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Zekai Sen
Ercan Oztemel
Caner Erden *Editors*

Recent Advances in Intelligent Manufacturing and Service Systems

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Preface

The 11th International Symposium on Intelligent Manufacturing and Service Systems (IMSS) that took place under the auspicious of Sakarya University, Faculty of Engineering, Department of Industrial Engineering, Sakarya, Turkey, provided a vivid scientific climate on the issues of conflicts between technology and humanity in future society and mind during 3-day sessions during 27–29 May 2021. The symposium covered a wide range of currently interesting hot topics mostly inclusive of artificial intelligence subjects among which the major items are robotics, simulation machine learning, sustainability, logical modelling, nano-systems, smart cities, decision support systems, defense strategy, biomedical engineering, medical informatics and related aspects. The symposium contributors were from different continents mostly through online connections due to the COVID-19 pandemic.

There came about more than 100 scientific articles to the symposium, but the preliminary elimination brought down the number of presentable articles down to 92. During the presentations, critical discussions and suggestions by the listeners provided an extensive platform for further innovative view fermentation and the session chairmen have provided the initial evaluation and provided their recommendations to the symposium organizers. After the symposium, each one of the articles was sent to some experts for their review assessments and finally, after a collective work the inclusion of the papers was decided on and this book includes all the relevant topics related to the scope of the symposium.

The organizing committee members appreciate and thank each contributor for their endurance and patience during the preparation, presentation and after the symposium revisions works according to the reviewers' comments, and hence this book took its present form in scientifically formatted material exposition. It is hoped that the articles in this proceedings book will sprout out further innovative research and technology directions in the future.

Sakarya, Turkey
July 2021

IMSS'21 Organizing Committee

Contents

About the Editors

Zekai Sen obtained B.Sc. and M.Sc. degrees from Technical University of İstanbul in 1971. His post-graduate studies were carried out at the University of London, Imperial College of Science and Technology. He was granted Diploma of Imperial College (D.I.C) and M.Sc. in Engineering Hydrology in 1972 and Ph.D. in Stochastic Hydrology in 1974. He has worked in different faculties as the head of department such as the Faculty of Earth Sciences, Hydrogeology Department; Faculty of Astronautics and Aeronautics, Meteorology Department. His main interests are hydrology, water resources, hydrogeology, hydrometeorology, hydraulics, science philosophy and history. He has published numerous papers in journals of national and international repute.

Ercan Oztemel graduated from the Department of Industrial Engineering, Sakarya Engineering Faculty at Istanbul Technical University in 1984. He completed his Master's degree at the Department of Industrial Engineering at Bosphorouos University in 1987 and his doctorate studies at the Department of Systems Engineering of the School of Electrical, Electronics and Systems Engineering at the University of Wales in England in 1992. Between 1993-2006, he worked as a faculty member at Sakarya University. From 1997 to 2010, he conducted research at the Western European Union Armaments Group (WEAG), served as a member of the Steering Commitee in Groups11 and 15, and as a Panel member of the System Analysis and Simulation (SAS) at NATO in 2001-2006. His research interests include artificial intelligence, intelligent manufacturing systems, management information systems, simulation and modeling, military simulation, simulators, strategic planning, and quality management.

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Visual Feeding of Magnetic Cores for Winding Automation

Ayberk Çelik, Sinan Özen, and Barış Öz

Abstract The influence of robot integration into the production process is rapidly increasing. Feeding systems of intermediate products are one of the most important steps in ensuring full system automation towards the fourth industrial revolution. Feeding systems generally consist of mechanical solutions. However, some production components cannot be fed to production cells with known methods due to mechanical restrictions such as fragility or sensitivity. In this paper, novel background estimation and edge detection methods are proposed to provide reliable magnetic core feeding by visual inspection methods. Mechanical solutions were inadequate due to the irregular shapes of magnetic cores. Also, the contortion of magnetic cores causes additional drawbacks. To overcome this problem, a method is developed to determine which products can be caught by the gripper and to check the conformity of their shapes to increase production yield. The proposed method provides a decisive feeding process and ensures 100% accuracy.

Keywords Visual inspection · Computer vision · Background estimation · Shape detection · Visual feeding

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1 Introduction

Feeding units are used in many automation machines to feed products to a machine. If the product to be processed by the machine is fed smoothly, process failures can be prevented. Feeding cycle time should be determined according to the needs of the machine.

Mechanical feeders work well in some situations, but they can only work in limited areas. In mechanical feeding units, vibration movement is generally used. A vibratory feeder is loaded with random bulk products in the center of the bowl and has an incline spiral track to transport products to the top of the feeder. Once parts make it to the top of the spiral track, the remaining tooling of the feeder is installed on a slightly downward angle to increase part separation. The vibration process allows products to follow a path. On this path, there are structures designed according to the shapes in which the products should be fed. Products pass through mechanical or pneumatic structures that reject unsuitable ones. Rejected products are sent back to stack and the process continues.

Wenbo Huang et al. [1] have proposed removing shadows based on illuminance using HSV color space. It has been observed that HSV color space gives positive results in light-based operations in the background. Patricia Angela Abu et al. [2] tested the performance of images in HSV color space and RGB color space on Teknomo-Fernandez, an algorithm used for background prediction. In terms of accuracy, it has been observed that HSV implementation produces a lower number of errors compared to RGB implementation. Karaköse et al. [3] proposed a background prediction method based on Gaussian distribution industrial systems. After background extraction was done, object recognition and counting are done effectively on an industrial line. Moghimi et al. [4] proposed a method to detect and remove shadows in HSV color space that cause changes and distortion of the shape of objects in video surveillance systems. Na Li et al. [5] proposed a robust real-time algorithm for video object segmentation from a static background in object detection. The disadvantage of the proposed algorithm is its dependence on the determination of some thresholds. This situation negatively affects the system.

Khan et al. [6] remove the shadow formed in the background in order to eliminate the problems arising from the shadows of the data to be used in machine learning. To detect shadow, the image is first converted to YCbCr format and then two-channel binarization processes are applied. After the image is detected, the shadow edges are found with the Canny edge detection algorithm and the main picture is cleared of shadows with the matting technique.

Wang et al. [7] have proposed a method to solve shadowing and color issues while reading the texts in the documents. This suggested an iterative neighboring information-based approach for the shadows to be removed. First, a tonal reference is determined from a general background color. After the shadows are detected due to different hues, they are estimated based on the global background color for recoloring. A tone fine-tuning process is designed for the normalization of output values. It has been stated that more successful results are obtained in studies on datasets than other algorithms.

In this study, a foreground estimation algorithm is developed to detect and derive gripping points of magnetic cores on a tote box. In the second phase, the skewness of the product is estimated using a novel curvature detection method. The traditional vibratory feeding system is not suitable for magnetic cores. In general computer feeding applications, the products are generally left in an external area as a stack, but magnetic cores are generally packaged on a tote box. These products cannot be poured into a vibratory feeder's bowl. As magnetic cores are extremely sensitive materials, fractures may occur in vibration phase. Therefore, magnetic cores should be fed by a distinctive gripper and gripping points should be derived. One of the main problems is deciding which products can be caught by the gripper. Magnetic cores on the tote box should be in a unique orientation as holding by its cylindrical surface may cause problems. Also, production defects such as fractures or skewness should be detected.

2 Material and Method

In this section, two proposed methods such as foreground estimation and curvature detection are detailed.

2.1 Foreground Estimation

The proposed method determines whether magnetic cores can be gripped by a gripper. It also detects fractures that may cause problems in machine operations. An example of a magnetic core on the tote box is given in Fig. 1.

According to the designed gripper, the cylindrical part of magnetic cores is reversed, and the flat part is determined as appropriate for the gripping operation. A bright background creates problems in determining the correct products. The input image is in RGB format. The input image is converted to HSV format and foreground estimation was made by using a color difference of background. Figure 2 illustrates an overview of the proposed method for foreground estimation.

The surface color of magnetic cores is similar to the color of the tote box. Illumination also causes nonhomogeneous irradiance distribution upon surfaces of magnetic cores as well as the tote-box surface. Therefore, HSV color space is used in the foreground estimation phase. As the HSV color space corresponds closely to the human perception of color, a reliable estimation can be performed.

Segmentation limits are defined as $\left[\rho^H_{min}, \rho^H_{max}\right]$, $\left[\rho^S_{min}, \rho^S_{max}\right]$, $\left[\rho^V_{min}, \rho^V_{max}\right]$ in each HSV domain. As magnetic cores are grey and the saturation layer indicates the range of grey in the color space, this layer is selected as an operational image matrix.

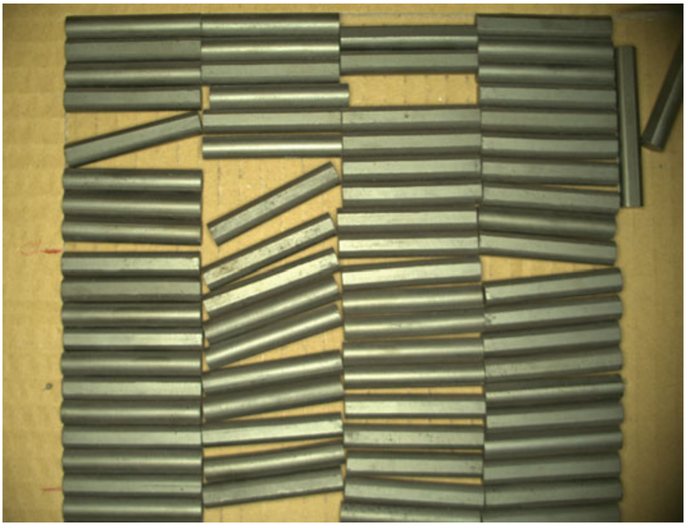

Fig. 1 Magnetic cores orientation

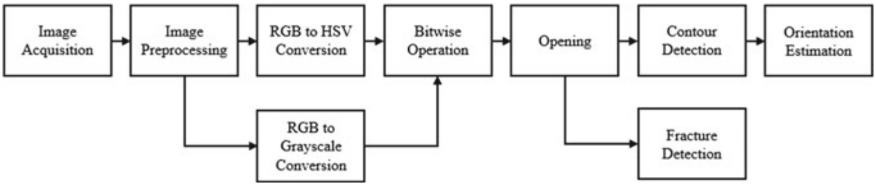

Fig. 2 Process of the proposed method for foreground estimation

Median filter is applied to the saturation layer. After segmentation and bitwise operation, opening/closing morphologies are performed on binary images to eliminate areas between magnetic cores.

Edge detection algorithm for tracking the edge points in the binary representation according to their neighboring values has been used to find the center points of the magnetic cores [8]. The edges are stored in a series and edge midpoints and moments are estimated [9]. $p^i_{x,y}$ to denote the array of n points in binary notation and $G(x_i, y_i)$ to show the coordinates of the edge in binary notation, the following equations can be defined [10].

$$p^i_{x,y} = G(x_i, y_i), i = 1 \dots n \quad (1)$$

Spatial moments, m_{ji}, are found as shown in Eq. (2).

$$m_{ji} = \sum\nolimits_{x,y}^{N} G(x, y) x^j y^i \quad (2)$$

Fig. 3 Magnetic core

$(\overline{x}, \overline{y})$ to denote center of mass, mu_{ji}, central moments can be expressed as follows.

$$mu_{ji} = \sum_{x,y}^{N} G(x, y)(x - \overline{x})^j (y - \overline{y})^i \quad (3)$$

$$\overline{x} = \frac{m_{10}}{m_{00}}, \overline{y} = \frac{m_{01}}{m_{00}} \quad (4)$$

After defining minimum and maximum allowed areas of magnetic cores, $\left[\rho_{min}^{core}, \rho_{max}^{core}\right]$, foreground estimation with suitable products and their center points are achieved.

2.2 *Curvature Detection*

After the gripping process, the magnetic core is placed into a box that has backlight module to determine the skewness of the product. The acquired image is shown in Fig. 3.

Although the magnetic core is placed in different positions, even measurements should be ensured with the image geometric transformations. Affine transformation is used as a geometric transformation. The parts of the outer contour obtained by morphological processes, which are called the bottom and top lines, are separated from the contour vector. These decomposed points are assigned to two separate vectors as underline and overline.

$f(x)$ is a function in which points other than the vertices of the lines in the horizontal line of the contour are taken. The valid equation is given in Eq. (5), where l_k denotes each line segment.

$$l_k = f\left(p_{x,y}^i\right), k = 1 \ldots t \quad (5)$$

According to the length of the magnetic core, t is determined instinctively. After the assignment process, the upper and lower lines enter the inclination control process separately. For the curvature process, it is defined to form line segments between consecutive points on the bottom and top lines.

$$\alpha_k = \text{atan}\frac{l_{k+1}}{l_k}, k = 1 \ldots t - 1 \quad (6)$$

When the slope of any line segments between these consecutive points is obtained more than a certain slope value, it is decided that the magnetic core is a defect.

3 Results

The results of the proposed method for foreground estimation are given in Fig. 4.

It is seen that products that are appropriate to grip can be estimated even if the upper surface of the magnetic cores has similar colors with tote-box background. Red boxes indicate that products cannot be grappled or have fractures. It has been empirically proven that the correct product selection algorithm can be run by making it independent from the background as seen in the picture, together with the hardware to be selected, and by looking at the area of the cardboard in the desired dimensions. These lens and lighting choices are suitable for the process.

The results of the proposed method about curvature detection are given in Fig. 5.

Red lines indicate line segments while red points are segmentation points. These two parts, multiple underline and overline segments, have enough information to

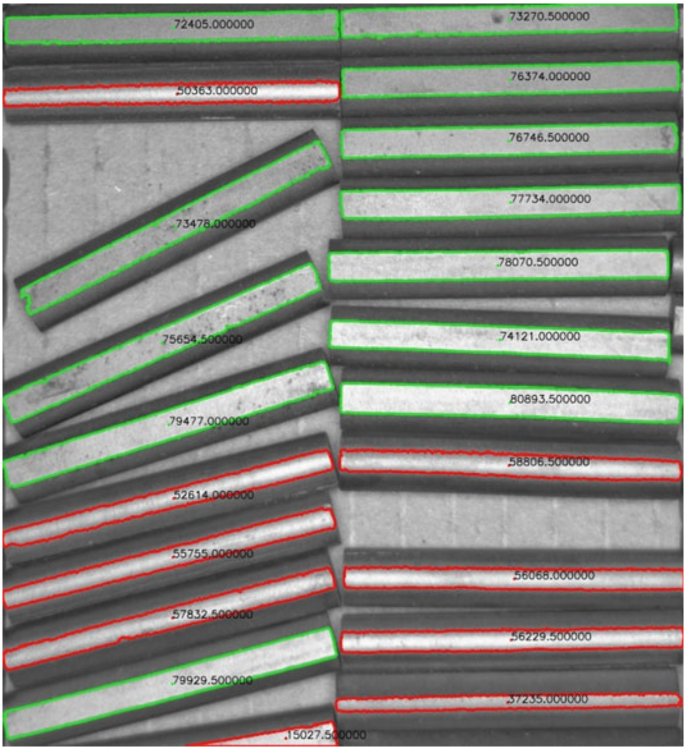

Fig. 4 Foreground estimation results

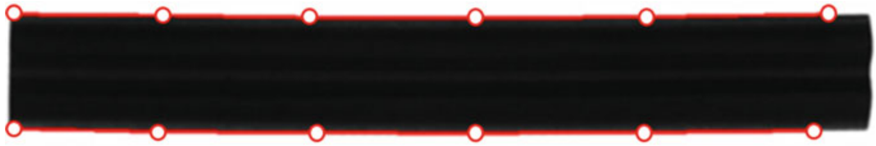

Fig. 5 Curvature detection results

classify a magnetic core if the skewness is appropriate for future processing of the product. When the slopes are checked consecutively at a certain threshold value between these points, the product determination is made in general terms of whether the magnetic core is suitable for production in shape. Although the previous process has already ensured that there is no break in the product or sieving in the desired dimensions, shape control is provided in this process as well.

This developed system is planned as an important process in order to significantly eliminate the defects in the final product, which consists of defects caused by the manufacturer. Thanks to these controls, faulty products are not fed into the machine, and the quality rate of the final product is increased, and any problems that may occur in the machine are resolved before the process.

4 Conclusion

Image processing methods are used for decision-making or quality control in automated production cells. As defects reduce the yield rate and increase the production costs, they need to be eliminated or fixed before the production process. In this paper, it is shown that feeding of sensitive materials into automated production cells is reliable by using specialized image processing methods. Experimental results have demonstrated that decisive proposed methods yield accurate results within the cycle time of the machine, which is roughly 2.2 s. Error analysis of the method is summarized in the table below (Table 1).

It is seen that the proposed method can supply appropriate magnetic cores into the robotic cell with 86,92%. Fracture and curvature detection methods indicate Fractures and Skewness products. As a result, the proposed method operates with a 97,38% accuracy in total.

