, G., Katsanos, C., Parmet, Y., Christou, G., Xenos, M., Hadzilacos, T., & Edan, Y. (2017). HRI usability evaluation of interaction modes for a teleoperated agricultural robotic sprayer. *Applied ergonomics*, 62, 237-246. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0003687017300674

[18] Moreno, F. A., Cielniak, G., & Duckett, T. (2013). Evaluation of laser range-finder mapping for agricultural spraying vehicles. *Towards Autonomous Robotic Systems*, 210-221, Berlin. Retrieved from https://link.springer.com/chapter/10.1007/978-3-662-43645-5_22

[19] Oberti, R., Marchi, M., Tirelli, P., Calcante, A., Iriti, M., Hočevar, M., Baur, J., Pfaff, J., Schütz, C., & Ulbrich, H. (2013). Selective spraying of grapevine's diseases by a modular agricultural robot. *Journal of Agricultural Engineering, 44*(2). https://doi.org/10.4081/jae.2013.271

[20] Akbar, S. A., Chattopadhyay, S., Elfiky, N. M., & Kak, A. (2016). A novel benchmark RGBD dataset for dormant apple trees and its application to automatic pruning. *In Proceedings of the IEEE conference on computer vision and pattern recognition workshops*, 81-88. Retrieved from https://www.cv-foundation.org/openaccess/content_cvpr_2016_workshops/w9/html/Akbar_A_Novel_Benchmark_CVPR_2016_paper.html

[21] Bac, C. W., Henten, E. J., Hemming, J., & Edan, Y. (2014). Harvesting robots for high-value crops: State-of-the-art review and challenges ahead. *Journal of Field Robotics, 31*(6), 888-911. https://doi.org/10.1002/rob.21525

[22] De-An, Z., Jidong, L., Wei, J., Ying, Z., & Yu, C. (2011). Design and control of an apple harvesting robot. *Biosystems engineering, 110*(2), 112-122. https://doi.org/10.1016/j.biosystemseng.2011.07.005

[23] Nuske, S., Achar, S., Bates, T., Narasimhan, S., & Singh, S. (2011). Yield estimation in vineyards by visual grape detection, *In 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2352-2358. https://doi.org/10.1109/IROS.2011.6095069

[24] Nuske, S., Achar, S., Gupta, K., Narasimhan, S. G., & Singh, S. (2011). Visual yield estimation in vineyards: Experiments with different varietals and calibration procedures. Retrieved from https://www.researchgate.net/publication/261437679_Visual_Yield_Estimation_in_Vineyards_Experiment

[25] Corollaro, M. L., Aprea, E., Endrizzi, I., Betta, E., Demattè, M. L., Charles, M., Costa, F., Biasioli, F., Corelli, L., & Gasperia, F. (2014). A combined sensory-instrumental tool for apple quality evaluation. *Postharvest Biology and Technology*, 96, 135-144. https://doi.org/10.1016/j.postharvbio.2014.05.016

[26] Donis-González, I. R., Guyer, D. E., & Pease, A. (2016). Postharvest noninvasive assessment of undesirable fibrous tissue in fresh processing carrots using computer tomography images. *Journal of Food Engineering*, 190, 154-166. https://doi.org/10.1016/j.jfoodeng.2016.06.024

[27] Lunadei, L., Diezma, B., Lleo, L., Ruiz-Garcia, L., Cantalapiedra, S., & Ruiz-Altisent, M. (2012). Monitoring of fresh-cut spinach leaves through a multi-spectral vision system. *Postharvest Biology and Technology, 63*(1), 74-84. https://doi.org/10.1016/j.postharvbio.2011.08.004

[28] Munera, S., Besada, C., Blasco, J., Cubero, S., Salvador, A., Talens, P., & Aleixos, N. (2017). Astringency assessment of persimmon by hyperspectral imaging. *Postharvest Biology and Technology*, 125, 35-41. https://doi.org/10.1016/j.postharvbio.2016.11.006

[29] Pace, B., Cefola, M., Renna, F., & Attolico, G. (2011). Relationship between visual appearance and browning as evaluated by image analysis and chemical traits in fresh-cut nectarines. *Postharvest Biology and Technology*, *61*(2-3), 178-183. https://doi.org/10.1016/j.postharvbio.2011.03.005

[30] Dael, M., Verboven, P., Dhaene, J., Hoorebeke, L., Sijbers, J., & Nicolai, B. (2017). Multisensor x-ray inspection of internal defects in horticultural products. *Postharvest Biology and Technology*, 128, 33-43. https://doi.org/10.1016/j.postharvbio.2017.02.002

[31] Cheein, F. A., Steiner, G., Paina, G. P., & Carelli, R. (2011). Optimized eif-slam algorithm for precision agriculture mapping based on stems detection. *Computers and Electronics in Agriculture, 78*(2), 195-207. https://doi.org/10.1016/j.compag.2011.07.007

[32] Lukenda, D. (2015). Economic justification of introducing robots in the production process, Zagreb, 2015. Retrieved from https://eprints.grf.unizg.hr/2430/

[33] Noguchi, N., Will, J., Reid, J., & Zhang, Q. (2004). Development of a master–slave robot system for farm operations. *Computers and Electronics in agriculture, 44*(1), 1-19. https://doi.org/10.1016/j.compag.2004.01.006

[34] Schueller, J. K. (2006). Cigr handbook of agricultural engineering (6), 46. Retrieved from https://cigr.org/node/640

[35] Iida, M., Suguri, M., Uchida, R., Ishibashi, M., Kurita, H., & Won-Jae, C. (2013). Advanced harvesting system by using a combine robot. *IFAC Proceedings Volumes, 46*(4), 40-44.