Table 1 Error analysis

	Number of Cores	Percentage (%)
Appropriate	299	86,92
Fractures	12	3,49
Skewness	24	6,98
Error	9	2,62
Total	344	

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References

1. Huang W, Kim K, Yang Y, KimYS (2015) Automatic shadow removal by illuminance in HSV color space. csit 3(3):70–75, May. https://doi.org/10.13189/csit.2015.030303
2. Abu PA, Fernandez P (2013) Performance comparison of the Teknomo-Fernandez Algorithm on the RGB and HSV colour spaces. Inf Technol 6
3. Karaköse M, Baygin M, Aydin İ, Sarimaden A, Akin E (2016) Endüstriyel Sistemlerde Arka Plan Çıkarımı Tabanlı Hareketli Nesne Tespiti ve Sayılması için Yeni Bir Yaklaşım. Muş Alparslan Üniversitesi Fen Bilimleri Dergisi 4(2):373–373. https://doi.org/10.18586/msufbd.327895
4. Moghimi MK, Pourghassem H (2014) Shadow detection based on combinations of HSV color space and orthogonal transformation in surveillance videos. In: Proceedings of içinde 2014 Iranian Conference on Intelligent Systems (ICIS), Bam, Iran, Şub. pp 1–6. https://doi.org/10.1109/IranianCIS.2014.6802548
5. Li N, Bu J, Chen C (2002) Real-time video object segmentation using HSV space", içinde Proceedings. In: Proceedings of International Conference on Image Processing, Rochester, NY, USA, vol 2, pp II-85–II-88. https://doi.org/10.1109/ICIP.2002.1039893
6. Khan S, Pirani Z, Fansupkar T, Maghrabi U (2019) Shadow removal from digital images using multi-channel binarization and shadow matting. In: Proceedings of 2019 Third International conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC), pp 723–728. https://doi.org/10.1109/I-SMAC47947.2019.9032447
7. Wang B, Chen CLP (2019) An effective background estimation method for shadows removal of document images. IEEE Int Conf Image Process (ICIP) 2019:3611–3615. https://doi.org/10.1109/ICIP.2019.8803486
8. Suzuki S, be K (1985) Topological structural analysis of digitized binary images by border following. Comput Vis Graph Image Process 30(1):32–46. https://doi.org/10.1016/0734-189X(85)90016-7
9. Gupta L, Srinath MD (1987) Contour sequence moments for the classification of closed planar shapes. Pattern Recognit 20(3):267–272. https://doi.org/10.1016/0031-3203(87)90001-X
10. Öz B, Sevim B, Akpak G, Işık S, Karakullukçu S, Özen S (2020) Kapasitör Dizgisine Yönelik Görü Tabanlı Bir Algoritma. In: Proceedings of 2020 International congress on human-computer interaction optimization and robotic applications (HORA), pp 1–4. https://doi.org/10.1109/HORA49412.2020.9152889

Effect of Build Orientation on Cross-Sectional Areas of Sliced Layers and Geometrical Accuracy in Selective Laser Melting

Ahmet Can Günaydın, Necmettin Kaya, and Ali Rıza Yıldız

Abstract Additive manufacturing is a manufacturing process that allows the production of complex parts and has many advantages over conventional production methods. However, the pre-processing stage is still time-consuming and open to failure. Build orientation is one of the pre-processing stages, which have a crucial effect on support requirement, build cost, and accuracy of the produced part. In recent years, a number of research have been made to optimize build orientation for surface roughness, the requirement of support structures, build time, and cost. For metallic additive manufacturing, a limited number of research has been carried out. Selective laser melting is one of the powder bed fusion technologies that allows the production of high-performance metallic parts. In the selective laser melting process, some defects may occur due to residual stresses resulting from solidification during the process. Build orientation is important in selective laser melting to ensure proper heat flow throughout to entire structure during the process. After the build orientation is selected, the part slices into layers. Each layer builds on the previous layer, and production carries out. The cross-sectional areas of these sliced layers depend on the build orientation. This study investigates the effect of cross-sectional areas on the geometric accuracy of the part. The numerical evaluation shows that the distribution of layers has a significant impact on geometrical accuracy. First, the effect of the mean cross-sectional area on the thermal distortion was investigated. It is observed that the geometric accuracy of the part decreases for the build orientation, which has a higher mean cross-sectional area. In addition, it is revealed that the increase and sudden change of the cross-sectional area in the build direction negatively affect the geometric accuracy.

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Keywords Additive manufacturing · Build orientation · Cross-section area · Geometrical accuracy · Selective laser melting

1 Introduction

Additive Manufacturing (AM), also known few other names as three-dimensional (3D) printing, rapid prototyping, etc., is defined "process of joining materials to make parts from 3D model data, usually layer upon layer" in ISO/ASTM standard [1]. AM processes have many advantages like design flexibility and less waste material over subtractive manufacturing techniques. In addition, complex parts like the final output of a topology optimization can be manufactured using AM technologies. Therefore, AM process is considered revolutionary in manufacturing industries. AM processes have been divided into seven main categories according to ISO 17296–1 where Powder Bed Fusion (PBF) is one of them.

Selective Laser Melting (SLM) is one of the PBF processes widely used for producing high-quality functional metallic parts, especially in the aerospace and medical industries. The working principle of SLM is melting and fusing metallic powder layer by layer with high-power laser to build part according to 3D data similar to other AM processes. The SLM process became one of the most exciting AM technologies available today for rapid prototyping and mass production with a range of high mechanical performance metallic alloy options. The SLM process starts with slicing 3D data considering layer thickness to two-dimensional scanning areas. For each manufacturing cycle, a recoater spreads metal powders with desired layer thickness. Each layer is then melted and fused by the laser beam controlled in the planned path to solidify the selected cross-section area.

However, besides all of these advantages, there are several problems, such as shape distortions and residual stress due to the high thermal gradient in the SLM process. The entire process may be disturbed after the collision between reacoater and the distorted part caused by undesired cracks, warpage, and delamination during the process. Another challenge is the geometric accuracy of the product after the manufacturing process. Due to residual stress, large deformation occurs on the part after removing it from the build plate. For these reasons, the SLM process differs from other AM processes. Pre-process stages become much more essential to achieve successful results in the SLM process.

The build orientation is very important for all additive manufacturing methods, especially the SLM process, and dramatically impacts the printing time, support structure volume, staircase effect, surface roughness, shrinkage, and distortion. Overall, the part quality and production cost highly depend on build orientation. In the literature, much research has been conducted to optimize the build orientation for different AM processes. Wodziak et al. [2] presented a method using Genetic Algorithms (GA) to determine the optimum arrangement of parts by considering their maximum dimensions. This study aimed to utilize the production volume and minimize the build time in the Stereolithography (SLA) process. Alexander et al.

[3] proposed a cost estimation method to predict the best build orientation in Fused Deposition Modeling (FDM) and SLA. Thrimurthulu et al. [4] presented a model to evaluate the surface quality and the build time. They used these estimation models and GA to obtain the optimum build orientation for the FDM process to enhance surface roughness and minimize build time. Byun and Lee [5] aimed to determine the optimum build orientation according to average weighted surface roughness, build time, and cost using the multi-attribute decision-making method in FDM, SLA, and Selective Laser Sintering (SLS) processes. Canellidis et al. [6] proposed GA and multi-optimization methods to detect near optimum build orientation in SLA. Build time, post-processing time, and surface roughness have been considered as the objectives. Li et al. [7] selected build orientation with established models to optimize support required area, surface quality, and build time using Particle Swarm Optimization (PSO).

The number of studies on build orientation has increased rapidly in the past decade. Most of these studies focused on minimizing support structure volume [8–13], enhancing part quality [9–15], reducing build time [9–17] and build cost [10, 15–19] in FDM, SLA, and SLS kind of non-metallic processes. GA, Non-Dominated Sorting Genetic Algorithm (NSGA), PSO electromagnetism-like algorithm, stretched simulated annealing algorithm, a grey incidence evaluation model, zooming-Taguchi method, and NSGA-II used for these studies.

However, a few studies were carried out in PBF processes to optimize build orientation. Calignano [20] investigated the trade-off between build orientation and minimal support structure requirement. Das et al. [21] provided an approach to determine optimal build orientation considering minimizing the support structure volume while meeting geometric accuracy in Direct Metal Laser Sintering (DMLS) process. The approach they used has been based on a mathematical model between build orientation and dimensional accuracy developed. Morgan et al. [22] presented a gradient-based single objective optimization of build orientation to minimize the volume of the support structure. Brika et al. [23] developed an approach to optimize build orientation for the PBF processes considering the volume of the support structure, mechanical properties, surface quality, build time, and build cost. Cheng and To [24] performed the multi-objective optimization considering residual stress and volume of the support structure. After obtaining optimal build orientation, experimental validation has been conducted on a complex part. Griffiths et al. [25] presented a methodology for detecting an optimum build orientation and bin packaging in the SLM process using an iterative tabu search procedure. The initial solution of the proposed approach has been benchmarked against commercial software. Qin et al. [26] proposed a method that contains two-step for PBF processes. In the first step, the facet clustering-based approach has been applied to create the different build orientations automatically [27]. And second, the weighted sum model has been used to select optimal build orientation considering support volume, volumetric error, surface roughness, build time, and cost.

In this study, the effect of the cross-sectional areas formed as a result of the build orientation on the geometric accuracy is investigated considering the mean value of cross-sectional area, the incrementation and decrementation behavior of cross-sectional area throughout build direction, and the sudden changes in the cross-sectional area throughout build direction.

2 Residual Stress and Deformation in Selective Laser Melting

One of the significant drawbacks of the SLM process, whose schematic diagram is shown in Fig. 1 is the residual stresses that occur and accumulate in rapid heating and cooling cycles. Residual stresses could lead to failure and have a bad influence on the mechanical properties and geometrical accuracy of the manufactured part. Therefore, unlike other AM processes, support structures are also used in the SLM process to minimize the effect by ensuring a uniform distribution of temperature and preventing errors that may occur due to residual stresses.

In the SLM process, the solidification process repeatedly occurs in a complex phase transformation zone created by rapid heating and cooling. According to Fang et al. [28], the residual stress source in the laser welding is very similar to the SLM process considering the thermo-mechanical conditions. During the SLM process, the high energy density laser melts the powder layer rapidly, and thermal expansion occurs in the affected area, as shown in Fig. 2a. As the laser beam moves across the selected area of the layer, the previously heated area starts to get cold and shrink as shown in Fig. 2b. The previously fused powders constrain this shrinkage, and therefore, residual stress arises in that region. The cycle of melting and solidification of cross-sectional areas through layer by layer continuously accumulates residual stress [28].

Residual stress in the SLM process can cause the failure of the performed part due to crack, warpage, delamination. These errors can occur directly on the part, between the part and the substrate, between the part and the support structure, and

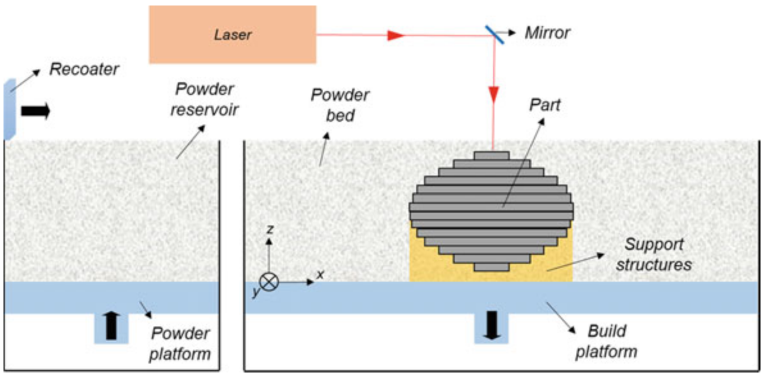

Fig. 1 Schematic representation of selective laser melting process

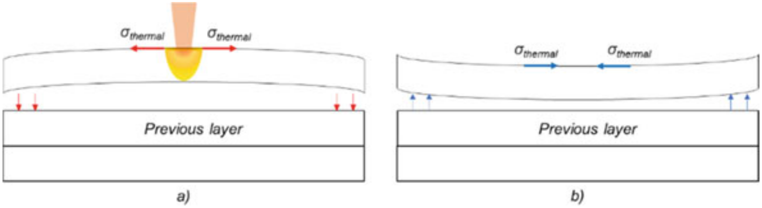

Fig. 2 **a** Thermal deformation from heat input, **b** thermal deformation from cooling

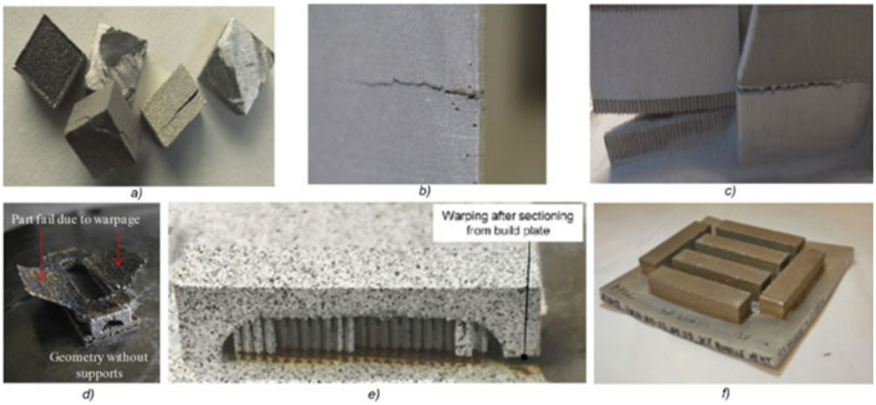

Fig. 3 Some failure examples of AM process: **a** cracking, **b** cracking, **c** cracking between support and part, **d** warpage of structure without a support structure, **e** warpage between the part and substrate, and **f** warping on test components [28]

between the support structure and the substrate, as shown in Fig. 3. Some studies were carried out to estimate residual stress in the SLM process [29–35].

3 Build Orientation and Its Effect on Geometric Accuracy

The build orientation determines the number of sliced layers and the cross-sectional area distribution of these layers. The cross-sectional areas affect the geometric accuracy of the part desired to be produced with AM due to thermal distortion generated by the high thermal gradient in the SLM process. Thermal distortion may cause a crash between recoater and the deformed part. Distortion of the manufactured part can be minimized with appropriate build orientation and support structure in the SLM process. This study showed that cross-sectional areas of layers affect distortion of the geometry in three different ways.

Thermo-mechanical analyses were carried out in Altair Inspire 2020 with process parameters that were given in Table 1.

Table.1 Process parameters

Parameter	Value
Velocity	1.3 m/s
Laser power	370 W
Powder layer thickness	3e–05 m
Powder absorption	10.0%
Cooling time	150 s
Base temperature	303.15 K

3.1 *Effect of Mean Value of Cross-Section Area Throughout Build Direction*

Thermo-mechanical analyses of the test specimen with a constant area, which is planned to be produced with the SLM process, were performed for different build orientations based on three different faces of the test specimen. The cross-sectional area will be the same in all layers after slicing the test specimen in the particular orientation shown in Fig. 4. Therefore, the mean value of the cross-sectional areas will be the same as the surface on which it is placed on the substrate. The mean value of the cross-sectional area, which is represented as A_m can be calculated with Eq. (1).

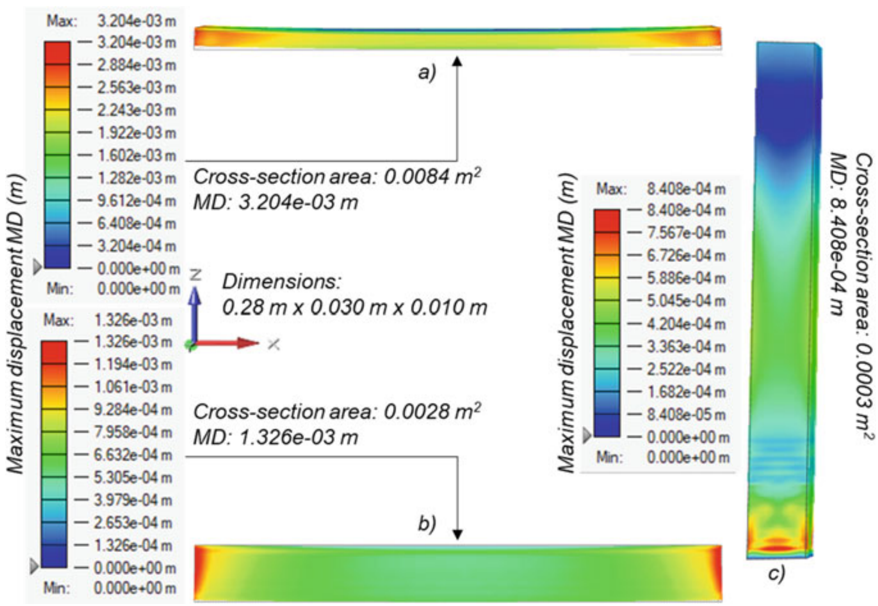

Fig. 4 Test specimen with constant area throughout build direction

$$A_m = \frac{\sum_{i=1}^{L} A_i}{L} \tag{1}$$

In this equation, A_i indicates the cross-sectional area in the relevant production step, and L indicates the number of layers.

In the orientation shown in Fig. 4a, the mean value of the cross-sectional area is calculated as 0.0084 m^2 and represents the largest area for the relevant sample. In this build orientation, the maximum displacement that occurred in the piece was determined as 3.204×10^{-3} m. For the mean value of cross-sectional area of 0.0028 m^2 (Fig. 4b) and 0.0003 m^2 (Fig. 4c), the maximum displacement that occurred in the piece was measured 1.326×10^{-3} m and 8.408×10^{-4} m, respectively. Printing times of given build orientations were determined as 5,233 s, 5,988 s, and 30,455 s, respectively.

The analysis results showed that the increase in the mean value of the cross-sectional area means that the distortion of the part also increases. However, the rise in the dimension of the part in the build direction dramatically increases the SLM process printing time. For this reason, the mean value of the cross-sectional area and production time should evaluate together to optimize build orientation.

3.2 Effect of Incrementation and Decrementation Behavior of Cross-Sectional Area Throughout Build Direction

A cone-shaped test specimen with the same mean value of the cross-sectional area in two different build orientations was designed. However, despite having the same mean value of the cross-sectional area in both build orientations, it is seen that the maximum displacement in Fig. 5b is five times higher than in Fig. 5a. The reason for this difference is due to the incrementation and decrementation behavior of the layer's cross-sectional areas throughout the build direction shown in Fig. 6. In the SLM process, it is wanted to decrease the cross-sectional area monotonously throughout

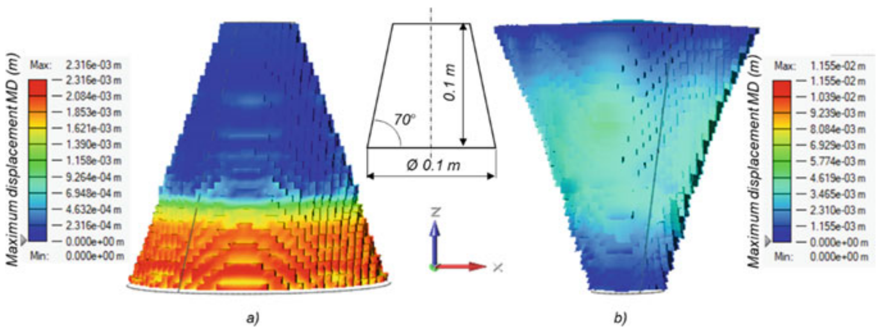

Fig. 5 Cone-shaped test specimen

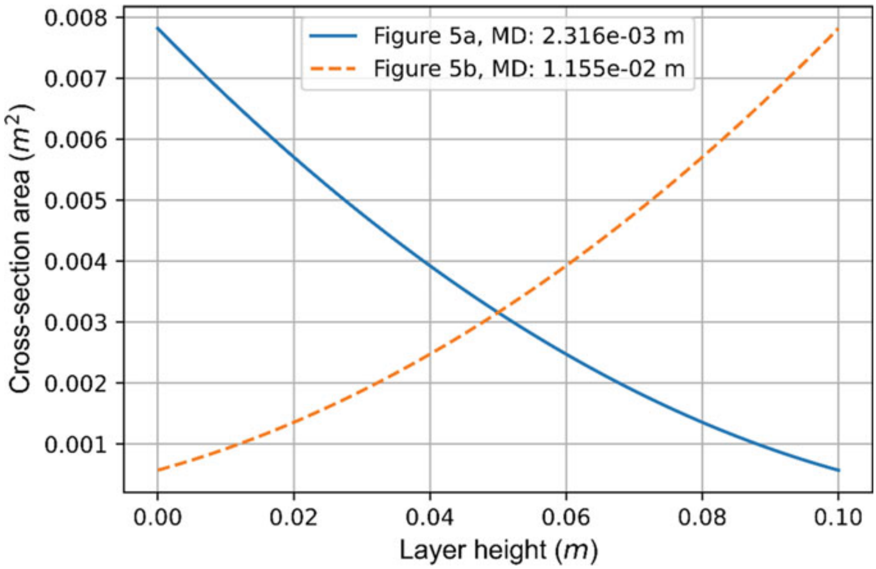

Fig. 6 Area distribution of cone-shaped test specimen throughout build direction

the build direction. This can be considered one of the most important things to be careful about optimizing build orientation in the SLM process. However, it is hard to evaluate this effect on a relatively complex part.