https://doi.org/10.3182/20130327-3-JP-3017.00012
[36] Bechar, A. & Vigneault, C. (2016). Agricultural robots for field operations: Concepts and components. *Biosystems, Engineering*, 149, 94-111. https://doi.org/10.1016/j.biosystemseng.2016.06.014
[37] Zhang, Z., Noguchi, N., Ishii, K., Yang, L., & Zhang, C. (2013). Development of a robot combine harvester for wheat and paddy harvesting. *IFAC Proceedings Volumes, 46*(4), 45-48. https://doi.org/10.3182/20130327-3-JP-3017.00013
[38] Soffar, H. (2020). Robots in the Workplace advantages, disadvantages and applications, *Robotics*. Retrieved from https://www.online-sciences.com/robotics/robots-in-the-workplace-advantages-disadvantages-applications/
[39] Nepalla, C. (2018). Agriculture robots the farmers of the future, Rajasthan. Retrieved from https://www.mpuat.ac.in/ singlePage.php?id=60&type=SP
[40] Jankhaniya, A. (2015). Pest controlling in agriculture by automatic robot, Gandhinagar. Retrieved from https://www.scribd.com/document/409423022/ppt-150909043244-lva1-app6891
[41] Canning, J. R., Edwards, D. B., & Anderson, M. J. (2004): Development of a fuzzy logic controller for autonomous forest path navigation. *Transactions of the ASAE, 47*(1), 301. https://doi.org/10.13031/2013.15855
[42] Crneković, M. (2016). Industrial and mobile robots. Zagreb. (in Croatian)
[43] Font, D., Pallejà, T., Tresanchez, M., Runcan, D., Moreno, J., Martínez, D., Teixidó, M., & Palacín, J. (2014). A proposal for automatic fruit harvesting by combining a low cost stereovision camera and a robotic arm. *Sensors, 14*(7), 11557-11579. https://doi.org/10.3390/s140711557
[44] http://robotics.ee.pusan.ac.kr/ (Accessed: 17.02.2021.)
[45] Chalwa, V. N. & Gundagi, S. S. (2014). Mechatronics Based Remote Controlled Agricultural Robot. *International Journal of Emerging Trends in Engineering Research, 2*(7). Retrieved from warse.org/pdfs/2014/ijeter01272014.pdf
[46] https://www.istockphoto.com/illustrations/smart-farm (Accessed: 17.02.2021)
[47] https://www.ecorobotix.com/en/autonomous-robot-weeder/ (Accessed: 17.02.2021)
[48] http://web.tuat.ac.jp/~toyama/research_assistancesuitE.html (Accessed: 17.02.2021)
[49] Milić, V. (2015). Minimax optimal control of nonlinear dynamical systems, Zagreb. Retrieved from https://urn.nsk.hr/urn:nbn:hr:235:830309
[50] https://www.naio-technologies.com/en/agricultural-equipment (Accessed: 17.02.2021)
[51] https://tertill.com/pages/tertill-reviews (Accessed: 17.02.2021)
[52] https://www.agrobot.com/e-series (Accessed: 27.02.2021)
[53] https://research.qut.edu.au/future-farming (Accessed: 27.02.2021)
[54] http://www.sweeper-robot.eu/ (Accessed: 27.02.2021)
[55] https://linx-global.com/blog/2017/10/17/an-agricultural-weed-killing-robot-that-doesnt-use-chemicals (Accessed: 27.02.2021)
[56] Biber, P., Weiss, U., Dorna, M., & Albert, A. (2012). Navigation System of the Autonomous Agricultural Robot "BoniRob". *Proceedings of the 2012 IROS Workshop on Agricultural Robotics: Enabling Safe, Efficient, Affordable Robots for Food Production*. https://www.cs.cmu.edu/~mbergerm/ agrobotics2012/01Biber.pdf (Accessed: 27.02.2021)
[57] https://milkomax.com/en/robomax/ (Accessed: 27.02.2021)

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Professional paper

Removal of Heavy Metals from Tie and Dye (Adire) Wastewater Using Low-Cost Adsorbents

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Abstract: Rapid industrialization has succeeded in constantly releasing hazardous heavy metals into the environment; however the need to minimize this risk has become a global concern. This study is to investigate the effectiveness of rice husk, sawdust and sugarcane bagasse as low cost adsorbents in heavy metals removal and to reduce the environmental pollution caused by these heavy metals. Columns of four different adsorbents (rice husk, sawdust, sugarcane bagasse and the mixture of the three) were set up and the Adire wastewater was passed through them. The adsorbents, the effluents and the filtrates were taken for physico-chemical and heavy metals analyses. The results showed that sugarcane bagasse adsorbent is the most effective in the physical and chemical treatment of the wastewater used, while the sawdust adsorbent is most effective in the removal of Copper, Chromium, Nickel and Iron.

Keywords: adsorbents; heavy metals; pollution; wastewater

1 INTRODUCTION

The removal of metal ions from effluents is important to many countries of the world both for environmental safety and for water re-use. Heavy metals have been excessively released into the environment due to rapid industrialization and have created a major global concern. Cadmium, Zinc, Copper, Nickel, Lead, Mercury and Chromium are often detected in industrial wastewaters, which originate from metal plating, mining activities, smelting, battery manufacture, tanneries, petroleum refining, paint manufacture, pesticides, pigment manufacture, printing, photographic industries, etc. (as cited in [1]). In addition, soil is a great geochemical reservoir for contaminant as well as a natural buffer for transportation of chemical materials and elements in the atmosphere, hydrosphere, and biomass. For this, it is the most important component of the human biosphere. As soil is an important constituent of the human biosphere, any harmful change to this segment of the environment seriously affects the overall quality of human life. The most adverse effect of heavy metals is that they can be introduced into the food chain and threaten human health [2].The search for low-cost adsorbents that have pollutant-binding capacities is extremely meaningful for efficient water and wastewater treatment. It was confirmed by [3] that the quality of drinking water, especially in developing countries can be enormously improved by the use of clay-sawdust composite filter. They submitted further that well water, harvested rainwater as well as surface runoff can be converted to potable water by subjecting them to filtration using Point-of-Use (POU) filters as this will go a long way to reduce the burden of water-borne diseases in developing countries and also ensure sustainable water supply. Sugarcane bagasse can be one of the materials to separate oil and water as an alternative method of separation. This alternative method can be used as one of the methods to separate oil from water for cleaning the waste oil from oil spills as well as a method to separate oil from palm oil industrial waste [4], similarly Sugar Cane Bagasse based Activated Carbons (SCBACs) were extremely viable adsorbents for application in the removal of phenol from aqueous solutions [5]. The properties of ceramic filter manufactured from local material clay and additives (sawdust and rice husk) by two simple techniques (slip casting and semi-dry pressing) were worked upon by [6]. They concluded that the slip casting technique was a more suitable procedure for producing a porous ceramic filter. The freely abundant, locally available, low-cost adsorbent like Teff straw can be treated as economically viable for the removal of metal ions from textile effluents [7], and the fixed bed column treatment system as proposed by [8] is appropriate and suitable domestic approach to arsenic removal in local areas, because of its simplicity, easy operation and handling. By-products of agricultural materials such as rice husk, sawdust and sugarcane bagasse which require little processing and are abundant in nature have been effective for removal of heavy metals from wastewater. These low cost adsorbents are valuable alternatives for commercial sorbents. However, the contamination levels in soil or water bodies can be determined from the index of geo-accumulation (I_{geo}) shown in Tab. 1(as cited in [2] and [9]).

Table 1 Index of geoaccumulation (Igeo) for contamination levels in soil/water bodies

I_{geo} Class	I_{geo} Value	Contamination Level
0	$I_{geo} \leq 0$	Uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated/moderately contaminated
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately/strongly contaminated
4	$3 < I_{geo} < 4$	Strongly contaminated
5	$4 < I_{geo} < 5$	Strongly/extremely contaminated
6	$5 < I_{geo}$	Extremely contaminated

The aim of this project is to investigate the effectiveness of rice husk, sawdust and sugarcane bagasse as low-cost adsorbents in heavy metals removal and to reduce the environmental pollution caused by the heavy metals.

2 EXPERIMENTAL

2.1 Materials and Equipment Required for the Study

The materials and equipment used include:

- Adire wastewater collected from Itoku market, Abeokuta
- Rice husk obtained at Imota, Lagos State
- Sawdust

- Sugarcane bagasse
- Distilled water
- Sieve
- Infusion sets
- Filtering media
- Separating columns (plastic bottles).

2.2 Experimental Procedure

2.2.1 Preparation of Rice Husk

The rice husk obtained from Idumota, Lagos State, was washed with distilled water to remove surface impurities and dried under the sun for 24 hours. The dried rice husk was further ground to increase the surface area and later sieved using 1mm sieve size.

2.2.2 Preparation of Sawdust

The sawdust obtained from Camp Sawmill, Abeokuta was washed with distilled water to remove surface impurities and dried under the sun for 24 hours. The dried material was sieved using sieve size 1 mm.

2.2.3 Preparation of Sugarcane Bagasse

The back peel of sugarcane was collected from local Hausa sellers and sun-dried for 24 hours. The dried samples were heated or burnt leaving the ash residue. The ash was further ground using pestle to increase the surface area of the material. Sugarcane bagasse obtained was passed through 1 mm sieve before use.

2.2.4 Wastewater Sample Collection

The wastewater was collected using grab sampling method. The process involved a single sample taken at a specific time or over as short a period as feasible. Sample bottle was rinsed first with ordinary water and then distilled water, before pouring the sample in the sample bottle. The coordinates of the location being N7.1568450 and E3.3423530.

2.2.5 Filters Set-Up and Filtration

The setup of the filters was done using a 75 cl plastic bottle for the column experiment and a retort stand was used to hold the bottle firm for the experiment. The adsorbents were poured in the plastic bottle (75 cl) at a height of 15 cm mark. The cover of the bottle was bored and a filtering media (light cloth) was used to prevent blockage and ease the discharge of the effluents. The infusion set was fixed to one end of the bottle and the other part to the effluent bottle. The weight of the rice husk, sawdust, sugarcane bagasse and the mixture of the three was found to be 2.06 g, 1.08 g, 1.54 g and 1.60 g respectively. The mixture was arranged as sugar cane bagasse, sawdust and rice husk in ascending order of the set up. After the setup of the filters, the Adire wastewater was then passed through each of the four filters

2.2.6 Batch Sorption Experiment

Batch adsorption experiment was performed at different temperatures and initial concentrations to obtain equilibrium isotherms. In order to obtain the adsorption capacity, the number of ions adsorbed per mass unit of the agricultural by-product was evaluated using the following expression:

$$Q_e = \frac{(C_0 + C_e) \cdot V}{m}. \quad (1)$$

Where Q_e is the amount adsorbed at equilibrium (mg/g), C_0 is the initial metal ions concentration (mg/l), C_e is the equilibrium metal ions concentration (mg/l), V is the volume of the aqueous phase (l), and m is the amount of the adsorbent used (g).

2.2.7 Physico-Chemical and Heavy Metals Analyses

The effluents and the adsorbents were taken to LAGOS STATE ENVIRONMENTAL PROTECTION AGENCY to carry out the parameter tests. Initial and final concentrations of metals were determined by atomic absorption spectroscopy (AAS).

3 RESULTS AND DISCUSSION

The results of the physio-chemical and heavy metal analyses of the effluents, the filtrates and the adsorbents are as shown in Tabs. 2-5.

Table 2 Physical Analysis of the Effluents

Physical Parameter	A	B	C	D	LASEPA Standard
Colour	4200	4137	2455	4110	250 Pt. Co. APHA
Appearance	Deep brown with odour	Brownish with odour	Light brown with sediment	Brownish with odour	Clear
Temperature °C	24.8	24.8	25.0	24.9	≤40 °C
pH	8.74	9.74	9.78	9.98	5.5 - 9.0
Turbidity	917	412	53.7	155	NTU
Conductivity	44.89	28.02	10.07	11.3	mS/cm
Total Suspended Solids	830	1076	413	495	25 mg/l

The effluent from sample D (combination of the three adsorbents) has the highest pH (9.98) which relates with basicity from Tab. 2 above. Effluent from sample C (sugarcane bagasse) has the lowest Turbidity, Conductivity and Total Suspended Solids with values 53.7 NTU, 10.07 mS/cm and 413 mg/l respectively in Tab. 2 above. This

shows that sugarcane bagasse is the most effective in the physical treatment of the wastewater used. Chemical Oxygen Demand and Biochemical Oxygen Demand has its lowest value in sample C of 758 mg/l and 189.5 mg/l respectively as shown in Tab. 3. Sample A has the highest COD and BOD of 7558 mg/l and 1889.5 mg/l respectively. This implies that sugarcane bagasse was the most effective in treating the chemical parameters of the wastewater.

Table 3 Chemical Analysis of the Effluents

Chemical Parameter	A	B	C	D	LASEPA Standard
Chloride	3870	2930	590	510	100 mg/l
Nitrate	0	3.0	1.3	0.15	
Phosphate	0.35	0.17	5.56	0.71	
Sulphate	0	0	0	1	100 mg/l
Chemical Oxygen Demand	7558	4605	758	2208	80.00 mg/l
Biological Oxygen Demand	1889.5	1151.25	189.5	552	20.00 mg/l

Table 4 Heavy Metals Analysis of the Effluents

Trace/Toxic Heavy Metals	A	B	C	D	E	LASEPA Standard
Lead	0.0012	0.0028	0.0004	0.0730	0.2182	0.1 mg/l
Copper	0.0011	0.0018	0.0026	0.0012	0.1102	0.5 mg/l
Chromium	0.0043	0.0207	0.0036	0.0127	0.6887	0.5 mg/l
Nickel	0.0011	0.0056	0	0.0041	0.3115	0.5 mg/l
Zinc	0.0106	0.0153	0.00037	0.00152	0.3894	2.0 mg/l
Iron	0.0388	0.0943	0.0693	0.02312	2.7447	NS

Table 5 Heavy Metals Analysis of the Adsorbents

Trace/Toxic Heavy Metals	A	B	C	D	E	LASEPA Standard
Lead	0.2100	0.2130	0.2150	0.1420	0.2182	0.1 mg/l
Copper	0.1080	0.1070	0.1065	0.1080	0.1102	0.5 mg/l
Chromium	0.6840	0.6675	0.6840	0.670	0.6887	0.5 mg/l
Nickel	0.3100	0.3045	0.3110	0.3065	0.3115	0.5 mg/l
Zinc	0.3780	0.3735	0.3880	0.3878	0.3894	2.0 mg/l
Iron	2.7049	2.6500	2.6740	2.7205	2.7447	NS

Key: A - Rice Husk; B – Sawdust; C - Sugarcane Bagasse; D - Rice Husk, Sawdust and Sugarcane Bagasse; E - Control Sample; NS - Not Specified; Pt. Co. APHA - Platinum Cobalt APHA Method

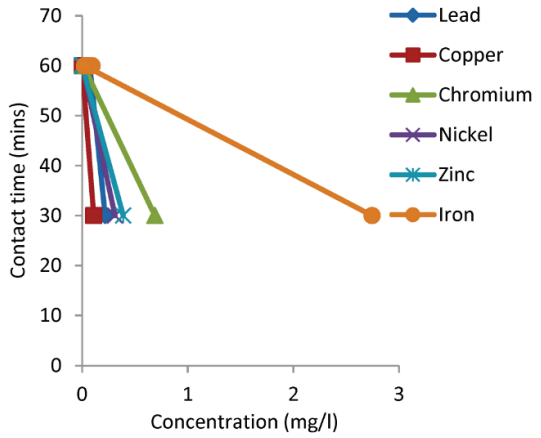

Figure 1 Adsorption Rate of Heavy Metals on the Effluents

The results of batch sorption experiment on the effluents, the filtrates and the adsorbents are as shown in Figs. 1-6. The volume V = 0.5 cl and mass m = 2.06 g, 1.08 g, 1.54 g and 1.60 g for rice husk, sawdust, sugarcane bagasse and the three mixtures respectively. From Figs. 3-6, it can be deduced that sample D has the highest adsorption rate for Lead (0.1775 mg/g), Sample B has the highest adsorption rate for Copper (0.0495 mg/g), Chromium (0.3090 mg/g), Nickel (0.1410 mg/g) and Iron (1.2269 mg/g). This implies that Sample B, sawdust, is most effective in the removal of Copper, Chromium, Nickel and Iron. Sample C has the highest adsorption rate for Zinc 0.126 mg/g.