3.3 *Effect of Sudden Changes in Cross-Sectional Area Throughout Build Direction*

The part shown in Fig. 7 is a relatively more complex part compared to the previous two specimens, and it is equally more difficult to evaluate. In this specimen, the mean value of cross-sectional area, change behavior in cross-sectional areas, and sudden cross-sectional area changes throughout the build direction were examined.

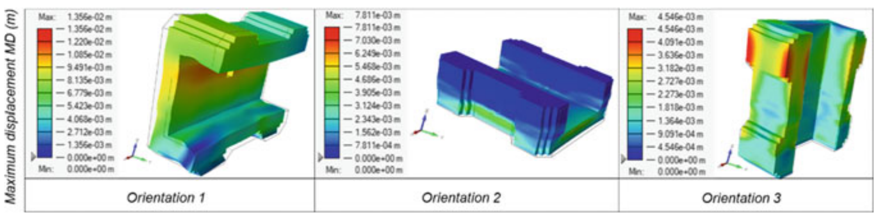

Fig. 7 Thermo-mechanical analysis result of the test specimen on different build orientations

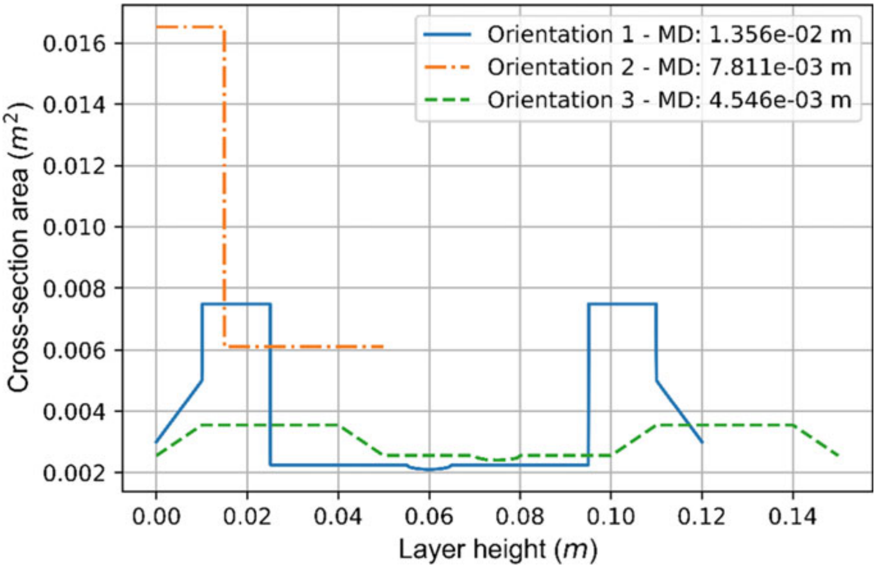

Fig. 8 Area distribution of test specimen throughout build direction

The magnitude of the cross-sectional area change and the mean value of the cross-sectional area in Orientation 1 seems less than Orientation 2 in Fig. 8. However, unlike Orientation 2, an increased behavior of the cross-sectional area was observed throughout the build direction in Orientation 1. For this reason, the maximum displacement in Orientation 1 was measured at 1.356×10^{-2} m, which is higher than Orientation 2.

Although the graphical behavior in Orientation 3 seems similar to Orientation 2, the mean value of the cross-sectional area and the magnitude of changes in the cross-sectional areas are quite small. Therefore, the maximum displacement obtained in this build orientation occurred at 4.546×10^{-3} m, and it was determined as the best build orientation in terms of geometric accuracy. The magnitude of the overall changes (S) in the cross-sectional areas can be evaluated with Eq. (2).

$$S = \sqrt{\frac{\sum_{i=1}^{L} (A_i - A_m)^2}{L}} \tag{2}$$

4 Conclusion and Future Work

In this research, the effect of the sliced layer's cross-sectional areas which occurs as a result of build orientation, on geometric accuracy has been investigated. First, the effect of the mean value of the cross-sectional areas was established by analyzing the result of the thermo-mechanical analysis. Evaluation of the mean value of the cross-sectional areas alone minimizes the maximum displacement that will occur on the manufactured part. Still, it is clear that increasing the dimension of the manufactured part in the build direction increases the printing time dramatically. Therefore, the mean value of the cross-sectional areas and dimension of the part's bounding box in the build direction must evaluate together.

The thermo-mechanical analysis showed that it is wanted to decrease cross-sectional area monotonous throughout the build direction in the SLM process. The behavior of change in the cross-sectional areas throughout build direction can be considered one of the most important things to be careful about optimizing build orientation in the SLM process. However, it is hard to evaluate this effect on complex parts. The magnitude of the cross-sectional area changes throughout build direction also has an impact on geometric accuracy. Sudden changes have a bad influence on geometric accuracy, especially impulsive incrementation behavior crucially affecting the SLM process. This paper provides a perspective for determining optimal build orientation in the SLM process.

As future work, we plan to integrate the knowledge of this paper into an optimization algorithm as an objective function to obtain optimal build orientation considering thermal distortion.

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References

1. Bourell DL (2016) Perspectives on additive manufacturing. Annu Rev Mater Res 46(1):1–18. https://doi.org/10.1146/annurev-matsci-070115-031606
2. Wodziak JR, Fadel GM, Kirschman C (1994) A genetic algorithm for optimizing multiple part placement to reduce build time. In: Proc Fifth Int Conf Rapid Prototyping, no. May, pp 201–210
3. Alexander P, Allen S, Dutta D (1998) Part orientation and build cost determination in layered manufacturing. CAD Comput Aided Des 30(5):343–356. https://doi.org/10.1016/S0010-4485(97)00083-3
4. Thrimurthulu K, Pandey PM, Reddy NV (2004) Optimum part deposition orientation in fused deposition modeling. Int J Mach Tools Manuf 44(6):585–594. https://doi.org/10.1016/j.ijmachtools.2003.12.004
5. Byun HS, Lee KH (2006) Determination of optimal build direction in rapid prototyping with variable slicing. Int J Adv Manuf Technol 28(3–4):307–313. https://doi.org/10.1007/s00170-004-2355-5
6. Canellidis V, Giannatsis J, Dedoussis V (2009) Genetic-algorithm-based multi-objective optimization of the build orientation in stereolithography. Int J Adv Manuf Technol 45(7–8):714–730. https://doi.org/10.1007/s00170-009-2006-y
7. Li A, Zhang Z, Wang D, Yang J (2010) Optimization method to fabrication orientation of parts in fused deposition modeling rapid prototyping. Int Conf Mech Autom Control Eng MACE2010 pp 416–419. https://doi.org/10.1109/MACE.2010.5535335

8. Luo Z, Yang F, Dong G, Tang Y, Zhao YF (2018) Orientation optimization in layer-based additive manufacturing process. Proc ASME Des Eng Tech Conf 1A–2016(January):2016. https://doi.org/10.1115/DETC2016-59969
9. Rocha AMAC, Pereira AI, Vaz AIF (2018) Build orientation optimization problem in additive manufacturing, vol 10961, LNCS, no. February 2019. Springer International Publishing
10. Ga B, Gardan N, Wahu G (2018) Methodology for part building orientation in additive manufacturing. Comput Aided Des Appl 16(1):113–128. https://doi.org/10.14733/cadaps.2019.113-128
11. Matos MA, Rocha AMAC, Pereira AI (2019) On optimizing the build orientation problem using genetic algorithm. In: AIP Conference Proceedings, vol 2116, p. 220006. https://doi.org/10.1063/1.5114224
12. Di Angelo L, Di Stefano P, Dolatnezhadsomarin A, Guardiani E, Khorram E (2020) A reliable build orientation optimization method in additive manufacturing: the application to FDM technology. Int J Adv Manuf Technol 108(1–2):263–276. https://doi.org/10.1007/s00170-020-05359-x
13. Matos MA, Rocha AMAC, Costa LA (2021) Many-objective optimization of build part orientation in additive manufacturing. Int J Adv Manuf Technol 112(3–4):747–762. https://doi.org/10.1007/s00170-020-06369-5
14. Phatak AM, Pande SS (2012) Optimum part orientation in rapid prototyping using genetic algorithm. J Manuf Syst 31(4):395–402. https://doi.org/10.1016/j.jmsy.2012.07.001
15. Zhang Y, Bernard A (2013) Using AM feature and multi-attribute decision making to orientate part in additive manufacturing. In: High value manufacturing: advanced research in virtual and rapid prototyping, CRC Press, pp 411–416
16. Zhang Y, De Backer W, Harik R, Bernard A (2016) Build orientation determination for multi-material deposition additive manufacturing with continuous fibers. Procedia CIRP 50:414–419. https://doi.org/10.1016/j.procir.2016.04.119
17. Zhang Y, Bernard A, Gupta RK, Harik R (2016) Feature based building orientation optimization for additive manufacturing. Rapid Prototyp J 22(2):358–376. https://doi.org/10.1108/RPJ-03-2014-0037
18. Ransikarbum K, Ha S, Ma J, Kim N (2017) Multi-objective optimization analysis for part-to-Printer assignment in a network of 3D fused deposition modeling. J Manuf Syst 43:35–46. https://doi.org/10.1016/j.jmsy.2017.02.012
19. Jaiswal P, Patel J, Rai R (2018) Build orientation optimization for additive manufacturing of functionally graded material objects. Int J Adv Manuf Technol 96(1–4):223–235. https://doi.org/10.1007/s00170-018-1586-9
20. Calignano F (2014) Design optimization of supports for overhanging structures in aluminum and titanium alloys by selective laser melting. Mater Des 64:203–213. https://doi.org/10.1016/j.matdes.2014.07.043
21. Das P, Chandran R, Samant R, Anand S (2015) Optimum part build orientation in additive manufacturing for minimizing part errors and support structures. Procedia Manuf 1:343–354. https://doi.org/10.1016/j.promfg.2015.09.041
22. Morgan HD, Cherry JA, Jonnalagadda S, Ewing D, Sienz J (2016) Part orientation optimisation for the additive layer manufacture of metal components. Int J Adv Manuf Technol 86(5–8):1679–1687. https://doi.org/10.1007/s00170-015-8151-6
23. Brika S, Zhao YF, Brochu M, Mezetta J (2017) Multi-Objective build orientation optimization for powder bed fusion by laser. Ind Eng Manag 6(4). https://doi.org/10.4172/2169-0316.1000236
24. Cheng L, To A (2019) Part-scale build orientation optimization for minimizing residual stress and support volume for metal additive manufacturing: theory and experimental validation. CAD Comput Aided Des 113:1–23. https://doi.org/10.1016/j.cad.2019.03.004
25. Griffiths V, Scanlan JP, Eres MH, Martinez-Sykora A, Chinchapatnam P (2019) Cost-driven build orientation and bin packing of parts in Selective Laser Melting (SLM). Eur J Oper Res 273(1):334–352. https://doi.org/10.1016/j.ejor.2018.07.053

26. Qin Y, Qi Q, Shi P, Scott PJ, Jiang X (2020) Automatic determination of part build orientation for laser powder bed fusion. Virtual Phys Prototyp. https://doi.org/10.1080/17452759.2020.1832793
27. Qin Y, Qi Q, Shi P, Scott PJ, Jiang X (2020) Automatic generation of alternative build orientations for laser powder bed fusion based on facet clustering. Virtual Phys Prototyp 15(3):307–324. https://doi.org/10.1080/17452759.2020.1756086
28. Fang ZC, Wu ZL, Huang CG, Wu CW (2020) Review on residual stress in selective laser melting additive manufacturing of alloy parts. Opt Laser Technol 129(15):106283. https://doi.org/10.1016/j.optlastec.2020.106283
29. Ning J, Sievers DE, Garmestani H, Liang SY (2019) Analytical modeling of in-process temperature in powder bed additive manufacturing considering laser power absorption, latent heat, scanning strategy, and powder packing. Mater (Basel) 12(5):1–16. https://doi.org/10.3390/MA12050808
30. Ning J, Wang W, Zamorano B, Liang SY (2019) Analytical modeling of lack-of-fusion porosity in metal additive manufacturing. Appl Phys A Mater Sci Process 125(11):1–11. https://doi.org/10.1007/s00339-019-3092-9
31. Ning J, Sievers DE, Garmestani H, Liang SY (2020) Analytical modeling of in-process temperature in powder feed metal additive manufacturing considering heat transfer boundary condition. Int J Precis Eng Manuf-Green Technol 7(3):585–593. https://doi.org/10.1007/s40684-019-00164-8
32. Xing W, Ouyang D, Li N, Liu L (2018) Estimation of residual stress in selective laser melting of a Zr-based amorphous alloy. Mater (Basel) 11(8). https://doi.org/10.3390/MA11081480
33. Li C, Liu JF, Guo YB (2016) Prediction of residual stress and part distortion in selective laser melting. Proc CIRP 45:171–174. https://doi.org/10.1016/j.procir.2016.02.058
34. Ning J, Praniewicz M, Wang W, Dobbs JR, Liang SY (2020) Analytical modeling of part distortion in metal additive manufacturing. Int J Adv Manuf Technol 107(1–2):49–57. https://doi.org/10.1007/s00170-020-05065-8
35. Park HS, Ansari MJ (2020) Estimation of residual stress and deformation in selective laser melting of Ti6Al4V alloy. Proc CIRP 93:44–49. https://doi.org/10.1016/j.procir.2020.03.091

Development of an Ontology for Defect Classification in Remanufacturing

Thomas R. Lechtenberg, Elif Elcin Gunay, Chih-Yuan Chu, Gül E. Kremer, Paul A. Kremer, and John K. Jackman

Abstract Remanufacturing within the automotive industry has become an important part of environmental and reusability efforts. A crucial aspect of the remanufacturing process workflow is the correct identification and classification of defects on the product. A comprehensive ontology was developed based on a literature review to define, distinguish, and prioritize various defects for the remanufacturing of cylinder heads to show the relationships between them. Furthermore, the opinions of experts who work with or within the remanufacturing industry were surveyed. Text-mining methods and input from standards documents where applicable were used to confirm and extend the ontology for defect classification in remanufacturing. Results from these efforts show that these methods can provide sufficient supplemental knowledge to validate critical or underdeveloped areas of ontology. Expert opinions are extremely valuable in communicating information that is not discussed in scholarly articles and in contributing to the process of validating information found in scholarly articles.

Keywords Remanufacturing · Ontology · Text-mining · Cylinder head · Defect

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1 Introduction

Companies utilize remanufacturing within the automotive industry to reduce their carbon emissions and to increase their sustainability. As automotive engines age, they become more susceptible to propagating cracks, general wear, and other fatigue defects within the engine block [1]. Remanufacturing efforts have been successful in producing second-life engine components; however, improper classification of defects has created excessive waste within the remanufacturing process. Often, a product will pass initial inspection; and, after repair efforts are conducted, the product is determined to be defective. Information provided by an automotive remanufacturer suggests that nearly 85% of defects are identified after the disassembly and inspection stage. Failure in the correct classification of components under evaluation for remanufacturing as defective or not can be attributed to improper classification methods and human error. Lin et al. [2] reported that improper classification might be due to using the same term for different concepts (semantic problem) or using different terms to represent the same entity (syntax problem).

As part of efforts to contribute to the development of standardized methods and guidance for defect identification and classification in remanufacturing, a validated collective presentation of information regarding the subject is needed. Current literature lacks cohesiveness in the presentation of remanufacturing defects information and the associated evaluation of which and whether corrective actions can be taken to cure the defects through subsequent remanufacturing processes. To illustrate this paucity of collective information in the literature associated with automotive remanufacturing applications, Lam et al. [1] discusses common defects found in automotive applications without any depth of discussion around decision-making using that information, and Carly [3] presents information on corrective measures for cracks in cylinder heads without a significant discussion about defect morphology. However, a collective ontology including both types of information will enable researchers and remanufacturing operators to quickly access information from various sources in one location. Moreover, the ontology can provide a structured framework around which automated inspection, identification, and classification systems can be developed.

The advantage of using an ontology to present information is evident by the features of an OWL (web ontology language). Kluska-Nawarecka describes the purpose of an OWL as "creating a kind of shared formal language, ontologies allow integrating a wide variety of distributed sources of knowledge in a given field" [4]. An OWL uses elements representing classes, individuals, and properties. Classes define the different comparative variables, such as defect location and repair method and the general storage of defects. Individuals are instances of classes, e.g., various types of defects make up the individual elements of the defect class. Properties show the relationships between individuals and classes. The visualization tools that show properties are the most advantageous aspect of an ontology.

This paper aims to create an informative ontology of service life defects commonly found in cylinder heads and with a specific focus on cast iron metallurgy. More specifically, the proposed ontology defines defects observed in remanufacturing processes and establishes a taxonomy to reflect the differences among them. Further, the ontology provides information about the corrective measures for the classified defects. In this regard, we use text mining, expert opinions, relevant studies from the literature, and existing standards to inform our development of the ontology. The text mining approach is used to verify whether main concepts and their relationships from scientific journals are accurately captured, while expert opinions, which also include aspects of existing standards, are used to consider remanufacturing application perspectives. By integrating these different resources, we can generate a comprehensive ontology for different users. The users of this ontology will be remanufacturing operators and researchers looking to gain an insight into the various relationships and properties of defects found in the remanufacturing processes of components for a second life. The methodology presented in Sect. 2 of this paper discusses how the ontology is established. Findings are reported in Sect. 3, and salient conclusions are drawn in Sect. 4.