1) Rice Husk

For Lead Q_e = 0.0510 mg/g, for Copper Q_e = 0.0262 mg/g, for Chromium Q_e = 0.1660 mg/g, for Nickel Q_e = 0.0752 mg/g, for Zinc Q_e = 0.0917 mg/g, for Iron Q_e = 0.6565 mg/g

2) Sawdust

For Lead Q_e = 0.0986 mg/g, for Copper Q_e = 0.0495 mg/g, for Chromium Q_e = 0.3090 mg/g, for Nickel Q_e = 0.1410 mg/g, for Zinc Q_e = 0.0017 mg/g, for Iron Q_e = 1.2269 mg/g

3) Sugarcane Bagasse

For Lead Q_e = 0.0698 mg/g, for Copper Q_e = 0.0346 mg/g, for Chromium Q_e = 0.2221 mg/g, for Nickel Q_e = 0.1010 mg/g, for Zinc Q_e = 0.1260 mg/g, for Iron Q_e = 0.8682 mg/g

4) Rice Husk, Sawdust and Sugarcane Bagasse

For Lead Q_e = 0.1775 mg/g, for Copper Q_e = 0.0338 mg/g, for Chromium Q_e = 0.2097 mg/g, for Nickel Q_e = 0.0973 mg/g, for Zinc Q_e = 0.1212 mg/g, for Iron Q_e = 0.8502 mg/g.

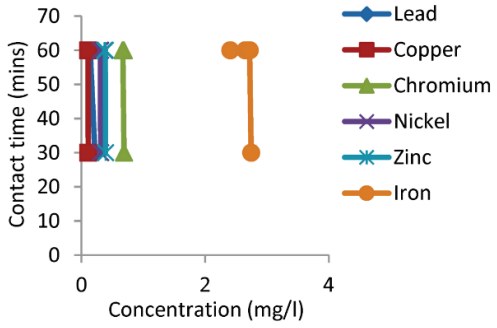

Figure 2 Adsorption Rate of Heavy Metals on the Adsorbents

Tabs. 6 and 7 show that the sediments have a low contamination level based on Pollution Load Index (*PLI*) and uncontaminated I_{geo} accumulation classification respectively.

$$PLI = \left(CF_1 \times CF_2 \times CF_3 \times \cdots \times CF_n\right)^{\frac{1}{n}}, \quad (2)$$

$$CF = \frac{Metal\ \ concentration\ \ in\ \ the\ \ sediments}{Background\ \ value\ \ of\ \ the\ \ metal}, \quad (3)$$

where n is the number of metals and CF is the Contamination Factor.

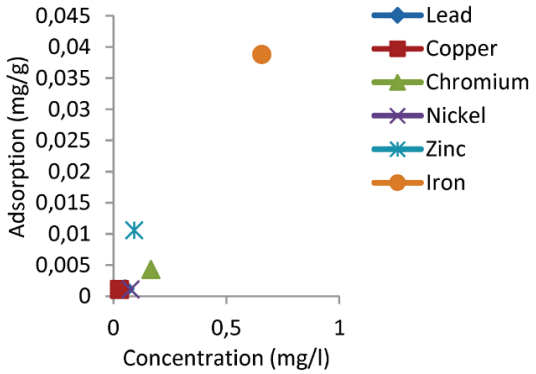

Figure 3 Adsorption of Heavy Metals by Rice Husk with pH of 8.74

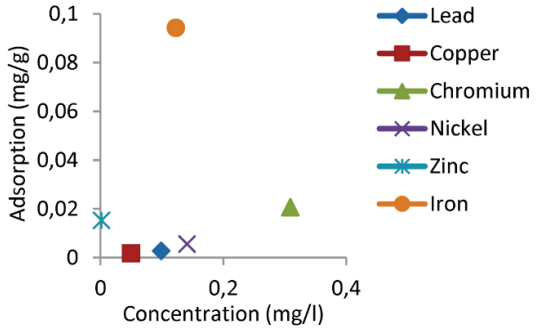

Figure 4 Adsorption of Heavy Metals by Sawdust with pH of 9.74

The PLI of each metal was classified as either low ($PLI \leq 1$), moderate ($1 < PLI \leq 3$) or high contamination ($PLI > 3$).

Geo-accumulation Index (I_{geo}):

$$I_{geo} = \log_2\left(\frac{C_n}{1.5 \times B_n}\right). \quad (4)$$

Wher C_n is the measured concentration of the metal n, within the sediment or size fraction; B_n represents the background concentration of the metal n.

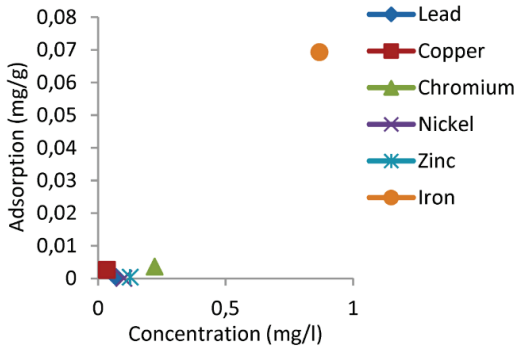

Figure 5 Adsorption of Heavy Metals by Sugarcane Bagasse with pH of 9.78

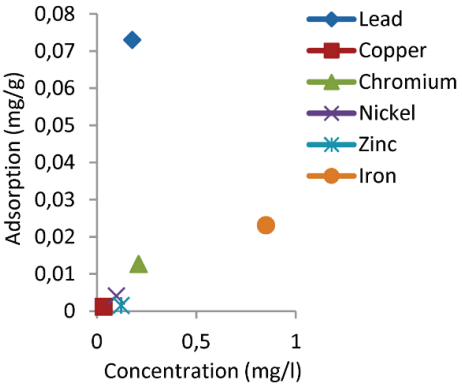

Figure 6 Adsorption of Heavy Metals by Rice Husk, Sawdust and Sugarcane Bagasse with pH of 9.98

Table 6 Contamination Factor and Pollution Load Indices of Heavy Metals

Heavy Metals	*CF* of A	*CF* of B	*CF* of C	*CF* of D	*PLI*	Classification
Lead	0.96242	0.976169	0.985335	0.650779	0.9190	low ($PLI \leq 1$)
Copper	0.980036	0.970962	0.966425	0.980036	0.9828	low ($PLI \leq 1$)
Chromium	0.993176	0.969217	0.993176	0.972847	0.9880	low ($PLI \leq 1$)
Nickel	0.995185	0.977528	0.998395	0.983949	0.9925	low ($PLI \leq 1$)
Zinc	0.970724	0.959168	0.996405	0.995891	0.9869	low ($PLI \leq 1$)
Iron	0.985499	0.965497	0.974241	0.991183	0.9860	low ($PLI \leq 1$)

Table 7 Geo-accumulation Index of the Heavy Metals Sediment

Heavy Metals	I_{geo} of A	I_{geo} of B	I_{geo} of C	I_{geo} of D	Classification
Lead	–0.6402	–0.6198	–0.6063	–1.2047	Uncontaminated ($I_{geo} \leq 0$)
Copper	–0.6141	–0.6275	–0.6342	–0.6141	Uncontaminated ($I_{geo} \leq 0$)
Chromium	–0.5948	–0.6275	–0.5948	–0.6247	Uncontaminated ($I_{geo} \leq 0$)
Nickel	–0.5919	–0.6178	–0.5873	–0.6083	Uncontaminated ($I_{geo} \leq 0$)
Zinc	–0.6278	–0.6451	–0.5902	–0.5909	Uncontaminated ($I_{geo} \leq 0$)
Iron	–0.6060	–0.6356	–0.6226	–0.5977	Uncontaminated ($I_{geo} \leq 0$)

Effect of Contact Time. The contact time of the adsorbents varied. The wastewater had a contact time of 1 hour with rice husk, sawdust and sugarcane bagasse, while it had a contact time of 30 minutes with the three adsorbents when mixed together. The average discharge was 0.0056 litres per minute (l/min). This implies that it will take 1.50 hours (One and a half hours) to get 0.5 l (0.5 litres) of wastewater effluent. The effect on contact time on the adsorbents is direct. This means that as the contact time increases, the rate of adsorption of the heavy metals increases also.