2 Methodology

A standard search for scholarly literature yields promising articles to assist in ontology formation. Articles such as Lam et al. [1] provide valuable information on cylinder head defects in remanufacturing applications. However, the application of conventional methodologies to evaluate the accuracy and information value of the ontology would be time-consuming and involve significant uncertainty. Therefore, supplementing initial ontology generation efforts with additional resources is necessary to overcome these difficulties with the application of conventional methods. A standard practice recommends three techniques to ensure clear and accurate information is communicated through an ontology: iteration [5], text mining, and expert opinions [6]. In general, all ontologies are developed through an iterative approach. However, evaluation of the comprehensiveness of an ontology through text mining or expert opinions occurs less frequently, and utilization of both methods for evaluation is rarely observed. In this study, we first built an information foundation from the scientific literature. Then, we employed text mining approaches to verify the built information foundation, i.e., whether the terms and relationships were accurately captured. Finally, we gathered experts' feedback and existing standards to consider the application side of remanufacturing in the construction of a comprehensive ontology.

2.1 Building An Information Foundation

The general methodology for ontology generation begins with defining the purpose of the ontology. The purpose of the ontology in this study is to describe defects commonly found in the remanufacturing of cylinder heads, associate them with potential causes, describe corrective processes, and present the relationships among them comprehensively and coherently. Next, to build a foundation of information from general sources, a standard text search was conducted in Google Scholar and Scopus search engines. Generally, the search structure can take many forms depending on several factors such as audience, available information, and scope. Considering the scope and the purpose of our study, we chose “fatigue defects”, “crack”, “cylinder head”, “engine block”, “remanufacturing”, and “FMEA” as our keywords to develop a consistent and logical structure for defect ontology. The search was limited to journal articles in English. At the end of the search, 136 articles were collected. Considering their relevance, we selected 24 of them as consistent with the scope. Among the 24 articles, 5 were used as main resources due to their high relevance to the objectives of the study. Then, an initial list of defects was structured based on the highly relevant articles. The application of the ontology dictates the structure and scope [5]. In consideration of our specific audience, we included classes to store general information and to communicate relationships and attributes.

The ontology information classes are the following:

Manufacturing_Defects- Defects that form during the manufacturing process and before the part is used.

Service_Life__Defect- A defect that occurs during a part’s life cycle and that can cause critical failure while the part is in use.

The purpose of this separation was to clearly observe the relationship between defects that occur during manufacturing and defects that occur during the component’s service life. Even though remanufacturers consider service life defects, their attribution of causal relationships and associated corrective measures might be the same for manufacturing and service life defects. In this way, information collected for one class could be used for the other when there are sufficient similarities. Building the information base for the *Manufacturing_Defects* class was very straightforward because there has been extensive documentation of cast metal defects in the Atlas of Casting Defects [7]. The substructure of the *Manufacturing_Defects* class stems from the Atlas of Casting Defects, with instances being divided into four subcategories: Dented, Jagged, Rough, and Smooth. These subcategories separate the defect instances by surface appearance and feel. By populating a class of manufacturing defects, causal relationships can be shown for the *Service_Life_Defect* class. Additionally, definitions can be stored for defects that typically propagate before the service life of the component begins. Formation of the *Service_Life_Defect* class stemmed from a select few literature sources, which yielded 13 distinct defects that form during an engine’s service life [1].

The ontology relational classes are the following:

Location- Allows the instances stored in the informative classes to be organized by location. Subclasses for location include general locations, such as *Top_of_Part* and *Sharp_Corners*, and component-specific *Engine_Components* locations such as *Valve_Seat* and *Water_Jacket*.

Remanufacturing_Method- Allows a visual representation of the method used to refurbish the engine components. Information such as cost and time can be stored in the instances of this class to aid in the formation of an FMEA analysis. However, we leave it for potential future work.

To communicate between classes, object properties are necessary within the ontology. Object properties represent the connections between instances and class nodes. For example, the Crack node has an object property *Located_on* which connects Crack to the instance *Valve_Seat* in the class Location. Other object properties are *Caused_By*, *Defect_Type*, *Repaired_By*, and *Similar_To*. As the ontology is further developed, more object properties could be added such as *Detected_By*. This property would communicate potential methods of detection such as visual, or advanced automated methods.

For this paper, Protégé was used to demonstrate the ontology. Protégé [8] is a free, easy-to-use OWL software. It offers multiple advantages, such as the Ontograf feature (Fig. 1) showing classes, properties, and individuals simultaneously.

Although much information was acquired from scientific sources, a proper ontology, much like a consensus standard, undergoes several iterations before it can be considered complete. The iterative ontology development process endeavors to converge on unbiased information and objectivity. As stated by Regulski et al. [5], "ontologies should be developed through iterative processes". To converge on an objective presentation of information, formation through iteration becomes important in the final development of an ontology. As in many applications, continuous review reduces errors and biases and increases clarity and accuracy [9]. To maintain utility, iteration should be conducted throughout the whole life cycle of the ontology [10].

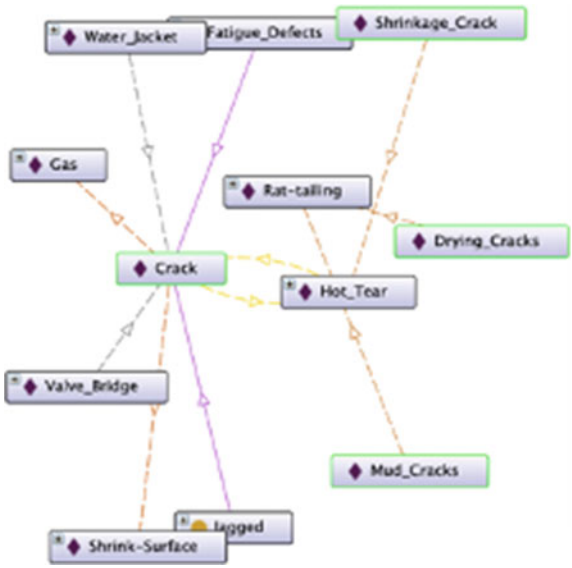

Fig. 1 Ontograf feature of Protégé OWL

2.2 Validation Through Text-Mining

Text mining is a trending approach to perform descriptive and predictive analysis on unstructured textual data. Useful techniques of text mining include term frequency analysis, correlation analysis, topic modelling (cluster analysis), sentiment analysis, text classification, etc. [11]. Several previous studies showed how text mining can find relationships among words and concepts to build concept hierarchies or ontology. For example, Chu et al. applied term frequency, correlation analysis, and topic modelling to categorize global supply chain risks into a hierarchical classification [12]; Rajpathak integrated text mining techniques, such as document annotation, semantic extraction, and frequently co-occurring term-based clustering, to assist in the development of an automotive diagnostic ontology [13]. These studies demonstrated that text mining has the capability to perform quantitative analysis on qualitative and unstructured textual data.

In this study, we employed mainly the term correlation analysis to verify the information foundation built in the ontology. There are several steps in the text mining phase of this research. First, initial screening started with a total of 136 research articles gathered as described in Sect. 2.1 that are related to defects and fatigue in cylinder heads. Second, we extracted the abstracts of those articles, and the bag-of-word method was used to create a word vector for each term in all abstracts. Third, we removed numbers, punctuations, and stop words from the word vectors to improve the clarity of the dataset. Fourth, the Pearson correlation coefficient was calculated for each term. The correlations were calculated on the document level, meaning that if one term has a high correlation with another, they appear frequently in the same document (research article). By looking into the ontology classes and their highly correlated terms, we verified and adjusted the information foundation, ensuring that both subjective (ontology development) and objective (text mining representation) perspectives were covered and cross-validated.

There are limitations to only using the abstracts of the scholarly articles. Limited resources prevented an analysis of the full texts. An analysis of the full texts could be done in the future to achieve better results.

2.3 Expert Opinions

We surveyed to receive experts' opinions on the draft ontology created by a detailed literature search. The goal of the expert evaluation was to contribute to the validation of the initial ontology and expand it according to experts' feedback. In this regard, a survey including several scenarios was created to collect experts' opinions. Survey questions were asked not only to understand how accurate and comprehensive the initial version of the ontology was in defining terms, relationships, and corrective measures in remanufacturing, but also to discover new terms and relationships in the field. Following Kitchenham & Pfleeger's [14] directions on survey elaboration, the objective of the ontology and the target audience were described first. Afterward, emphasis was put on the coherence between the used terms and relationships so that the reason for narrowing down the remanufacturing concept with the defect types, potential causes, and corrective processes could be rationalized. Moreover, the survey questions were decided in such a way that an appropriate number of questions could easily capture the correct terminology. Because the survey was unsupervised, utmost attention was paid to stating the questions and the instructions clearly so that experts were not left to misinterpret the questions.

Even though the ontology is extensive enough to cover full relationships between the defects, causes, and repair methods, we created simple scenarios to avoid an overloaded presentation of the complex relationships. An example scenario extracted from the ontology was as follows: *"Scenario 1 Service Life Defects Classification: The Service Life Defects, the defects you observe in remanufacturing, are divided into two subclasses to show the mechanical distinction between defects. "Surface Defects" are defined as defects that propagate on the surface of the automotive parts. "Part Failure" includes defects that cause a structural change in the geometry of a part. The below figure shows the defect types under each subclass."* Figure 2 shows the classification for the considered scenario. For a given scenario, experts were asked to evaluate the appropriateness of the terms (disassembly damage, fastener failure,

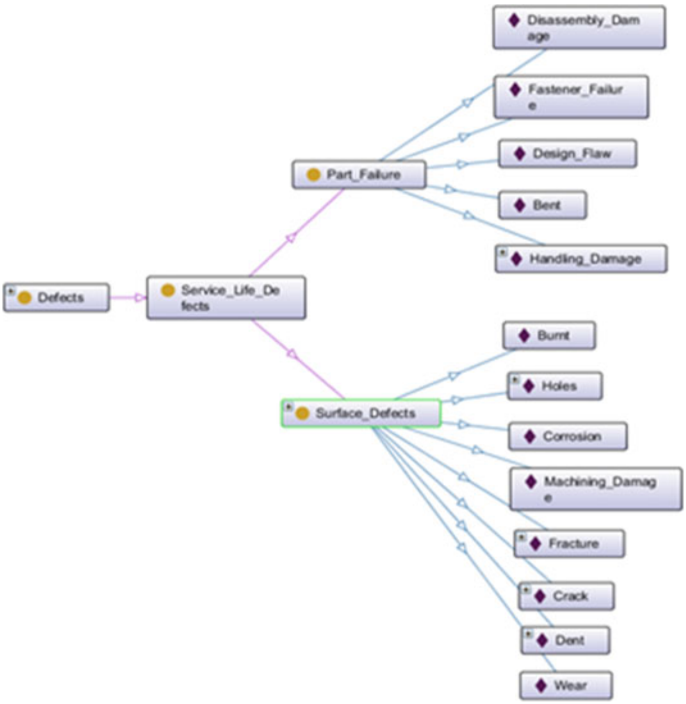

Fig. 2 An example scenario used in the expert survey

etc.). Their feedback regarding removing the term, exchanging it with an alternative name, or introducing new terms was collected. As the last step, they were asked to rate their final agreement with the classification.

3 Results

We created the list of defects based on the existing literature. Considering the purpose of the study, we first categorized whether they were manufacturing or service-life defects. Then, in an effort to add additional descriptive information, the defects were split into two categories: Part Failure and Surface Defects based on the mechanical distinction of each defect. "Part Failure" included defects that cause a structural change in the geometry of a part: disassembly damage, fastener failure, design flaw, bent, and handling damage. "Surface Defects" were defined as defects that propagate on the surface of the automotive parts: burnt, holes, corrosion, machining damage, fracture, crack, dent, and wear. Next, the location and cause information of those defects were populated. Last, these defects were linked with possible repair methods. The initial structure of this defect terminology was presented in Fig. 3.

Results from the text-mining validation approach yielded a correlation between terms. Table 1 highlights the relevant terms and their respective correlation value. The terms mostly contribute to the validation of defect modes such as shrinkage, pit, corrosion, and cracks captured in the information foundation. The term "Failure" identifies a few locations that appear relevant in the ontology. The term "Deck" likely refers to the fire deck component of a cylinder head, which is often subject to cracks and wear [15] (See Fig. 3). Additionally, the correlation between "Remanufacture" and "clad" is of particular interest because clad (referring to laser cladding) can be validated as a common and acceptable method of remanufacturing.

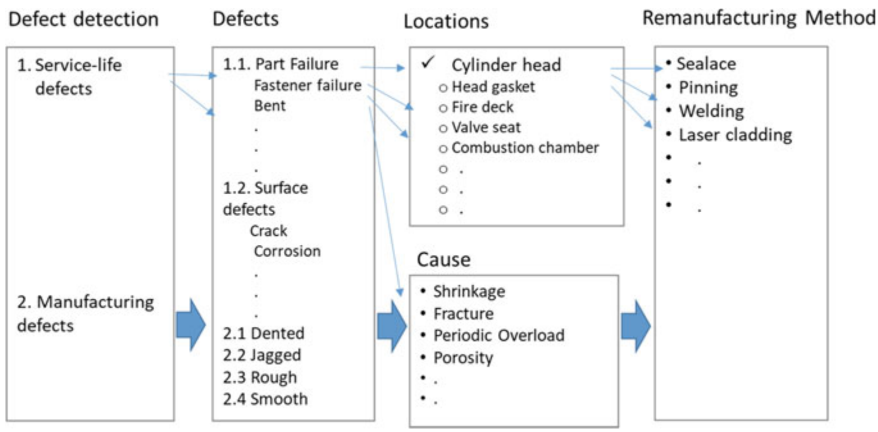

Fig. 3 Structure of the ontology

Table 1 Results from text-mining

Term	Correlated term	Correlation	Ontology Validation Location
Fatigue	Microshrinkage	0.23	Service_Life_Defects
Defect	Pit	0.53	Service_Life_Defects
Defect	Scratch	0.53	Service_Life_Defects
Defect	Microshrinkage	0.44	Manufacturing_Defects
Defect	Shrinkage	0.39	Manufacturing_Defects
Defect	Micropores	0.34	Manufacturing_Defects
Defect	Corrosion	0.27	Service_Life_Defects
Failure	Microstructure	-0.25	Manufacturing_Defects
Failure	Deck	0.23	Engine Components
Failure	Piston	0.32	Engine Components
Surface	Pore	0.33	Manufacturing_Defects
Surface	Microcracks	0.28	Service_Life_Defects
Surface	Bend	0.24	Service_Life_Defects
Surface	Crack	0.21	Service_Life_Defects
Surface	Wear	0.20	Service_Life_Defects
Engine	Wear	0.26	Service_Life_Defects
Engine	Valve	0.20	Engine Components
Remanufacture	Clad	0.81	Remanufacturing_Method

Further analysis of the term correlation produced new relationships as well. Referring to Fig. 4, there is a correlation between deformation and (head) gasket which indicates that deformation commonly occurs on the surface of the gasket component.

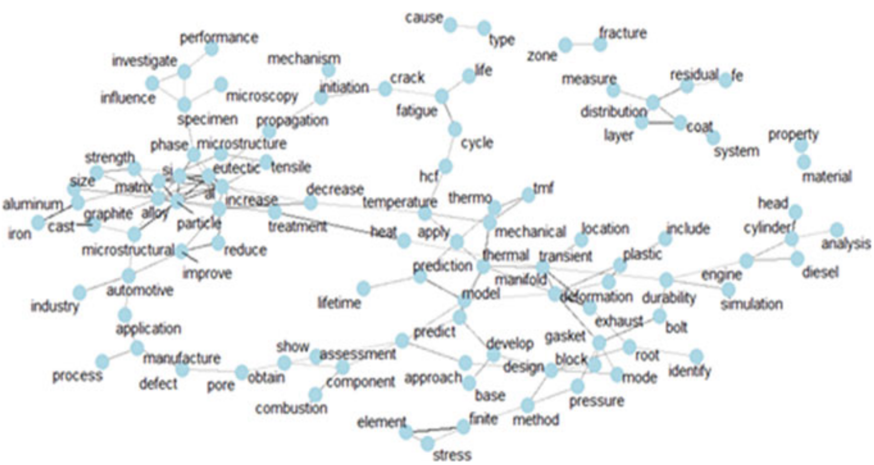

Fig. 4 Word cloud analysis of text mining approach

Additionally, the large cluster of terms around Al and Si indicates that the primary metals used for engine components are Aluminium and Silicon.

The information from experts contributes to a more comprehensive ontology. A total of four experts who were knowledgeable and had substantial experience (10 + years) in the remanufacturing field completed the survey. Received responses to the survey were very practical as the clarity of the terms and relationships were improved, and new ones were offered to develop a more enhanced version of the ontology. Combining the literature search with experts' feedback allowed us to consider the research and application sides of the field; consequently, a comprehensive terminology relating to defect identification, causes, and possible corrective solutions could be reached in a single place. Table 2 shows the initial version of the defect classification and the corresponding changes with respect to the experts' feedback. The location information of these defects is tabulated in Table 3.

Additionally, expert opinions led to the addition of sealace as a remanufacturing method and helped to identify a few specific locations within a cylinder head where cracks occur. Table 4 shows an example of information for the crack instance. Text mining contributes to this instance through the validation of causes–specifically shrinkage. Through the correlation analysis (see Table 1), shrinkage can be determined as a cause of a crack. Conjoining expert opinions and text mining methods provide clarity, improves accuracy, and helps to reduce bias within the ontology. Many components of the ontology are critical for our audience yet they are not

Table 2 Revised ontology based on experts' view

Initial version	Action	Final version after experts' feedback
(1) Part Failure	*Remove*	
Design flaw	*Remove*	
Disassembly damage	*Remove*	
Fastener failure	*Exchange with →*	Stripped thread
Handling damage	*Remove*	
Bent	*Exchange with →*	Warped
(2) Surface Defects	*Remove*	
Burnt	*Remove*	
Corrosion	*Exchange with →*	Pitting
Crack	*Keep*	Crack
Dent	*Remove*	
Fracture	*Exchange with →*	Fracture (chipped off)
Holes	*Keep*	Holes (unwanted)
Machining damage	*Combined →*	Surface out of spec (Wear, Machining Damage)
Wear		
	Add new term	Gouge/Dent
	Add new term	Broken Bolt

Table 3 The relationship between defects and their locations

Location	Broken bolt	Warped	Pitting	Crack	Gouge/Dent	Fracture	Surface out of spec	Stripped thread	Holes
Intake surface	x	x	x	x	x	x	x	x	x
Exhaust surface	x	x	x	x	x	x	x	x	x
Valve guide				x		x	x		
Valve seat			x	x	x	x	x		
Combustion chamber			x	x	x				x
Spark plugs bore (Gasoline engine)	x			x	x	x		x	x
Fire deck	x	x	x	x	x	x	x	x	x
Fuel injectors bore (Diesel engine)	x		x	x	x		x	x	x
Overhead camshaft bore	x	x	x	x	x	x	x	x	x
Rocker stud	x		x	x	x	x	x	x	x
External feature	x	x	x	x	x	x	x	x	x

Table 4 Information stored in the crack instance

Defect	Description	Location	Remanufacturing method	Cause
Crack	A failure point of material typically caused by stress or a pre-existing defect	• Sharp Corners • Valve Seat • Fire Deck • Valve Bridge	• Pinning • Welding • Sealace	• Fracture • Periodic Overload • Porosity • Holes • Shrinkage

communicated in scholarly articles. In particular, contributions from expert opinions strengthen the knowledge foundation and improve the validation efforts.

4 Conclusion

Storing information within an OWL format has many applications and audiences. However, importance must be placed during the formation process of an ontology on the evaluation of the correctness and comprehensiveness of the information collected. Two appropriate evaluation approaches, text mining and expert opinion solicitation, allowed us to consider the research and application sides of the ontology domain; consequently, a comprehensive terminology on defect identification, defect causes, and possible corrective solutions was integrated into a single tool. Expansion of this ontology through the addition of other properties can provide a structured framework around which automated inspection, identification, and classification systems employing non-destructive testing, machine learning, and other applicable methodologies can be developed.

Both methods also confirm the information provided by scientific journals. These associated methods applied in an iterative manner for cross-validation reduce bias and increase objectivity within the ontology. Further investigation of this topic could include a deeper analysis of the text mining approach, including gathering a larger data set and skimming complete articles as opposed to just abstracts. Regardless, both validation techniques supply ample information to compensate for weaknesses that emerge from the application of a single technique and to emphasize specified areas of the ontology to help deliver a quality presentation of concepts to the desired audience. Another extension of the ontology can support cost–benefit analysis for defects reparability in the remanufacturing process through consideration of defect location, severity, quantity, and causal relationships.

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References

1. Lam A, Sherwood M, Shu L (2001) FMEA-Based design for remanufacture using automotive-remanufacturer data. SAE Technical Paper 2001-01-0308. https://doi.org/10.4271/2001-01-0308
2. Lin HK, Harding JA, Shahbaz M (2004) Manufacturing system engineering ontology for semantic interoperability across extended project teams. Int J Prod Res 42(24):5099–5118
3. CarleyL (2012) Cylinder head repair methods. Engine Builder Magazine. www.enginebuildermag.com/2012/01/cylinder-head-repair-methods/. Accessed 5 Jan
4. Kluska-Nawarecka S, Nawarecki E, Dobrowolski G, Haratym A, Regulski K (2013) The platform for semantic integration and sharing technological knowledge on metal processing and casting. Comput Methods Mater Sci 13(2):304–312
5. Regulski K, Rojek G, Kusiak J (2014) Process of ontology construction of rolling metal sheets industrial process. In Key Eng Mater 622–623:978–985. https://doi.org/10.4028/www.scientific.net/kem.622-623.978
6. Huang C, Cai H, Xu L, Xu B, Gu Y, Jiang L (2019) Data-driven ontology generation and evolution towards intelligent service in manufacturing systems. Futur Gener Comput Syst 101:197–207
7. Investment Casting Institute. Atlas of Casting Defects. Retrieved September 23, 2020, from http://61746c6173.investmentcasting.org/casting/defects/
8. Protégé 4.3 (2021) Stanford University. https://protege.stanford.edu/products.php
9. Bessant J, Caffyn S, Gilbert J, Harding R, Webb S (1994) Rediscovering continuous improvement. Tecnovation 14(1):17–29
10. Gómez-Pérez A (2004) Ontology evaluation. In: Staab S, Studer R (eds) Handbook on ontologies. International handbooks on information systems. Springer, Berlin, Heidelberg
11. Gupta V, Lehal GS (2009) A survey of text mining techniques and applications. J Emerg Technol Web Intell 1(1):60–76
12. Chu C, Park K, Kremer GE (2020) A global supply chain risk management framework: an application of text-mining to identify region-specific supply chain risks. Adv Eng Inform 45:101053
13. Rajpathak DG (2013) An ontology based text mining system for knowledge discovery from the diagnosis data in the automotive domain. Comput Ind 64(5):565–580
14. Kitchenham BA, Pfleeger SL (2002) Principles of survey research part 2: designing a survey. ACM SIGSOFT Softw Eng Notes 27(1):18–20
15. Vertin KD, Haller CL, Lubnow Jr TS (1995) A root cause investigation of cylinder head cracking in large diesel engine standby power generators. SAE Trans 104(3):937–948

MRI Image Analysis with Deep Learning Methods in Brain Tumor Diagnosis

Yasin Kırelli, Seher Arslankaya, and Pelin Alcan

Abstract The use of Magnetic Resonance Images (MRI) is a frequently used tool in disease detection. The use of healthcare professionals to examine MRI images and to identify diseases are among traditional methods. Therefore, one way to improve clinical health care is to present and analyze medical images more efficiently and intelligently. Brain tumors can be of different types, and accordingly, they can cause serious health problems in adults and children. Such bulks can occur anywhere in the brain in different sizes and densities. This is not a standardized situation due to its nature. The diagnoses are revealed by the experts by analyzing the tumor images manually. In the proposed model, it is aimed at automating the process and reducing human errors in the system. The model is based on the deep learning technique, which is a probabilistic neural network to identify unwanted masses in the brain. In this study, a model has been created with VGG and CNN (Convolutional Neural Network) architectures, which are among the deep learning techniques. The performance values of the model outputs, accuracy, error rates, and specificity separators are discussed comparatively.

Keywords Machine learning · Image processing · Deep learning · CNN · VGG

1 Introduction

Healthcare professionals rely on medical images for disease detection and treatment when visual inspection is not possible. For this reason, medical images should

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be examined more efficiently in order to develop this method, which is frequently preferred in health services [1]. On the other hand, the devices and the created images are developed to obtain better quality results. Thus, the analysis of images with smart systems in order to facilitate their use in healthcare services has become a research topic. Physicians and radiologists can obtain more effective results in image analysis with computer-aided systems. Computing and data-based repetitive processes can be automated with computers and have become an important reference source for healthcare professionals [2].

In classical machine learning techniques, the feature extraction process is revealed manually, unlike deep learning methods, and the obtained images can be defined numerically. The manual feature extraction method is not an approach that can be possible in every field and on the other hand the necessary competence in the medical field may not be achieved. In addition, manually extracted features cannot produce effective results in all cases and successful results cannot be obtained in complex scenarios. One possible solution is to learn research-related features directly from medical data. Such a data-driven approach can naturally learn domain information from data without manual feature engineering. However, constraints such as optimization difficulty and hardware limitation are encountered. Since such architectures also lead to the use of shallow architectures, healthier results can be obtained with deep learning models [3].

El Kaitoun et al. have used an improved Markov method and a U-net-based deep learning method for brain tumor detection [4]. Ramirez et al. have presented a new variational model for MRI image segmentation [5]. Sobhaninia et al. have obtained more effective results by using multiple scales and the utilization of two cascade networks as an image segmentation method [6]. Wu et al. have used a 3D U-net-based deep learning model for tumor image segmentation [7]. Chetty et al. have presented a new approach model for classifying brain MRI images based on the 3D U-Net deep learning architecture [17].

The development of computer hardware and artificial learning techniques in recent years has enabled deep learning models on problems. Thus, classification with deep learning models, object perception, and computer vision problems became research topics. In this context, calculations that have transformed from traditional machine learning methods to deep learning methods have gained great momentum. Although deep learning in medical fields has become widespread, there is still much field for improvement. In this study, a model has been developed for the classification problem on brain tumor images with CNN and VGG deep learning methods, which are among the computer vision methods, is presented.

2 Materials and Methods

In this study, a classification model has been created using MR images frequently used by healthcare professionals. With this model, brain tumor symptoms in patients can be detected by computer vision methods. As a data source, publicly available

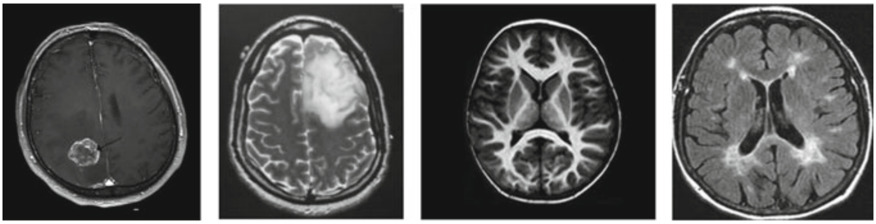


Fig. 1 Dataset sample ımages

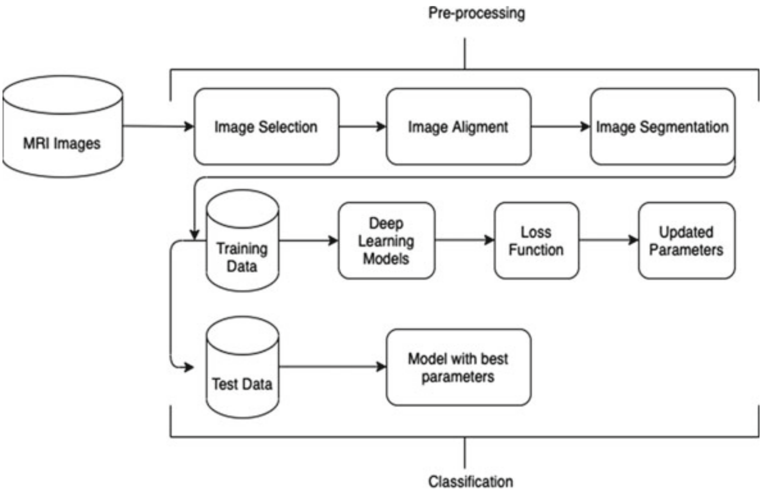


Fig. 2 Classification model

data on Kaggle has been used [8]. The dataset includes 155 tumor patients images separated according to patient data and 98 healthy MR images. Figure 1 contains sample data from the tumor and healthy brain images in the dataset.

Performance results of classification models created with CNN and VGG architectures, among deep learning techniques, have been compared. Images are rearranged to a fixed pixel size of 224 × 224. The created model is designed with the steps as in Fig. 2.

2.1 CNN and VGG Architecture

A convolutional neural network consists of layers in Fig. 3. The image is processed with the Convolutional Layer, Pooling Layer, Fully Connected Layer, and Output Layer steps, respectively, as indicated in Fig. 4 [9–16].

Each step in which the image is processed consists of the following processes.

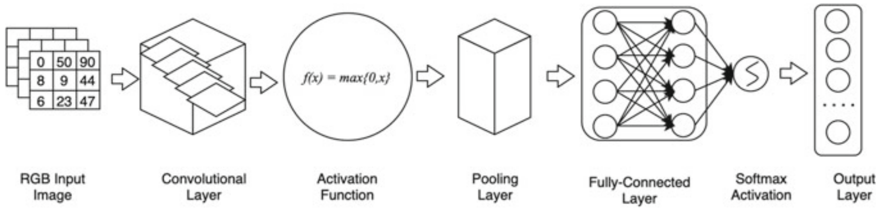


Fig. 3 CNN architecture

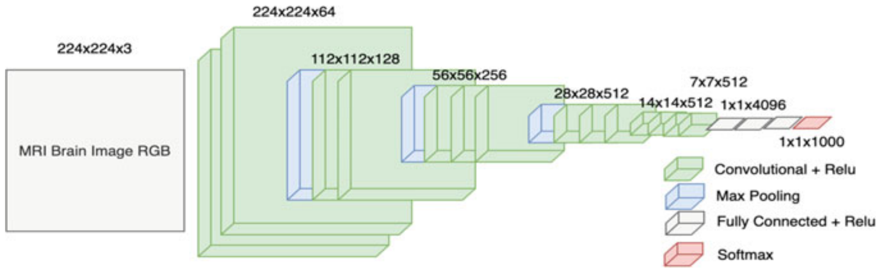


Fig. 4 VGG architecture

Convolutional Layer and Activation Function: It takes place to reveal the features and the non-linearity is introduced to the model through the activation function.

Pooling Layer: This layer is added after convolutional layer and helps to reduce the number of weights in the model. Thus, by reducing the number of parameters in the network, it allows a reduction of computational complexity.

Flattening Layer: Prepares the classical neural network data by making the matrix that consists of convolutional layer and pooling layer steps into one-dimensional array.

Fully Connected Layer: The standard neural network method used in the classification process is applied to the one-dimensional array taken from the pooling layer.

Relu Activation Function: This layer comes into effect after convolutional layers. The main task of this layer is to convert negative values from input data to zero. The model that comes from the operations before this layer has a linear structure and is required to turn it into a nonlinear structure. Thus, the model learns more efficiently [10, 11].

Softmax Activation Function: Softmax is mainly used in the output layer. Calculates the probability that the input belongs to a particular class. This is calculated by generating values between 0 and 1 with a probabilistic interpretation. It is mathematically expressed as in Eq. (1). The input vector x is a real number and consequently, a probability result p is produced [12, 13].

$$p = \begin{pmatrix} p_1 \\ \vdots \\ p_n \end{pmatrix}, \; p_i = \frac{e^{x_i}}{\sum_{j=1}^{n} e^{x_j}} \tag{1}$$

2.2 Model Implementation and Performance Analysis

The model has been implemented with the Python programming language version 3.7 and using the Keras deep learning library [15]. The dataset that used in the study has been divided into two groups as train and test datasets. The rate is 75–25%. First of all, the images are adjusted to a fixed size. Images have been rearranged in 224 × 224 size and thus it has aimed to achieve more effective results. Two different models proposed that based on CNN and VGG architectures have been designed. Layer information and the number of parameters for presented models have been created as shown in Table 1–2.

Model performances have been measured after training with two different models. According to the performance results, since the success rate in model 2 is higher and the loss function is closer to the value of zero, a better classification result has been obtained compared to model 1. As a result, a classification performance result of 92% in model 2 and 85% in model 1 has been obtained. It has been observed that model 2 with a result closer to 0 is more effective. As the performance values obtained from these models, accuracy and loss function graphs have obtained for 50 epochs as in

Table 1 Model 1 Parameters

Model 1: CNN-Based Classification		
Layer (type)	Output Shape	Parameter Count
Conv2D	(None, 222, 222, 32)	896
MaxPooling	(None, 111, 111, 32)	0
Conv2D	(None, 109, 109, 32)	9248
MaxPooling	(None, 54, 54, 32)	0
Conv2D	(None, 52, 52, 64)	18,496
MaxPooling	(None, 26, 26, 64)	0
Conv2D	(None, 24, 24, 128)	73,856
MaxPooling	(None, 12, 12, 128)	0
Flatten	(None, 18,432)	0
Dense	(None, 128)	2,359,424
Dropout	(None, 128)	0
Dense	(None, 1)	129
Total Parameters		2,462,049

Table 2 Model 2 Parameters

Model 2: VGG Based Classification		
Layer (type)	Output Shape	Parameter Count
Vgg16	(None, 7, 7, 512)	14,714,688
Flatten	(None, 25,088)	0
Dense	(None, 128)	3,211,392
Dropout	(None, 128)	0
BatchNormalization	(None, 128)	512
Dense	(None, 1)	129
Total Parameters		17,926,721

Table 3. Only the accuracy criterion does not give sufficient results in cases where there are unbalanced data sets [14], thus accuracy, precision, and recall values have also been observed as other performance metrics in Table 4.

TP (True positive): Correct detection of the tumor image.
FP (False positive): Incorrect detection of the healthy image.
TN (True negative): Correct detection of the healthy image.

Table 3 Accuracy and loss rates

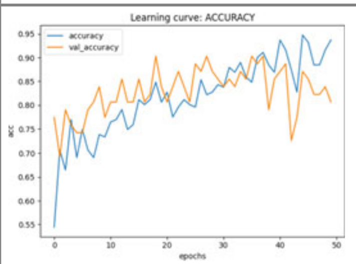
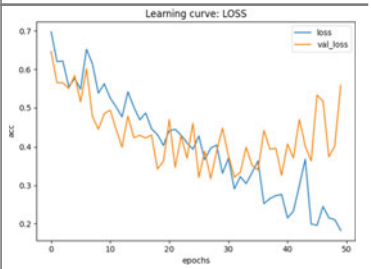
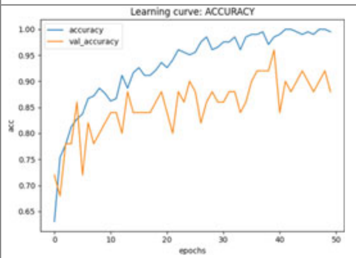
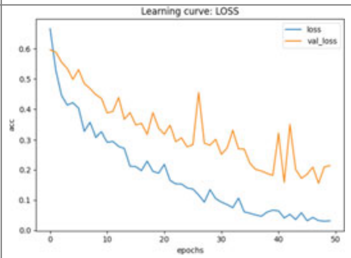
Model	Accuracy rate	Loss rate
Model 1 (CNN Based Architecture)		
Model 2 (VGG16 Based Architecture)		

Table 4 Precision and Recall Metrics

Model	Precision	Recall
Model 1	0.84	0.82
Model 2	0.91	0.91

FN (False negative): False detection of the tumor image.
Precision rate (P) = TP / (TP + FP).
Recall rate (R) = TP / (TP + FN).

3 Conclusion

In this study, the performance performances of CNN- and VGG-based proposed models for tumor detection through MRI images, which are frequently used in health care, in classification have been evaluated. The number of convolutional layers, dataset quality, number of epochs can be among the main criteria that can affect the success of the model during training. The number of patient samples may be limited in the training set and thus this situation may lead to over-learning. It has been observed that better results can be obtained with a limited number of images with the VGG-based model, which has a pre-trained architecture for such cases. As a result, it has been observed that pre-trained VGG-based models have high applicability in the health field where data acquisition is limited even if they are trained with objects with different characteristics. It has been observed that the learned features during training can be transferred with high accuracy on different models and it makes such models a viable option for classification problems in the healthcare field.