4 CONCLUSION

Agricultural by-products appear as effective and cheap sorbents for removal of heavy metals from wastewater. The sorption capacity of sawdust adsorbent was the most effective while the sugarcane adsorbent was the most effective in treating the physical and chemical pollutants of the wastewater.

5 REFERENCES

[1] Parmar, M. & Thakur, L. S. (2013). Heavy Metal Cu, Ni and Zn: Toxicity, Health Hazards and their Removal Techniques by Low Cost Adsorbents: A Short Overview. *International Journal of Plant, Animal and Environmental Sciences, 3*(3), 143-157.

[2] Rahman, S. H., Khanam, D., Adyel, T. M., Islam, M. S., Ahsan, M. A., & Akbor, M. A. (2012). Assessment of Heavy Metal Contamination of Agricultural Soil around Dhaka Export Processing Zone (DEPZ), Bangladesh: Implication of Seasonal Variation and Indices. *Journal of Appl. Sci.*, 2, 584-601. https://doi.org/10.3390/app2030584

[3] Nnaji, C. C., Afangideh, B. C., & Ezeh, C. (2016). Performance Evaluation of Clay-Sawdust Composite Filter for Point of Use Water Treatment. *Nigerian Journal of Technology (NIJOTECH), 35*(4), 949-956. https://doi.org/10.4314/njt.v35i4.33

[4] Noor Atikah Binti Mohd Badruddin. (2012). *Separation of Oil and Water Using Sugarcane Bagasse*, Universiti Malaysia Pahang, Faculty of Chemical & Natural Resources Engineering, Pahang. http://umpir.ump.edu.my/id/eprint/5120/1/CD6476.pdf

[5] Akl, M. A. A., Dawy, M. B., & Serage, A. A. (2014). Efficient Removal of Phenol from Water Samples Using Sugarcane Bagasse Based Activated Carbon. *Journal of Analytical& Bio-analytical Techniques, 5*(2), 1-12. https://doi.org/10.4172/2155-9872.1000189

[6] Shukur, M. M., Aswad, M. A., & Bader, S. M. (2018). Effects of Sawdust and Rice Husk Additives on Physical Properties of Ceramic Filter. *Journal of University of Babylon, Engineering Sciences, 26*(1), 221-228.

[7] Desta, M. B. (2013). Batch Sorption Experiments: Langmuir and Freundlich Isotherm Studies for the Adsorption of Textile Metal Ions onto Teff Straw (*Eragrostis tef*) Agricultural Waste. *Journal of Thermodynamics*, 1-6. https://doi.org/10.1155/2013/375830

[8] Asif, Z. & Chen, Z. (2017). Removal of Arsenic from Drinking Water Using Rice Husk. *Journal of Applied Water Science*, 7, 1449-1458. https://doi.org/10.1007/s13201-015-0323-x

[9] Rabee, A. M., Al-Fatlawy, Y. F., Abd-Al-Husain Najim Abd Own, & Nameer, M. (2011). Using Pollution Load Index (PLI) and Geoaccumulation Index (I-Geo) for the Assessment of Heavy Metals Pollution in Tigris River Sediment in Baghdad Region. *Journal of Al-Nahrain University, 14*(4), 108-114. https://doi.org/10.22401/JNUS.14.4.14

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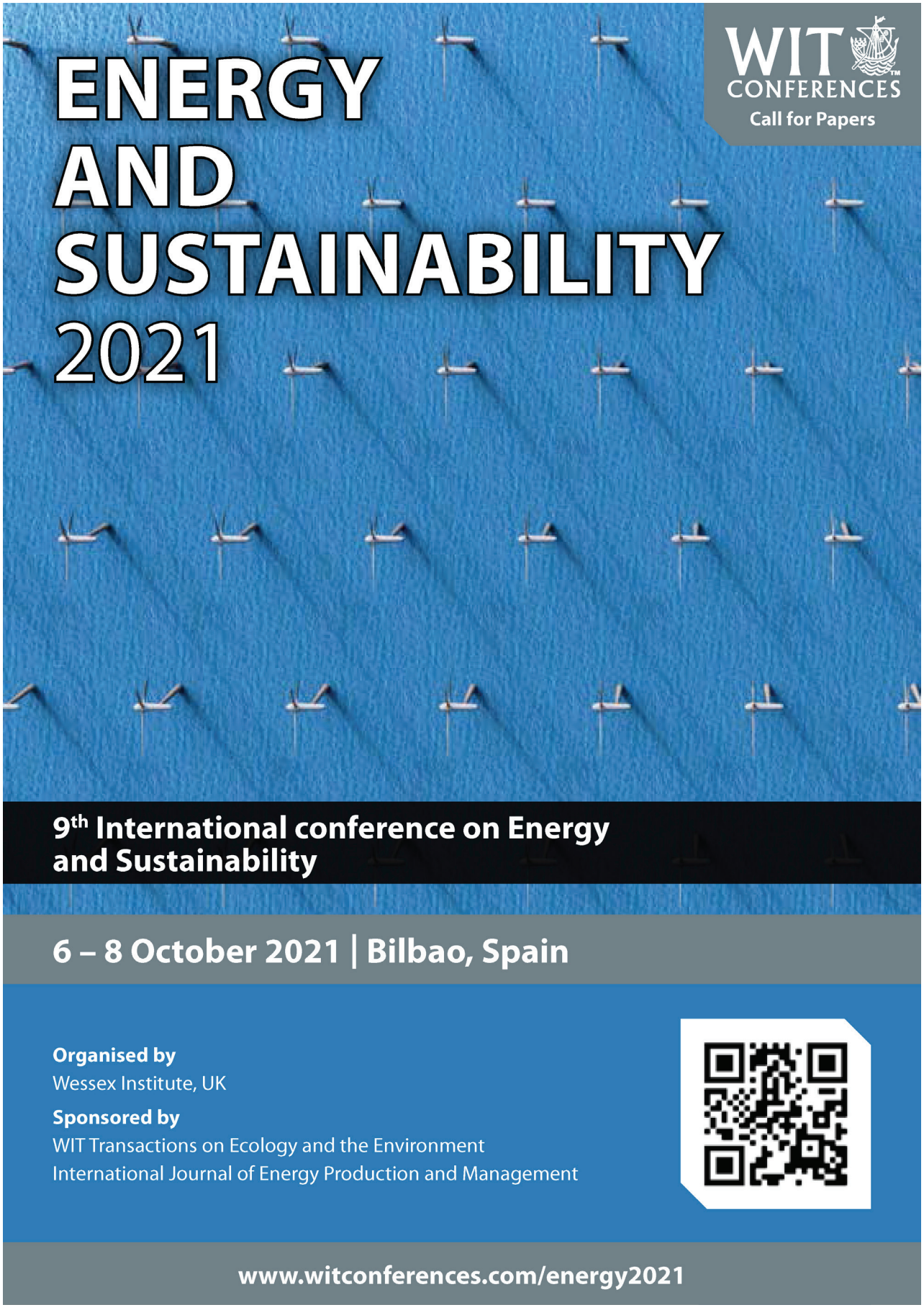
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14pt
14pt

Article Title Only in English (Style: Arial Narrow, Bold, 14pt)

14pt

Ivan Horvat, Thomas Johnson, Marko Marić (Style: Arial Narrow, Normal, 10pt)

14pt

Abstract: Article abstract contains maximum of 150 words and is written in the language of the article. The abstract should reflect the content of the article as precisely as possible. TECHNICAL JOURNAL is a trade journal that publishes scientific and professional papers from the domain(s) of mechanical engineering, electrical engineering, civil engineering, multimedia, logistics, etc., and their boundary areas. This document must be used as the template for writing articles so that all the articles have the same layout. (Style: Arial Narraw, 8pt)

8pt

Keywords: keywords in alphabetical order (5-6 key words). Keywords are generally taken from the article title and/or from the abstract. (Style: Arial Narraw, 8pt)

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1 INTRODUCTION (Article Design)

(Style: Arial Narrow, Bold, 10pt)

10pt

(Tab 6 mm) The article is written in Latin script and Greek symbols can be used for labelling. The length of the article is limited to eight pages of international paper size of Letter (in accordance with the template with all the tables and figures included). When formatting the text the syllabification option is not to be used.

10pt

1.1 Subtitle 1 (Writing Instructions)

(Style: Arial Narrow, 10pt, Bold, Align Left)

10pt

The document format is Letter with margins in accordance with the template. A two column layout is used with the column spacing of 10 mm. The running text is written in Times New Roman with single line spacing, font size 10 pt, alignment justified.

Article title must clearly reflect the issues covered by the article (it should not contain more than 15 words).

Body of the text is divided into chapters and the chapters are divided into subchapters, if needed. Chapters are numbered with Arabic numerals (followed by a period). Subchapters, as a part of a chapter, are marked with two Arabic numerals i.e. 1.1, 1.2, 1.3, etc. Subchapters can be divided into even smaller units that are marked with three Arabic numerals i.e. 1.1.1, 1.1.2, etc. Further divisions are not to be made.

Titles of chapters are written in capital letters (uppercase) and are aligned in the centre. The titles of subchapters (and smaller units) are written in small letters (lowercase) and are aligned left. If the text in the title of the subchapter is longer than one line, no hanging indents.

10pt

Typographical symbols (bullets), which are being used for marking an item in a list or for enumeration, are placed at a beginning of a line. There is a spacing of 10pt following the last item:

- Item 1
- Item 2
- Item 3

10pt

The same rule is valid when items are numbered in a list:

1) Item 1
2) Item 2
3) Item 3

10pt

1.2 Formatting of Pictures, Tables and Equations

(Style: Arial Narrow, 10pt, Bold, Align Left)

10pt

Figures (drawings, diagrams, photographs) that are part of the content are embedded into the article and aligned in the centre. In order for the figure to always be in the same position in relation to the text, the following settings should be defined when importing it: text wrapping / in line with text.

Pictures must be formatted for graphic reproduction with minimal resolution of 300 dpi. Pictures downloaded from the internet in ratio 1:1 are not suitable for print reproduction because of unsatisfying quality.

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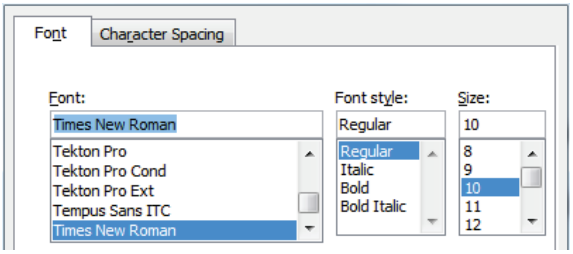

Figure 1 Text under the figure [1]
(Style: Arial Narraw, 8pt, Align Centre)

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The journal is printed in black ink and the figures have to be prepared accordingly so that bright tones are printed in a satisfactory manner and are readable. Figures are to be in colour for the purpose of digital format publishing. Figures in the article are numbered with Arabic numerals (followed by a period).

Text and other data in tables are formatted - Times New Roman, 8pt, Normal, Align Center.

When describing figures and tables, physical units and their factors are written in italics with Latin or Greek letters,

while the measuring values and numbers are written upright.

10pt

Table 1 Table title aligned centre

(Style: Arial Narraw, 8pt, Align Centre)

	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

10 pt

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

$$F_{\text{avg}}(t, t_0) = \frac{1}{t}\int_{t_0}^{t_0+t} F\left[q(\tau), p(\tau)\right] \mathrm{d}\tau, \tag{1}$$

$$\cos\alpha + \cos\beta = 2\cos\frac{\alpha+\beta}{2}\cdot\cos\frac{\alpha-\beta}{2}, \tag{2}$$

$$(\boldsymbol{AB})^{\mathrm{T}} = \boldsymbol{B}^{\mathrm{T}}\boldsymbol{A}^{\mathrm{T}}. \tag{3}$$

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Variables that are used in equations and also in the text or tables of the article are formatted as *italics* in the same font size as the text.

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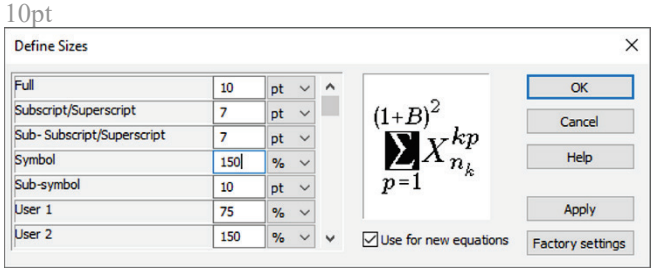

Figure 2 The texts under figures

(Style: Arial Narraw, 8pt, Align Centre)

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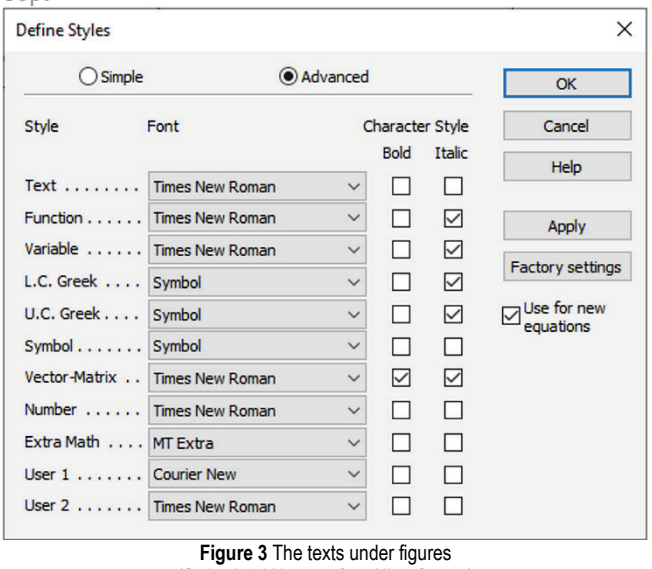

Figure 3 The texts under figures

(Style: Arial Narraw, 8pt, Align Centre)

Figures and tables that are a part of the article have to be mentioned inside the text and thus connected to the content i.e. " … as shown in Fig. 1…" or "data from Tab. 1…" and similar.