References

1. Sangeetha R, Mohanarathinam A, Aravindh G, Jayachitra S, Bhuvaneswari M (2020) Automatic detection of brain tumor using deep learning algorithms. In: Proceedings of 2020 4th International Conference on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India, pp 1–4. https://doi.org/10.1109/ICECA49313.2020.9297536
2. Santos J, Santos dos HDP, Vieira R (2020) Fall detection in clinical notes using language models and token classifier. In: Proceedings of 2020 IEEE 33rd International Symposium on Computer-Based Medical Systems (CBMS) Rochester, MN, USA, pp 283–288. https://doi.org/10.1109/CBMS49503.2020.00060
3. Sufri NAJ, Rahmad NA, Ghazali NF, Shahar N, As'ari MA (2019) Vision based system for banknote recognition using different machine learning and deep learning approach. In: Proceedings of 2019 IEEE 10th Control and System Graduate Research Colloquium (ICSGRC) Shah Alam, Malaysia, pp 5–8. https://doi.org/10.1109/ICSGRC.2019.8837068
4. El kaitouni SEI, Tairi H (2020) Segmentation of medical images for the extraction of brain tumors: a comparative study between the Hidden Markov and deep learning approaches. In: Proceedings of 2020 International Conference on Intelligent Systems and Computer Vision (ISCV), Fez, Morocco, pp 1–5. https://doi.org/10.1109/ISCV49265.2020.9204319
5. Ramírez I, Martín A, Schiavi E (2018) Optimization of a variational model using deep learning: an application to brain tumor segmentation. 2018 IEEE 15th International Symposium on Biomedical Imaging (ISBI 2018) Washington, DC, USA, pp 631–634. https://doi.org/10.1109/ISBI.2018.8363654
6. Sobhaninia Z, Rezaei S, Karimi N, Emami A, Samavi S (2020) Brain tumor segmentation by cascaded deep neural networks using multiple image scales. In Proceedings of 2020 28th

Iranian Conference on Electrical Engineering (ICEE), Tabriz, Iran, pp 1–4. https://doi.org/10.1109/ICEE50131.2020.9260876

7. Wu P, Chang Q (2020) Brain tumor segmentation on multimodal 3D-MRI using deep learning method. In: Proceedings of 2020 13th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI) Chengdu, China, pp 635–639. https://doi.org/10.1109/CISP-BMEI51763.2020.9263614
8. Chakrabarty N (2019) Brain mri images for brain tumor detection. Retrieved April 10, 2021, from https://www.kaggle.com/navoneel/brain-mri-images-for-brain-tumor-detection
9. Basaveswara SK (2019) CNN Architectures, a Deep-dive - towards data science. Medium. https://towardsdatascience.com/cnn-architectures-a-deep-dive-a99441d18049
10. Stursa D, Dolezel P (2019) Comparison of ReLU and linear saturated activation functions in neural network for universal approximation. In: Proceedings of 2019 22nd International Conference on Process Control (PC19), Strbske Pleso, Slovakia, pp 146–151. https://doi.org/10.1109/PC.2019.8815057
11. Kirana KC, Wibawanto S, Hidayah N, Cahyono GP, Asfani K (2019) Improved neural network using Integral-RELU based prevention activation for face detection. In: Proceedings of 2019 International Conference on Electrical, Electronics and Information Engineering (ICEEIE), Denpasar, Indonesia, pp 260–263. https://doi.org/10.1109/ICEEIE47180.2019.8981443
12. Galindo O, Ayub C, Ceberio M, Kreinovich V (2019) Faster quantum alternative to softmax selection in deep learning and deep reinforcement learning. 2019 IEEE Symposium Series on Computational Intelligence (SSCI) Xiamen, China, pp 815–818. https://doi.org/10.1109/SSCI44817.2019.9003167
13. Alabassy B, Safar M, El-Kharashi MW (2020) A high-accuracy implementation for softmax layer in deep neural networks. 2020 15th Design & Technology of Integrated Systems in Nanoscale Era (DTIS) Marrakech, Morocco, pp 1–6. https://doi.org/10.1109/DTIS48698.2020.9081313
14. Steiniger Y, Stoppe J, Meisen T, Kraus D (2020) Dealing with highly unbalanced sidescan sonar image datasets for deep learning classification tasks. Global Oceans, 2020 Singapore–U.S Gulf Coast, Biloxi, MS, USA, pp 1–7. https://doi.org/10.1109/IEEECONF38699.2020.9389373
15. Team K (n.d.) Simple. Flexible. Powerful. Retrieved from https://keras.io/
16. Allibhai E (2019) Building a Convolutional Neural Network (CNN) in Keras. Medium. https://towardsdatascience.com/building-a-convolutional-neural-network-cnn-in-keras-329fbbadc5f5
17. Chetty G, Singh M, White M (2019) Automatic brain image analysis based on multimodal deep learning scheme. In: Proceedings of International Conference on Machine Learning and Data Engineering (iCMLDE) 2019, pp 97–100. https://doi.org/10.1109/iCMLDE49015.2019.00028

Determining the Priority Criteria for Personnel Selection With Fuzzy Dematel and Grey-Based Dematel Approaches

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Abstract Although robots and other technologies replace manpower in today's business world with digitalization, the human factor is still one of the most important productivity and efficiency factors for many businesses. Managers have to consider many factors and constraints while selecting the human resources to be employed in their companies. In this study, the DEMATEL method was applied to determine the important criteria for the personnel to be recruited into an enterprise. It was combined as Fuzzy DEMATEL and Grey DEMATEL in order to remove the ambiguity in the linguistic expressions of the decision-makers while indicating the degree of importance between the criteria.However, the linguistic expressions taken from experts while conducting the research may be in a range other than being expressed in clear numbers, the system becomes more reliable, and expert evaluations are obtained with grey numbers instead of triangular fuzzy numbers used in fuzzy logic, and this increases the reliability of the evaluations. Therefore, the problem applied the Fuzzy DEMATEL method was solved with Grey DEMATEL, in other words, the flexible structure of Grey DEMATEL was adapted to the problem. At the end of both methods, the criteria were ranked according to their weights and the results were compared.

Keywords Personnel Selection · Fuzzy DEMATEL · Grey-Based DEMATEL · Priority Criteria

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1 Introduction

The human factor is the most important factor of the organization with its dynamic structure. If the personnel to be hired are selected as the most suitable person for the business and the work, the performance of the enterprise can increase. The success of an enterprise is also directly proportional to the success of the employees. Therefore, choosing the most suitable candidate for the business is an important decision for most businesses. Due to the developing competitive environment, the personnel who employs for an enterprise is of great importance. Having the manpower at a level and capability to meet the real needs of the enterprise and choosing the most beneficial for the enterprise among these are considered as a standalone problem in terms of human resources. Delays in personnel selection and selection cause delays in the work and an increase in costs. For all these reasons, the selection process is a difficult, careful and critical process that must be carried out with right decision. Especially in institutionalized enterprises, the coexistence of many criteria and objectives may cause the conflict of objectives and criteria to ignore the really important decisions for the business. In the literature, there are many studies on this subject using different methods. In the literature, there are many studies on this subject using different methods. The DEMATEL method is a powerful tool, originated from the Geneva research centre of battle memorial institute for capturing the cause and effect relationship by Fontela [1] and Gabus [2] in 1972. Especially, it is useful for visualizing the complicated structure with matrices or digraphs. The classical DEMATEL method only deals with crisp values $\{0, 1\}$ to provide the correlations among factors. In real-life situations, correlated factor analysis problems may involve the uncertainty of fuzzy data. Thus, the fuzzy DEMATEL method was extended using fuzzy numbers by Lin 3, 4]. In many practical decision problems, experts may provide uncertain linguistic terms to express their opinion when they have no clear idea or inadequate experience. The uncertain linguistic term is frequently used as a form of inputs in decision analysis activities. Visioner researchers have focused on the uncertain linguistic terms in group decision-making processes. Lin 2008, Lin 2004 proposed a Fuzzy extension of the DEMATEL method where uncertain linguistic terms converted into triangular fuzzy numbers. Victor Devadoss and Felix [5] have extended the DEMATEL method by representing linguistic variables into hexagonal, heptagonal, octagonal fuzzy numbers.

Also, there are multiple studies in the literature on personnel selection. Some of the applications for literature review related to the topic of the study have been examined and summarized below.

Samanlioglu et al. in a study for personnel selection, multi-criteria decision-making was applied in the field of the IT department of the Turkish dairy company. The aim of the paper is to choose the best employee in this field. For this solution, Fuzzy AHP and Fuzzy TOPSIS were applied. Hierarchical level weights, reflecting the importance of Decision-Makers' linguistic evaluations, are utilized first, with fuzzy AHP, the importance weights of thirty sub-criteria are determined, and then, with fuzzy TOPSIS five IT personnel alternatives are ranked utilizing the weights obtained with fuzzy AHP [6]. Another study has been applied in the automotive industry. Ozturk and Kaya aimed to contribute to personnel selection, especially in the automotive supplier industry in their study. The study used VIKOR method to make the right choice among the candidates based on conflicting criteria, and fuzzy logic was used to make the results more reliable [7]. In another study on personnel selection Ozdemir and Nalbant, the best staffing was found by combining the integrated Consistent Fuzzy Preference Relationships (CFPR) and Fuzzy Analytical Hierarchy Process (FAHP) methodology. CFPR is used to obtain the importance weight of personnel selection criteria (22 sub-criteria are categorized under 5 main criteria). Then, the importance weights of personnel selection criteria are integrated with a Fuzzy AHP model to prioritize the personnel alternatives. The main contribution in this study is the reduction of judgments for a preference matrix using the proposed methodology. To the authors', this study will be the first to integrate CFPR and Fuzzy AHP methods for personnel selection [8]. Kazancıoğlu and Özkan aimed to present a structural competence model in their studies, to obtain new criteria for personnel selection within the scope of Industry 4.0, and to contribute to the operation management literature by focusing on human resources activities within the scope of Industry 4.0. Using the Fuzzy Dematel method, they presented 11 personnel selection criteria.Merdivenci and Oğuz used the Entropy-based Edaş method in the logistics personnel selection problem in their study. With this method, five candidates for a logistics company were evaluated with four criteria. First, the criteria were weighted with the entropy method, and then the most suitable candidates were determined by ranking the candidates with the EDAS method [9, 10].

2 Methods in the Study

2.1 Multi-Criteria Decision-Making

Multi-Attribute Decision-Making is the most well-known branch of decision-making. It is a branch of a general class of Operations Research (or OR) models, which deal with decision problems under the presence of a number of decision criteria. This superclass of models is often called multi-criteria decision-making (or MCDM). According to many authors, MCDM is divided into Multi-Objective Decision-Making and Multi-Attribute Decision-Making [11]. It is necessary to take into account many evaluation criteria in the selection of human resources, which are vital for the business. Therefore, personnel selection problem is examined as a multi-criteria decision-making problem. Multi-criteria decision-making techniques are used to make healthy decisions by considering different criteria. There are many proven and applicable models such as Analytical Hierarchy Process (AHP), Electre, TOPSIS, Grey Theory.

2.2 Fuzzy DEMATEL Method

The DEMATEL is a method used to determine the affected and affecting factors that have a complex structure in developing events. Basically, this method aims to draw meaningful results by visualizing complex cause and effect relationships and to determine the priority order of the criteria. However, it is very difficult to determine the degree of interaction between factors in these relationships. This is because it is very difficult to quantify the interaction between factors. Therefore, Lin and Wu carried the DEMATEL method to the cloudy environment. As stated earlier, it is important to investigate the amount of influence a given criterion practices over another one and vice versa. Hence, the DEMATEL method could be suggested as an appropriate approach capable of highlighting the most influencing risk factors.

Zimmermann [12] presents The Fuzzy DEMATEL method including the following steps.

Step #1. Determination of problem criteria and fuzzy assessment scale. A decision group consisting of expert employees in the company is formed in order to determine the criteria according to the characteristics of the company and the industry where the problem is addressed.

Step #2. Creation of fuzzy direct-relation matrix.

Each expert is asked to determine the degree to which i criterion affects criterion j, in order to determine the level of relationship between criteria. At this stage, Fuzzy diversity is used for this process. The interaction between factors in this diversity is considered as a linguistic variable and is expressed in five linguistic terms defined as "too much", "much", "normal", "less", and "a little". These linguistic terms are shown with triangular fuzzy numbers. In order to measure the relationship between the $C = \{Ci \mid i = 1,2\ldots, nn\}$ criteria of decision-makers, a binary comparison matrix is created by experts with linguistic terms. Considering that the decision group consists of p experts, each expert's matrix is formed from the fuzzy matrices of p $\tilde{Z}$ (1), $\tilde{Z}$ (2) … $\tilde{Z}$ (P), each corresponding to an expert. It indicates the level of influence of criterion on j. The short form of representation of the Fuzzy Language Scale is $(l_{ij} m_{ij} u_{ij})$.

Fuzzy evaluation consisting of fuzzy scale and triangular fuzzy number equivalents proposed by Li in the study scale has been used. Table 1 includes these scale values [13].

Table 1 Fuzzy linguistic scale $(l_{ij} n_{ij} u_{ij})$

Linguistic terms	Influence scores	Triangular fuzzy numbers
No influence	0	(0, 0, 0,25)
Very low influence	1	(0, 0.25, 0.5)
Low influence	2	(0.25, 0.5, 0.75)
High influence	3	(0.5, 0.75, 1)
Very high influence	4	(0.75, 1, 1)

Linguistic definitions are obtained from the decision-maker and a pairwise comparison matrix is created. After the matrix is created; Eq. 1 is used if there is more than one decision-maker. Shortly, the triangular fuzzy number equivalents of the linguistic comments of decision-makers are averaged.

$$\tilde{\alpha}_{\imath j} = \frac{1}{H}\sum_{k=1}^{H} X_{\imath j}^{\tilde{k}} \tag{1}$$

Step 3. Equations and Fuzzy Direct Relationship Matrix is normalized.

Normalization is performed using Eqs. 2 and 3 in the following. In this step, u values of each criterion are summed up. Based on the number of the available criteria, there are so many *u*-values. Then the whole matrix is divided by the highest u-value.

$$\tilde{x}_{ij}^{(k)} = \frac{\tilde{z}_{ij}^{k}}{r^{(k)}} = \left(\frac{l_{ij}^{k}}{r^{(k)}}, \frac{m_{ij}^{k}}{r^{(k)}}, \frac{u_{ij}^{k}}{r^{(k)}}\right) \tag{2}$$

$$r^{(k)} = \underset{1 < i < n}{\max}\left(\sum_{j=1}^{n} u_{ij}^{k}\right) \tag{3}$$

Step 4. Creating Fuzzy-Sum Relationship Matrix

$$M = X(1 - X)^{-1} \tag{4}$$

The elements of these matrices are calculated using the following formulas to calculate the elements of the total relation fuzzy matrix. Equations 4 and 5 are used. The values of all criteria (l, m, u) are processed separately as in Eq. 5. For all (l, m, u) values, first, the matrix is subtracted from the unit matrix and the inverse is taken. Then the new matrix formed; multiplied by the matrix itself.

$$\begin{aligned} Matrix[l_{ij}^{''}] &= X_l \text{ X } (I - X_L)^{-1} \\ Matrix[l_{ij}^{''}] &= X_l \text{ X } (I - X_m)^{-1} \\ Matrix[l_{ij}^{''}] &= X_l \text{ X } (I - X_u)^{-1} \end{aligned} \tag{5}$$

Step 5. Identification of Affected and Affecting (Sender and Recipient) Groups:

Based on the matrix (F) in step 4, the sum of the ith row of this matrix *Di* indicates the sum of direct and indirect effects sent to other criteria by i criterion. Column sum *Ri*; whereas it shows the sum of the effects of the same criterion from other criteria. For each criterion, the total effect value sent and received by the index ($D\dot{I} + R\dot{I}$) is determined by row and column totals; ($D\dot{I} - R\dot{I}$) index value shows the net effect of the i factor on the system. The fact that this value is positive indicates that the net i criterion is “net affecting”; negative means “Net affected”. ($D\dot{I} + R\dot{I}$) value shows the degree of criterion i in the total system. D and R values are found using Eqs. 7 and 8.

It can be said as (Dİ + Rİ) central role degree and (Dİ − Rİ) influence degree.

$$M = \left[\mathrm{m}_{ij}\right],\ \mathrm{i,j} = 1, 2, \ldots, \mathrm{n} \quad (6)$$

$$D = \left[\sum_{j=1}^{n} m_{ij}\right]_{n\mathrm{x}1} = [t_i]_{n\mathrm{x}1}$$
$$R = \left[\sum_{i=1}^{n} m_{ij}\right]_{1\mathrm{xn}} = [t_i]_{1\mathrm{xn}} \quad (7)$$

$$D + R = 1/4(l + 2m + u)$$
$$D - R = 1/4(l + 2m + u) \quad (8)$$

Step 6: Finding the weights.

Equation 9 and 10 is used to find the weights of the criteria after (Dİ + Rİ) and (Dİ − Rİ) values are found. After determining the criterion weights, they are listed in ascending order and priority criteria are determined.

$$w_i = \left\{\left(\tilde{D}_i^{def} + \tilde{R}_i^{def}\right)^2 + (\tilde{D}_i^{def} - \left(\tilde{R}_i^{def}\right)^2\right\}^{1/2}. \quad (9)$$

$$W_i = \frac{w_i}{\sum_{i=1}^{n} W_i} \quad (10)$$

2.3 Grey System Theory

Grey System Theory is mainly used to analyze relationships between uncertain systems, build models, and analyze future predictions and decisions in a healthy way. Grey System Theory is generally recommended for the solution of problems that do not need distribution with multivariate statistics, do not contain sufficient data, and cannot be modeled due to uncertainty, where the criteria are to be assigned importance level.

Grey system theory can be used to solve uncertainty problems in cases with discrete data and incomplete information [14]. Its major advantage is the ability to generate satisfactory outcomes using are a latively small amount of data or when there is great variability in factors [15]. Grey system theory has been a popular analysis technique used in many sectors and fields in the past two decades. grey production, grey relationship analysis, grey modeling, grey prediction, grey decision-making, and grey control can be examined under six main headings.

2.4 Grey-Based DEMATEL

The application methodology in which the grey system theory and DEMATEL methods will be used in an integrated way consists of 8 stages. These stages will be explained sequentially.

Step 1. Determining the Rating Scale for Grey Relationships.

In the DEMATEL method, the effects of the elements that are compared in pairs are determined as 0 = ineffective, 1 = low effect, 2 = medium effect, 3 = high effect, 4 = very high effect, respectively. At this stage, these effects, which decision-makers express their evaluations verbally, are transformed into values consisting of grey numbers according to the Grey Linguistic Expression Scale shown in Table 2 [16].

Step 2. Creating the Grey Direct-Relation Matrix (X).

At this stage, decision-makers who will be suitable for the purpose of the study are asked to make binary evaluations in accordance with the scale in Table 2. As a result of the evaluations, the grey direct-relation matrix is obtained.