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2 PRELIMINARY ANNOTATION

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Article that is offered for publication cannot be published beforehand, be it in the same or similar form, and it cannot be offered at the same time to a different journal. Author or authors are solely responsible for the content of the article and the authenticity of information and statements written in the article.

Articles that are accepted for publishing are classified into four categories: original scientific papers, preliminary communications, subject reviews and professional papers.

Original scientific papers are articles that according to the reviewer and the editorial board contain original theoretical or practical results of research. These articles need to be written in such a way that based on the information given, the experiment can be repeated and the results described can be achieved together with the author's observations, theoretical statements or measurements.

Preliminary communication contains one or more pieces of new scientific information, but without details that allow recollection as in original scientific papers. Preliminary communication can give results of an experimental research, results of a shorter research or research in progress that is deemed useful for publishing.

Subject review contains a complete depiction of conditions and tendencies of a specific domain of theory, technology or application. Articles in this category have an overview character with a critical review and evaluation. Cited literature must be complete enough to allow a good insight and comprehension of the depicted domain.

Professional paper can contain a description of an original solution to a device, assembly or instrument, depiction of important practical solutions, and similar. The article need not be related to the original research, but it should contains a contribution to an application of known scientific results and their adaptation to practical needs, so it presents a contribution to spreading knowledge, etc.

Outside the mentioned categorization, the Editorial board of the journal will publish articles of interesting content in a special column. These articles provide descriptions of practical implementation and solutions from the area of production, experiences from device application, and similar.

10pt

3 WRITING AN ARTICLE

10pt

Article is written in the English language and the terminology and the measurement system should be adjusted to legal regulations, standards and the International System of Units (SI) (Quantities and Units: ISO 80 000 - from Part 1 to Part 14). The article should be written in third person.

Introduction contains the depiction of the problem and an account of important results that come from the articles that are listed in the cited literature.

Main section of the article can be divided into several parts or chapters. Mathematical statements that obstruct the reading of the article should be avoided. Mathematical statements that cannot be avoided can be written as one or more addendums, when needed. It is recommended to use an example when an experiment procedure, the use of the work in a concrete situation or an algorithm of the suggested method must be illustrated. In general, an analysis should be experimentally confirmed.

Conclusion is a part of the article where the results are being given and efficiency of the procedure used is emphasized. Possible procedure and domain constraints where the obtained results can be applied should be emphasized.

10pt

4 RECAPITULATION ANNOTATION

10pt

In order for the articles to be formatted in the same manner as in this template, this document is recommended for use when writing the article. Finished articles written in MS Word for Windows and formatted according to this template must be submitted using our The Paper Submission Tool (PST) (https://tehnickiglasnik.unin.hr/authors.php) or eventually sent to the Editorial board of the Technical Journal to the following e-mail address: tehnickiglasnik@unin.hr

The editorial board reserves the right to minor redaction corrections of the article within the framework of prepress procedures. Articles that in any way do not follow these authors' instructions will be returned to the author by the editorial board. Should any questions arise, the editorial board contacts only the first author and accepts only the reflections given by the first author.

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5 REFERENCES (According to APA)

10pt

The literature is cited in the order it is used in the article. No more than 35 references are recommended. Individual references from the listed literature inside the text are addressed with the corresponding number inside square brackets i.e. "… in [7] is shown …". If the literature references are web links, the hyperlink is to be removed as shown with the reference number 8. Also, the hyperlinks from the e-mail addresses of the authors are to be removed. In the literature list, each unit is marked with a number and listed according to the following examples (omit the subtitles over the references – they are here only to show possible types of references):

9pt

[1] See http://www.bibme.org/citation-guide/apa/

[2] See http://sites.umuc.edu/library/libhow/apa_examples.cfm

[3] (Style: Times New Roman, 9pt, according to APA)

[4] Amidzic, O., Riehle, H. J., & Elbert, T. (2006). Toward a psychophysiology of expertise: Focal magnetic gamma bursts as a signature of memory chunks and the aptitude of chess players. *Journal of Psychophysiology, 20*(4), 253-258. https://doi.org/10.1027/0269-8803.20.4.253

[5] Reitzes, D. C. & Mutran, E. J. (2004). The transition to retirement: Stages and factors that influence retirement adjustment. *International Journal of Aging and Human Development, 59*(1), 63-84. Retrieved from http://www.baywood.com/journals/PreviewJournals.asp?Id=0091-4150

[6] Jans, N. (1993). *The last light breaking: Life among Alaska's Inupiat Eskimos*. Anchorage, AK: Alaska Northwest Books.

[7] Miller, J. & Smith, T. (Eds.). (1996). *Cape Cod stories: Tales from Cape Cod, Nantucket, and Martha's Vineyard*. San Francisco, CA: Chronicle Books.

[8] Chaffe-Stengel, P. & Stengel, D. (2012). *Working with sample data: Exploration and inference*. https://doi.org/10.4128/9781606492147

[9] Freitas, N. (2015, January 6). People around the world are voluntarily submitting to China's Great Firewall. Why? Retrieved from http://www.slate.com/blogs/future_tense/2015/01/06/tencent_s_wechat_worldwide_internet_users_are_voluntarily_submitting_to.html (Style: Times New Roman, 9pt, according to APA)

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Authors' contacts:

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Full Name, title
Institution, company
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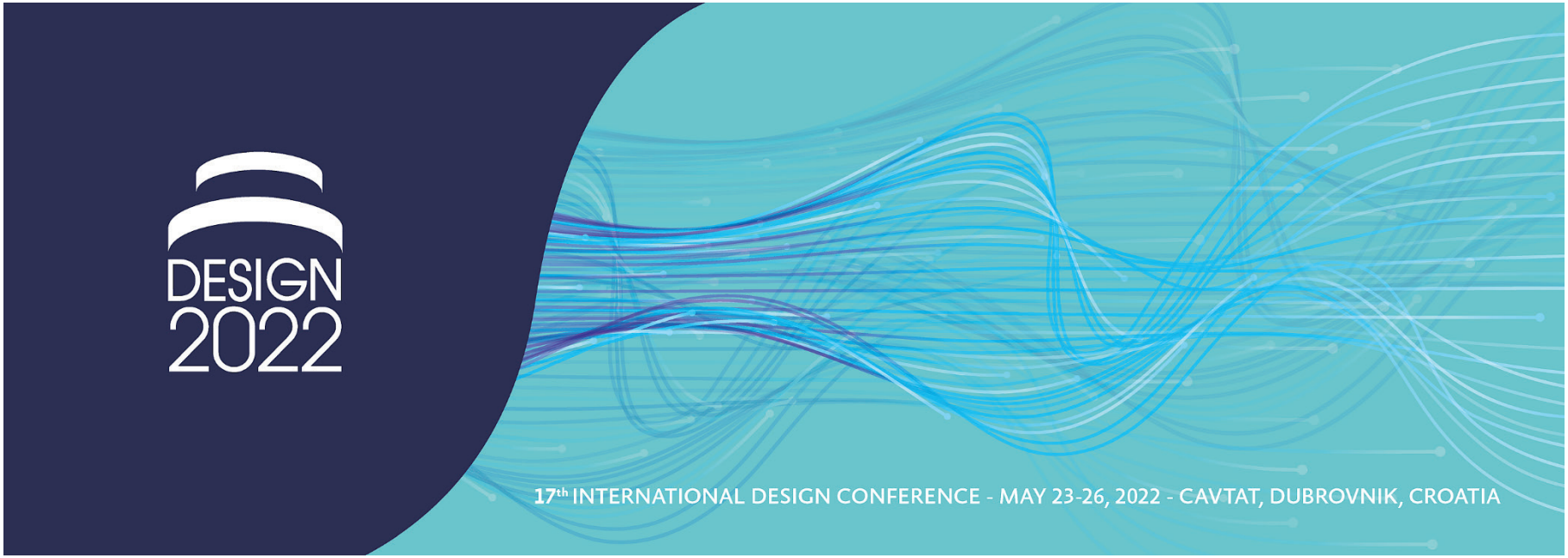
Note: Gray text should be removed in the final version of the article because it is for guidance only.