Step 3. Clarifying the Grey Direct-Relation Matrix (Z).

At this stage, the numbers in the grey direct-relation matrix are converted into clear numbers. The representation of the grey numbers is as in formula 11.

$$\otimes X_{ij}^{k} = \left[\overleftarrow{\emptyset} X_{ij}^{k}, \vec{\emptyset} X_{ij}^{k}\right] \tag{11}$$

In order to obtain clear numbers, the rinsing method developed by Opricovic and Tzeng is used. The following equations will be used for the clarification process from three sub-stages [17]. Equations 12, 13, 14 is used to calculate net values.

i. Normalization

$$\overleftarrow{\emptyset} X_{ij}^{k} = \left(\overleftarrow{\emptyset} X_{ij}^{k} - \min \overleftarrow{\emptyset} X_{ij}^{k}\right) / \Delta_{\min}^{\max}$$

$$\overrightarrow{\emptyset} X_{ij}^{k} = \left(\overrightarrow{\emptyset} X_{ij}^{k} - \min \overrightarrow{\emptyset} X_{ij}^{k}\right) / \Delta_{\min}^{\max}$$

Table 2 Grey linguistic expression scale

Value	Impact degree	Grey numbers
4	very high effect	0,75–1
3	high effect	0,5–0,75
2	medium effect	0,25–0,5
1	low effect	0–0,25
0	ineffective	0–0

$$\Delta_{\min}^{\max} = \max \overrightarrow{\emptyset}\, X_{ij}^{k} - \min \overleftarrow{\emptyset}\, X_{ij}^{k} \quad (12)$$

ii. Obtaining Total Normalized Condition Values

$$Y_{iJ}^{k} = \frac{\overleftarrow{\emptyset}\, \tilde{x}_{ij}^{k}\left(1 - \overleftarrow{\emptyset}\, \tilde{x}_{ij}^{k}\right) + \left(\overrightarrow{\emptyset}\, \tilde{x}_{ij}^{k} X \overrightarrow{\emptyset}\, \tilde{x}_{ij}^{k}\right)}{1 - \overleftarrow{\emptyset}\, \tilde{x}_{ij}^{k} + \overrightarrow{\emptyset}\, \tilde{x}_{ij}^{k}} \quad (13)$$

iii. Obtaining Clear Values

$$Z_{ij}^{k} = \min \overleftarrow{\emptyset}\, \tilde{x}_{ij}^{k} + Y_{ij}^{k} X \Delta_{\min}^{\max} \quad (14)$$

If there is only one decision-maker in the evaluation process, the fifth stage should be passed with the matrix (Z) consisting of the clarified values obtained at this stage. If there is more than one decision-maker, it is necessary to determine the weight of the decision-makers in Stage 4.

Step 4. Determining the Weights of the Decision-Makers.

If there is more than one decision-maker in the evaluation process, the weights of those decision-makers should be determined. If the evaluations of decision-makers are handled with equal weight, the following Eq. 15 should be used. In this equation, ij z values indicate the rinsed values obtained in the previous stage, and k indicates the number of decision-makers.

$$z_{ij} = \frac{1}{k}\left(z_{ij}^{1} + z_{ij}^{2} + \cdots + z_{ij}^{k}\right) \quad (15)$$

In case the evaluations of decision-makers are handled with different weights, the following Eq. 16 should be used.

$$Z_{ij} = w_1 Z_{ij}^{1} + w_1 Z_{ij}^{1} + \cdots + w_k Z_{ij}^{k} \quad (16)$$

Step 5. Normalizing the Total State Direct-Relation Matrix (N).

In the previous stages, a clear direct-relation matrix was obtained by transforming grey values into clarified values. After this stage, the DEMATEL method will be included in the application and the application steps of the method will be applied [18, 19]. The pure direct-relation matrix is normalized at this stage. The normalization process is carried out by making use of Eqs. 17 and 18.

$$\mathrm{N} = \mathrm{Z.s} \quad (17)$$

$$s = \frac{1}{\underset{1 < i < n}{max} \sum_{j=1}^{n} Z_{ij}} \tag{18}$$

Step 6. Obtaining the Total Impact Matrix.

In this step, using the pure direct-relation matrix normalized in the previous step, it is transformed into the total effect matrix in the following Eq. 19. First, the matrix is subtracted from the unit matrix and the inverse is taken. Then the new matrix formed; multiplied by the matrix itself.

$$T = N + N^2 + \ldots + N^h = N(I - N)^{(-1)}$$

$$T = \begin{bmatrix} t_{11} & \cdots & t_{1n} \\ \vdots & \ddots & \vdots \\ t_{n1} & \cdots & t_{nn} \end{bmatrix} \tag{19}$$

Step 7. Getting Row and Column Totals.

In this step, all the values in the row (D) in the interaction of each criterion with the other criterion from the total relationship matrix and the values in the column when each criterion interacts with the other criterion (R). Equations 20 and 21 are shown.

$$d_i = \sum_{j=1}^{n} t_{ij} \rightarrow D = \begin{bmatrix} d_1 \\ d_l \\ d_n \end{bmatrix}_{n \times 1} \tag{20}$$

$$r_i = \sum_{j=1}^{n} t_{ij} \rightarrow R = [r_1 \ldots r_i \ldots r_n]_{1xn} \tag{21}$$

Using the equations above, di + rj and di - rj values will be calculated. According to this,

The higher the d*j* + r*j* value means that the performance criterion is more related to others. The performance criterion or criterions with a positive d*i* - r*j* value affects the others, while the performance criterion or criterions with a negative d*i* - r*j* value is influenced by the others.

Step 8: Finding the weights.

The weights of the criteria are found using the below Eq. 22 and 23.

$$w_i = \left\{ (\tilde{D}_i^{def} + \left(\tilde{R}_i^{def}\right)^2 + (\tilde{D}_i^{def} - \left(\tilde{R}_i^{def}\right)^2 \right\}^{1/2} \tag{22}$$

$$W_i = \frac{W_i}{\sum_{i=1}^{n} w_i} \tag{23}$$

3 Application

3.1 Recommended Fuzzy DEMATEL Method

This study, the DEMATEL method, which determines the relationships and the effects of the criteria on each other in order of importance, was used when determining the relations and priorities between the criteria for personnel selection in an enterprise that will recruit white-collar personnel.

A linguistic variable/term is a variable whose value is not a crisp number but a word or sentence linguistic in a natural language [20]. Since it is difficult to express the interaction between the criteria quantitatively, the Fuzzy DEMATEL method was used. Opinion of the decision-makers on the criteria and the fuzzy number of opinions and comments were assigned according to Table 1. In the study, the opinions of the department manager and the department leader were taken from the department to be recruited and the criteria for the relevant department were determined. Six criteria were determined as a result of the expert opinions. That is, there are 2 decision-makers and 6 criteria in this study. Our criteria are Experience (C1), Grammar (C2), Ability to work in teams and sociability (C3), Strategic thinking and innovativeness (C4), Computer knowledge (C5), Educational Background (C6). The criteria are numbered for convenience.

Experts may provide their judgment in the linguistic term when they have no clear idea about it. This uncertain linguistic term is used as an input in decision analysis. Linguistic values are represented as a fuzzy number. As mentioned earlier [14], fuzzy evaluation consisting of fuzzy scale and triangular fuzzy number equivalents proposed by Li in the study scale has been used and Table 1 includes these scale values.

Step 1. The fuzzy number values were given according to the below scale by obtaining the opinion (Tables 3 and 4).

Step 2. Equation 1 is used to obtain the normalization matrix (Table 5).

Step 3. Normalized Fuzzy Direct-Relation Matrix.

Equations 2 and 3 are used to obtain the normalization matrix (Table 6).

Step 4. Creating Fuzzy-Sum Relationship Matrix.

The following table is created by using Eqs. 4 and 5 (Table 7)

Step 5. Identification of Affected and Affecting (Sender and Recipient) Groups:

The following table is created by using Eqs. 7–8 (Table 8).

According to Table 9, the following table was created.

Also, the higher the (D + R) value, the higher the criterion is with other criteria. D + R value shows the relationship between the criteria as a result of the calculated values. It states that it is in interaction and its total effect value is high. In the table above, it is understood that the C1 criterion has a high effect on other criteria. Then, respectively, C6, C3, C4, C5, C2. If the D-R value is negative, it is the affected criteria, if it is positive, it is the criteria that affect. It can be seen from the table that all criteria are in the category of criteria that affect this situation.

Step 6. Determination of criterion weight.

Table 3 Expert 1 opinion direct-relation matrix

	C1			C2			C3			C4			C5			C6		
C1	0	0	0	0	0,25	0,5	0,5	0,75	1	0,75	1	1	0,25	0,5	0,75	0	0	0,25
C2	0	0,25	0,5	0	0	0	0	0,25	0,5	0	0,25	0,5	0	0	0,25	0	0	0,25
C3	0,25	0,5	0,75	0	0	0,25	0	0	0	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5
C4	0,5	0,75	0,1	0	0	0,25	0,25	0,5	0,75	0	0	0	0	0	0,25	0	0	0,25
C5	0,25	0,5	0,75	0	0	0,25	0	0,25	0,5	0	0,25	0,5	0	0	0	0	0	0,25
C6	0	0	0,25	0,25	0,5	0,75	0,25	0,5	0,75	0,5	0,75	1	0,25	0,5	0,75	0	0	0

Table 4 Expert 2 opinion direct-relation matrix

	C1			C2			C3			C4			C5			C6		
C1	0	0	0	0	0	0,25	0,5	0,75	1	0,5	0,75	1	0	0,25	0,5	0	0	0,25
C2	0	0,25	0,5	0	0	0	0	0,25	0,5	0	0,25	0,5	0	0	0,25	0	0	0,25
C3	0	0	0,25	0,25	0,5	0,75	0	0	0	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5
C4	0,5	0,75	1	0	0	0,25	0,25	0,5	0,75	0	0	0	0	0	0,25	0	0	0,25
C5	0	0	0,25	0	0	0,25	0	0,25	0,5	0	0,25	0,5	0	0	0	0	0	0,25
C6	0	0	0,25	0,25	0,5	0,75	0,5	0,75	1	0,25	0,5	0,75	0,25	0,5	0,75	0	0	0

Table 5 Fuzzy direct-relation matrix

	C1			C2			C3			C4			C5			C6		
C1	0	0	0	0	0,125	0,375	0,5	0,75	1	0,625	0,875	1	0,12	0,375	0,625	0	0	0,25
C2	0	0,25	0,5	0	0	0	0	0,25	0,5	0	0,25	0,5	0	0	0,25	0	0	0,25
C3	0,125	0,25	0,5	0,125	0,25	0,5	0	0	0	0,25	0,5	0,75	0	0,25	0,5	0	0,25	0,5
C4	0,5	0,75	0,55	0	0	0,25	0,25	0,5	0,75	0	0	0	0	0	0,25	0	0	0,25
C5	0,125	0,25	0,5	0	0	0,25	0	0,25	0,5	0	0,25	0,5	0	0	0	0	0	0,25
C6	0	0	0,25	0,25	0,5	0,75	0,375	0,625	0,875	0,375	0,625	0,88	0,25	0,5	0,75	0	0	0

Table 6 Normalized fuzzy direct-relation matrix

	C1			C2			C3			C4			C5			C6		
C1	0,00	0,00	0,00	0,00	0,03	0,10	0,14	0,21	0,28	0,17	0,24	0,28	0,03	0,10	0,17	0,00	0,00	0,07
C2	0,00	0,07	0,14	0,00	0,00	0,00	0,00	0,07	0,14	0,00	0,07	0,14	0,00	0,00	0,07	0,00	0,00	0,07
C3	0,03	0,07	0,14	0,03	0,07	0,14	0,00	0,00	0,00	0,07	0,14	0,21	0,00	0,07	0,14	0,00	0,07	0,14
C4	0,14	0,21	0,15	0,00	0,00	0,07	0,07	0,14	0,21	0,00	0,00	0,00	0,00	0,00	0,07	0,00	0,00	0,07
C5	0,03	0,07	0,14	0,00	0,00	0,07	0,00	0,07	0,14	0,00	0,07	0,14	0,00	0,00	0,00	0,00	0,00	0,07
C6	0,00	0,00	0,07	0,07	0,14	0,21	0,10	0,17	0,24	0,10	0,17	0,24	0,07	0,14	0,21	0,00	0,00	0,00

Table 7 Fuzzy sum relationship matrix

	C1			C2			C3			C4			C5			C6		
C1	0,03	0,10	0,35	0,01	0,06	0,39	0,16	0,29	0,72	0,19	0,32	0,72	0,03	0,13	0,47	0,00	0,02	0,31
C2	0,00	0,10	0,36	0,00	0,01	0,20	0,00	0,11	0,46	0,00	0,11	0,46	0,00	0,02	0,29	0,00	0,01	0,23
C3	0,04	0,13	0,43	0,03	0,09	0,39	0,01	0,08	0,44	0,08	0,21	0,61	0,00	0,10	0,41	0,00	0,08	0,33
C4	0,15	0,25	0,37	0,00	0,03	0,28	0,09	0,21	0,53	0,03	0,10	0,35	0,00	0,04	0,30	0,00	0,02	0,24
C5	0,03	0,10	0,36	0,00	0,01	0,27	0,01	0,11	0,46	0,01	0,11	0,46	0,00	0,02	0,22	0,00	0,01	0,23
C6	0,02	0,09	0,44	0,07	0,16	0,49	0,11	0,25	0,72	0,11	0,25	0,72	0,07	0,17	0,52	0,00	0,02	0,25

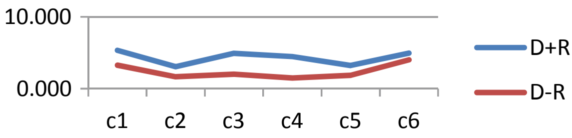
Table 8 Calculation of **D + R** and **D − R** values

	d + r			d-r		
C1	4,58	5,09	6,61	4,03	3,52	2,00
C2	2,47	2,72	4,36	2,25	2,00	0,35
C3	3,85	4,53	6,79	3,09	2,40	0,15
C4	3,39	4,09	6,31	2,57	1,87	-0,34
C5	2,51	2,88	4,62	2,29	2,50	0,18
C6	4,47	4,62	6,05	4,47	4,33	2,90

Table 9 Clarified values of **D + R** and **D − R**

	D + R	D-R
C1	5,342	3,266
C2	3,065	1,648
C3	4,925	2,011
C4	4,472	1,493
C5	3,223	1,867
C6	4,938	4,006

Fig. 1 Relationship diagram



Using Eqs. 9 and 10, the weight of each criterion is found (Table 10).

According to the table, C1 and C6 criteria have been determined as the most important criteria in personnel selection since they have the highest normalized weight value. Later, the C3, C4, C5, C2 criteria are also important criteria for personnel selection with high weight values (Figs. 1 and 2).

Table 10 Determination of criterion weights

	D + R	D-R	w	Priority Order
C1	5,342	3,266	0,210	2
C2	3,065	1,648	0,117	6
C3	4,925	2,011	0,178	3
C4	4,472	1,493	0,158	4
C5	3,223	1,867	0,125	5
C6	4,938	4,006	0,213	1

3.2 Recommended Grey-Based DEMATEL Method

Step 1–2. Determining the Rating Scale for Grey Relationship After determining the criteria to be addressed is within the scope of the application. The relationships between these criteria were determined as linguistic in accordance with the Grey Linguistic Expression Scale as shown in the Table by the decision-makers (Tables 11, 12 and 13).

Step 3. Establishing the Grey Direct-Relation Matrix (Z).

In the next step, the numbers in the grey direct-relation matrix created by the administrators should be converted into clear numbers. For this, the Eqs. (12)–(14) previously explained will be used. Expert 1 defined the effect of C3 criterion on C4 as moderately effective. Considering Table 12, this value is shown as the value of 2 and as the grey number [0.25, 0.5].

The lower limits of the grey numbers in the corresponding column minimum equal to zero, the upper limits of the grey numbers in the corresponding column.

Δ will be 1 for calculations in this column since its maximum is equal to 1 (Tables 14 and 15).

$$Y_{iJ}^{k} = \frac{\overleftarrow{\emptyset}\,\tilde{x}_{ij}^{k}\left(1 - \overleftarrow{\emptyset}\,\tilde{x}_{ij}^{k}\right) + \left(\overrightarrow{\emptyset}\,\tilde{x}_{ij}^{k} X\, \overrightarrow{\emptyset}\,\tilde{x}_{ij}^{k}\right)}{1 - \overleftarrow{\emptyset}\,\tilde{x}_{ij}^{k} + \overrightarrow{\emptyset}\,\tilde{x}_{ij}^{k}} = \frac{(0,25(1-0,25) + (0,5 * 0,5)]}{1 - 0,25 + 0,5}$$

$$Z_{ij}^{k} = \min \overleftarrow{\emptyset}\,\tilde{x}_{ij}^{k} + Y_{ij}^{k} X\,\Delta_{\min}^{\max} = 0 + 0,35 * (1) = 0,35$$

Table 11 Grey linguistic expression scale

Linguistic terms	Influence scores	Grey Numbers
4	Very high	0,75–1
3	High	0,5–0,75
2	Middle	0,25–0,5
1	Low	0–0,25
0	Ineffective	0–0

Table 12 Grey direct-relation matrix for expert-1

	C1	C2	C3	C4	C5	C6
C1	0	0	3	3	1	0
C2	1	0	1	1	0	0
C3	0	2	0	2	1	1
C4	3	0	2	0	0	0
C5	0	0	1	2	0	0
C6	0	2	3	1	2	0

Table 13 Grey direct-relation matrix for expert-2

	C1	C2	C3	C4	C5	C6
C1	0	1	3	4	2	0
C2	1	0	1	1	0	0
C3	2	0	0	2	1	0
C4	3	0	2	0	0	1
C5	2	0	1	1	0	0
C6	1	2	2	3	2	0

Table 14 Established direct-relation matrix for expert-1

	C1	C2	C3	C4	C5	C6
C1	0	0,6	0,687	0,95	0,41	0
C2	0,061	0	0,061	0,05	0	0
C3	0,368	0	0	**0,35**	0,6	0
C4	0,687	0	0,368	0	0	0,125
C5	0,368	0	0,061	1	0	0
C6	0,061	0,41	0,368	0,65	0,41	0

Table 15 Established direct-relation matrix for expert-2

	C1	C2	C3	C4	C5	C6
C1	0	0	0,687	0,687	0,6	0
C2	0,061	0	0,061	0,061	0	0
C3	0	0,41	0	0,368	0,6	0
C4	0,687	0	0,368	0	0	0,125
C5	0	0	0,061	0,368	0	0
C6	0	0,41	0,687	0,061	0,41	0

Step 4. Establishing the Total Direct-Relation Matrix—Determination of Decision-Maker Weights.