TOPICS

DESIGN SUPPORT TOOLS AND METHODS
- Configuration and modularisation
- Design for additive manufacturing
- PDM/PLM
- Requirements and change management
- Usage and integration of supportive technologies

INDUSTRIAL DESIGN
- User-centred design
- Aesthetics and visual impressions
- Product semantics
- User experience design
- Emotional design

DESIGN INFORMATION AND KNOWLEDGE
- Representations of information and knowledge
- Decision-making rationale and support
- Knowledge-intensive design
- Knowledge-based engineering
- Emerging IT technologies in knowledge management

HUMAN BEHAVIOUR IN DESIGN
- Human factors in design
- Designer's attitudes and skills
- Design thinking
- Design cognition and problem-solving
- Designer's activity

DESIGN THEORY AND RESEARCH METHODS
- Multidisciplinary research approaches
- Design theories and models
- Experimental design research
- Design typology
- New infrastructure for design research

ENGINEERING DESIGN PRACTICE
- Geometrical modelling and CAD
- Simulation-based design
- Advanced visualisation and virtualisation
- Case studies of design methods application
- Best design practices from industry

DESIGN FOR SUSTAINABILITY
- Sustainability awareness
- Design for social equity and cohesion
- Design for circular economy
- Technology and sustainable society
- Product-service systems

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SYSTEMS ENGINEERING AND DESIGN
- Architecting complex engineering systems
- Simulation within complex systems
- Model-based systems engineering (MBSE)
- Cyber-physical systems design
- Approaches to socio-technical systems design

DESIGN ORGANISATION AND MANAGEMENT
- Organisational and design processes
- Product development models and strategies
- Market and business implications
- Global product development
- Agile management

ARTIFICIAL INTELLIGENCE AND DATA-DRIVEN DESIGN
- Artificial intelligence in product development
- Generative design and topological optimisation
- Data-driven design process
- Knowledge discovery and data mining in design
- Smart systems for Industry 4.0

DESIGN CREATIVITY
- Creative design processes
- Cognitive processes in design creativity
- Supporting design creativity and innovation
- Creativity assessment and measurement
- Bioinspired design

COLLABORATIVE DESIGN
- Design teams
- Design communication and collaborative processes
- Co-design
- Multidisciplinary/Interdisciplinary/Transdisciplinary collaboration
- Open/Social innovation

DESIGN FOR HEALTHCARE
- Healthcare ecosystems
- Healthcare design
- Healthcare services
- Use of advanced technologies in healthcare
- Life sciences and design

DESIGN EDUCATION
- Competency development
- Digital learning and ICT in education
- Project-based learning
- Adopting different teaching and learning environments
- Lifelong and organisational learning

INVITATION

By tradition, DESIGN Conference is a forum for discussion and further development of design knowledge from cognition and philosophy to methods and tools, from research theory to practice.

The transition from known and comfortable to unknown and challenging is ubiquitous. It is challenging every aspect of our being. How can design research and practice respond to changes, influence wellness, ensure sustainable development, reimagine the future, rethink the product design and development?

How to improve design methodologies, tools, projects, and processes? How to develop products and services to make the world a healthier place? Which competencies, information, and communication technologies are needed? What is the impact on everyday design work? Which social and legal issues should be considered? How will we teach future designers, communicate ideas and share knowledge? How to adapt to the new normal?

Applied, theoretical, and results-oriented papers from academia and industry, based on thorough analysis or argumentation, will be considered for the conference programme. The submitted papers should fit into one of the proposed conference topics. It is expected that these specific topics are extensive and nonexhaustive.

A list of examples is added to illustrate the core topics. It is required explicitly from all contributors to show how they contribute to the overall research within these areas. A detailed description of topics and instructions for online submission is available at www.designconference.org.

Programme chairs welcome the high-quality submissions covering substantial, original, and previously unpublished research.

Rigour academic research should provide designers with the next generation of methods and tools appropriate to the demands.

PROGRAMME

The DESIGN Conference provides an interactive environment where participants proactively create opportunities to share design knowledge and new cross-disciplinary research that leads to innovation.

PLENARY SESSIONS

The new ideas and visions will be presented by the keynote speakers.

TOPIC ORIENTED SESSIONS

Will host papers selected around common research questions in order to foster discussion.

WORKSHOPS

DESIGN 2022 workshops will promote integration of different views, approaches and methods. Workshop coordinators could invite selected presentations and demonstrations in order to stimulate the debate as well as to propose any format of delivery that inspires interaction. The workshops will be organised on the 23rd of May.

PHD STUDENTS' FORUM

The forum will be a unique opportunity for younger researchers and PhD students to discuss their research questions and ideas with experienced researchers, practitioners and R&D managers in order to facilitate their research efforts.

THE DESIGN DEBATE

The purpose of the design debate is to investigate in a forensic manner some key topics that affect the engineering design research community. Two opponents and the debate moderator will be distinguished key players in the community presenting evidence for or against a particular topic.

INDUSTRIAL FORUM

The industrial forum will be an opportunity to discuss industrial views, needs and expectations of design research, tracing emerging trends in industrial innovation and the right strategies for a sustainable future. The forum will offer a platform for debate among decision makers, practitioners and academics about the future of design research, needs and expectations.

REVIEWING POLICY

The papers will be accepted on the double-blind review basis made by the members of the Scientific Advisory Board.

The review criteria will be the novelty and level of contribution, validity of conclusions, industrial or application perspective and formal qualities of the contribution.

DESIGN Conference papers are published online at Cambridge Core Journals pages as: Proceedings of the Design Society: DESIGN Conference. All papers are indexed in SCOPUS and WOS - CPCI and referenced in CrossRef with DOI identifier.

Selected papers will be recommended for publication in international journals.

STEP 01 Full paper submission deadline **November 15, 2021**

STEP 02 Final acceptance of papers **February 1, 2022**

STEP 03 Publish-ready papers **February 25, 2022**

STEP 04 Final conference programme **April 2022**

STEP 05 **DESIGN 2022 CONFERENCE** **May 23-26, 2022**

PROGRAMME CHAIRS

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