The clarified direct-relation matrices calculated for both managers are transformed into the "Total Direct-Relation Matrix" shown in the Table by making use of Eq. 15 (Table 16).

Step 5: Normalizing the Total Direct-Relation Matrix (N).

After obtaining the Total Direct-Relation Matrix, the Total Impact Matrix is calculated with the help of Eqs. 17 and 18. After the Grey numbers are found in the processes, the DEMATEL is continued with its own steps. Equations 17 and 18 are used to perform the normalization process (Table 17).

Step6. Obtaining the Total Impact Matrix.

Table 16 Total direct-relation matrix

	C1	C2	C3	C4	C5	C6
C1	0	0,3	0,687	0,8185	0,505	0
C2	0,061	0	0,061	0,0555	0	0
C3	0,184	0,205	0	0,359	0,6	0
C4	0,687	0	0,368	0	0	0,125
C5	0,184	0	0,061	0,684	0	0
C6	0,0305	0,41	0,5275	0,3555	0,41	0

Table 17 Normalizing the total direct relation matrix

	C1	C2	C3	C4	C5	C6
C1	0,000	0,130	0,297	0,354	0,219	0,000
C2	0,026	0,000	0,026	0,024	0,000	0,000
C3	0,080	0,089	0,000	0,155	0,260	0,000
C4	0,297	0,000	0,159	0,000	0,000	0,054
C5	0,080	0,000	0,026	0,296	0,000	0,000
C6	0,013	0,177	0,228	0,154	0,177	0,000

After obtaining the Total Direct Relation Matrix, the Total Impact Matrix is calculated using Eq. 19. The total impact matrix has been calculated as shown in the table. By using the total impact matrix, it will be possible to divide the criteria into groups as affecting or affected (Table 18).

Step 7. Getting Row and Column Totals.

The total effect matrix is shown in the above table. It will be possible to draw an impact diagram showing the interaction between the criteria. The total effect matrix is divided into groups affecting and affected by the equation numbered 20–21, with the sum of rows being D and the sum of columns being R (Table 19).

According to the table above, the criteria C1 and C4 are the criteria that interact the most with the other criteria. Among the D-R values; C1 and C6 criteria are factors that affect the other criteria, as they are positive. Negative C2, C3, C4, C5 are criteria

Table 18 Total impact matrix

	C1	C2	C3	C4	C5	C6
C1	0,279	0,218	0,512	0,668	0,419	0,036
C2	0,050	0,012	0,052	0,058	0,025	0,003
C3	0,234	0,136	0,146	0,372	0,352	0,020
C4	0,428	0,099	0,354	0,278	0,198	0,069
C5	0,235	0,050	0,176	0,441	0,101	0,024
C6	0,187	0,238	0,364	0,379	0,316	0,021

Table 19 Determining the affected and affecting values

	D	R	D + R	D-R
C1	2,131	1,412	3,543	0,719
C2	0,201	0,753	0,954	-0,552
C3	1,260	1,604	2,864	-0,344
C4	1,427	2,196	3,623	-0,769
C5	1,028	1,412	2,440	-0,384
C6	1,504	0,173	1,677	1,331

Fig. 2 Impact Diagram

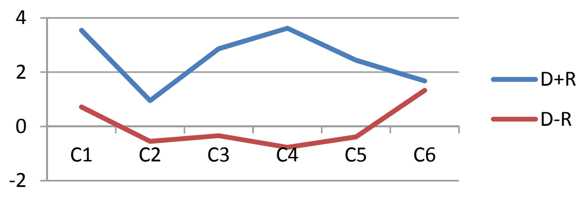


Table 20 Determination of criterion weights

Criterias	w	Priority Order
C1	0,227	2
C2	0,069	6
C3	0,181	3
C4	0,233	1
C5	0,155	4
C6	0,135	5

that are affected by the others. You will notice that C2, C3, C4, and C5 criteria are the criteria with the lowest value among the affecting criteria in the fuzzy DEMATEL method.

Step 8. Determination of criterion weight.

Using Eqs. 22 and 23, the weight of each criterion is found.

According to the table, C4 and C1 criteria have been determined as the most important criteria in personnel selection since they have the highest normalized weight value. Later, the C3, C5, C6, C2 criteria are also important criteria for personnel selection with high weight values (Table 20).

4 Conclusion

Personnel selection is one of the important processes that affect the cost of the enterprise nowadays. The reason why the personnel selection process is so effective in the cost item is that the people who will build the position and future of the enterprise, determine the general qualifications and criteria correctly, and as a result determine the needs correctly. In Turkey the interest in personnel selection is increasing day by day, and many research studies on this subject are carried out by both academicians and business managers who want to increase their competitiveness. In this study, it was planned to use the DEMATEL method to determine the relationships and degrees of importance between the criteria, but because it is difficult to determine whether a criterion affects another criterion, the DEMATEL method was combined with two methods; fuzzy DEMATEL and grey DEMATEL. Then, criterion weights were determined. And at the end of the application of these two methods, it was concluded which are the most important criteria.

While conducting a research, linguistic expressions taken from experts may be in a different range rather than being expressed in clear numbers. In such cases, it is thought that the system becomes more reliable if expert evaluations are made with grey numbers, that is, expert evaluations are obtained with grey numbers instead of linguistic expressions used in fuzzy logic, and this increases the reliability of the evaluations. This study was conducted for comparison by using both methods, considering that more reliable results will be obtained if grey numbers are used instead of a triangular fuzzy number. The results of the study is described in the following.

In this study by the Fuzzy DEMATEL, the most important 3 criteria were obtained. These are educational background (C6), experience (C1), ability to work in teams and sociability (C3) obtained. And as a result of Grey DEMATEL, strategic thinking and innovativeness (C4), experience (C1) and ability to work in teams and sociability (C3) criteria were determined as the most important criteria. Considering the common points of the first 3 criteria, it is seen that the criteria that should be given priority are experience (C1), working in a team and sociability (C3). As can be seen from the table, it is seen that the grammar (C2) criteria is the last criteria in the priority order. In this study, the DEMATEL Method was combined with two different methods and the results were compared. Fuzzy DEMATEL and Grey DEMATEL method results difference in intermediate rankings have shown. The first 3 criterion priorities gave results close to each other. Results with low significance maintained their place in the last rankings. By taking experience (C1), and ability to work in teams and sociability (C3), which are common to the first 3 important criteria in both methods, the study can be advanced by adding alternative candidates to the study, and the most suitable candidate can be selected by using another method.

References

1. Gabus A (1972) Fontela E World problems an invitation to further thought within the framework of DEMATEL. Battelle Geneva Research Centre, Geneva
2. Gabus A, Fontela E (1973) Perceptions of the world problematique: communication procedure, communicating with those bearing collective responsibility (DEMATEL Report no.1). Battelle Geneva Research Centre, Geneva

3. Lin W (2004) A fuzzy extension of the dematel method for group decision-making. McGraw Hill, New York, USA
4. Lin W (2008) A causal analytical method for decision making under fuzzy environment. Expert Syst Appl
5. Devadoss AV, Felix A (2013) A new Fuzzy DEMATEL method in an uncertain linguistic environment. Adv Fuzzy Sets Syst 16(2):93–123
6. Samanlioglu TGCA (2018) Fuzzy Ahp,Topsis-based group decision making approach to IT Personnel Selection. 20:1576–1591
7. Ozturk K (2020) Istanbul Medeniyet University, faculty of engineering and natural sciences, industrial engineering. GU J Sci Part C 8(1):94–108
8. Ozdemir Y, Nalbant KG (2020) Personnel selection for promotion using an integrated consistent fuzzy preference relations - fuzzy analytic hierarchy process methodology: a real case study. Asian J Interdiscip Res 3(1):219–236
9. Kazancioglu Y, Ozkan-Ozen YD (2018) Analyzing workforce 4.0 in the Fourth Industrial Revolution and proposing a road map from operations management perspective with fuzzy DEMATEL. J Enterp Inf Manag 31(6):891–907
10. Merdivenci F, Oğuz S (2020) Personnel selection with entropy based Edas method: an application in logistics sector. Gumushane Univ Inst Soc Sci Electron J 11(3):615–624
11. Xiwei W, Stolein M, Kan W (2010) Designing knowledge chain networks in China a proposal for a risk management system using linguistic decision making. Technol Forecast Soc Chang 77(6):902–915
12. Zimmermann H-J (1991) Fuzzy set theory and its applications. Kluwer Academic Publishers, Second Edition, Boston, MA
13. Li RJ (1999) Fuzzy method in group decision making. Comput Math Appl 38(1):91–101
14. Deng JL (1989) Introduction to grey system theory. J Grey Syst 1(1):1–24
15. Li P, Tan TC, Lee JY (1997) Grey relational analysis of a mine inhibition of mild steel corrosion in acids 1989. Corrosion 53(3):186–194
16. Bai C, Sarkis J (2013) A grey-based DEMATEL model for evaluating business process management critical success factors. Int J Prod Econ 146(1):281–292
17. Opricovic S, Tzeng GH (2003) Defuzzification within a multicriteria decision model. J Uncertain, Fuzziness Knowl-Based Syst 11(5):635–652
18. Chen CH, Tzeng GH (2011) Assessment model for improving educational curriculum materials based on the DANP Technique with Grey Relational Analysis. Int J Inf Syst Logist Manag 6(2):23–36
19. Wang YL, Tzeng GH (2012) Brand marketing for creating brand value based on a MCDM model combining DEMATEL with ANP and VIKOR methods. Expert Syst Appl 39:5600–5615
20. Zadeh LA (1975) The concept of a linguistic variable and its application to approximate reasoning (Part II). Inf Sci 8:301–357

An Intelligent Psychiatric Recommendation System for Detecting Mental Disorders

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Abstract The inadequacy of the number of specialists and the resultant heavy workloads impede diagnostic efforts, making it very difficult to receive appropriate medical services and manage the treatment process. Such problems underscore the need for auxiliary systems to help experts in making diagnoses, saving both labor and time. For this reason, we propose a new intelligent psychiatric recommendation system with the Comprehensive Psychiatric Differential Diagnosis Test (CPDDT), which we created to screen and differentiate among psychiatric diagnoses. To guide experts in using the system, we included axis one and axis two diagnosis groups, which, respectively, refer to clinical and personality disorders in the DSM-4. The goal was to measure areas affecting the course of an illness and the treatment plan developed by a specialist, including functionality, memory, and suicidal thoughts. The CPDDT can detect 48 different diagnostic groups from the answers to 319 questions. The system was subjected to an online test of 676 users via a web system developed by DNB Analytics. Psychiatrists evaluated the results in a clinical setting. The test results were then evaluated by the evolutionary simulation annealing LASSO logistic regression model. After determining the importance of each question on the scale, the algorithm eliminated the questions with the least impact and the test was

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reduced to 147 questions, producing a .93 level of accuracy. In addition, the algorithm found the probability of each patient suffering from a disorder. In summary, the new machine-learning-based CPDDT was finalized to include 147 questions; the algorithm is presented here as a useful suggestion system for experts engaging in the diagnostic process.

Keywords Recommendation System · Feature Selection · Machine Learning · Psychiatric Diagnosis · Mental Health Disorder · Differential Diagnosis

1 Introduction

Mental disorders often begin in childhood, experience a development period, and have continued effects throughout life. Studies have shown that they can negatively impact functionality, socialization, and even academic and business success [20]. In addition to their individual effect on a person's life, mental illnesses have also been found to reduce the overall quality of family life [19]. It has been shown that an individual's mental illness increases the susceptibility of their children to such illness by up to four times the regular rate [12]. These various issues underscore the importance of the accurate diagnosis of mental illnesses and the necessity of effective treatment. Yet, according to a 2017 report by the National Council for Behavioral Health, treatment can often be significantly delayed, due to a lack of access to mental health services, leading to adverse outcomes and increased costs. The main source of such delays is a shortage of experts. Experts often must operate under heavy workloads, and as a result, are unable to allocate sufficient time to their patients [11].

Moreover, the fact that different diagnostic groups share similar characteristics can create conflicts in the diagnostic process [7]. Issues can arise even when highly structured comprehensive assessments are followed closely [21]. It is essential that the right diagnostic decisions be made because the first step in effective psychiatric treatment (as in every health-related field) is an accurate differential diagnosis and a corresponding treatment approach [13]. In pursuit of such goals, studies have shown that self-report scales can help experts with the psychiatric diagnosis process and offer a solution to this problem [22]. In addition, the use of objective psychiatric scales also supports the completeness of expert's clinical judgement about whether the person is sick, and if so, the effects and severity [2].

Some of the scales commonly used in this field are listed in Table 1. Generally, the scales used in clinical and personality disorders are separate. The MMPI is the most researched and oft-used scale for personality measurements. It consists of 566 questions and includes 10 clinical symptom pattern subscales [9]. Another test used for personality disorders is the Rorschach test. This is a projective test in which the patient is asked to interpret ink blots [1]. However, this test is only rarely employed because it requires detailed training, takes substantial time for application and analysis, and projective tests, in general, are scientifically controversial [8].

Table 1 Examples of scales used in psychiatry

Name of the scale	Number of questions	Disorders or structures measured by the test	References
Beck Depression Inventory	21	Depression	[16]
Beck Anxiety Inventory	21	Anxiety	[5]
ADHD Self Report Scale	18	Attention Deficit Hyperactivity Disorder	[6]
Maudsley Obsessive–Compulsive Inventory	37	Obsessive–Compulsive Disorder	[15]
Liebowitz Social Anxiety Scale	24	Social Anxiety Disorder	[10]
The Michigan Alcoholism Screening Test	25	Alcohol Use Disorder	[14]
Minnesota Multiphasic Personality Inventory	566	Hypochondriasis Depression Hysteria Psychopathic Deviate Masculinity/Femininity Paranoia Psychasthenia Schizophrenia Hypomania Social Introversion	[9]
SCL-90R	90	Somatization Obsessive–Compulsive Interpersonal sensitivity Depression Anxiety Hostility Phobic Anxiety Paranoid Ideation Psychoticism	[3]

In terms of clinical disorders, the majority of scales are designed to measure a single disease. For example, the Beck Depression Inventory [16] is frequently used to measure depression, and the Beck Anxiety Inventory [5] is commonly applied as an anxiety scale. The ADHD Self-Report Scale is often employed to measure attention deficit and hyperactivity disorders in adults [6]. These are just a few of the many scales created to facilitate psychiatric diagnoses.

Scales for multiple clinical disorders are less common. The most widely used is the SCL-90R, a Likert-type self-report scale that includes nine basic subscales and 90 questions [3]. Another, the Brief Psychiatric Screening Scale, consists of 18 questions, roughly inquiring as to the frequency of one symptom for each question

[4]. However, these scales are not comprehensive and tend to be impractical. For this reason, they are rarely applied clinically, and instead are reserved for research.

To summarize, there is a need for a comprehensive scale applicable to clinical practice. Considering the workload of the experts and the conflicts in the diagnosis process, we propose a comprehensive intelligent system that will help the experts to close this gap. Accordingly, The Comprehensive Psychiatric Differential Diagnosis Test (CPDDT) was created to serve as a self-report scale for examining in detail the mental health of prospective patients. A specialist can send this test to the patient via a digital platform and have the results analyzed by artificial intelligence, thus providing the expert with comprehensive information about the subject in a practical and efficient way. This scale includes two diagnostic groups, axis one and axis two, which reference clinical and personality disorders outlined in the DSM-4, respectively. The goal was also to measure areas affecting the course of a disease and the related treatment plan, such as functionality, memory, attention, and suicidal thoughts.

We also developed an intelligent psychiatric recommendation system that served to shorten and further establish this scale at a high level of accuracy; experts can now use an online platform to practically apply the recommendation system to detect mental disorders. This research is an introductory study of the proposed algorithm. It sets an example in terms of its adaptability to many health services and fills the gap in the literature through the holistic perspective it provides.

2 Methodology

2.1 General Structure of the Test

The CPDDT is a test that examines in detail the mental state of a prospective patient. It was created to assist specialists in the psychiatric examination of individual subjects. The test uses 319 questions to measure 48 sub-diagnoses (see Table 2). In addition to conditions such as the personality and anxiety disorders listed in the DSM IV and V, subscales for symptoms such as suicidal thoughts, which are considered important for the treatment process, were also included. The response options for the 5-point Likert-type scale range from 0 to 4, reflecting the answers of "Never," "Rarely," "Sometimes," "Often," and "Always," respectively.

2.2 Test Creation Phase

The first draft of the CPDDT was created after a comprehensive literature review. The scales and sources used to determine the questions were as follows: the DSM IV and V, SCL90R, MMPI, Five-Factor Personality Test, Beck Depression Scale, Hamilton

Table 2 Diagnostic groups included in the comprehensive psychiatric differential diagnostic test

• Paranoid Personality • Schizoid Personality • Schizotypal Personality • Antisocial Personality • Borderline Personality • Histrionic Personality • Narcissistic Personality • Avoidant Personality • Dependent Personality • Obsessive–Compulsive Personality • Introvert Structure • Sociopathy • Decrease in Functionality • Decreased Insight • Cognitive Impairment (Memory) • Movement Disorders • Suicidal Thoughts	• Generalized Anxiety Disorder • Panic Disorder • Separation Anxiety Disorder • Agoraphobia • Social Phobia • Posttraumatic Stress Disorder • Acute Stress Disorder • Psychotic Disorder • Paranoid Schizophrenia • Dissociation • Sleeping disorders • Sexual Disorders • Lack of Attention • Impulsiveness • Alcohol Use Disorder • Substance Use Disorder	• Obsessive–Compulsive Disorder • Body Dysmorphic Disorder • Hoarding Disorder • Trichotillomania (Hair Pulling Disorder) • Misophonia • Illness Anxiety Disorder • Conversion Disorder • Somatic Symptom Disorder • Orthorexia Nervosa • Depressive Episode • Manic Episode • Seasonal Affective Disorder • Premenstrual Dysphoric Disorder • Hostility • Psychological Rigidity

Depression Rating Scale, Seasonal Pattern Assessment Questionnaire, Beck Anxiety Scale, Adult ADHD Self-Report Scale, Panic Disorder Severity Scale, Liebowitz Social Anxiety Scale, Dissociative Experiences Scale, Social Functioning Scale, Yale-Brown Obsessive Compulsive Scale, Michigan Alcoholism Screening Test, Positive Symptom Rating Scale, and Negative Symptom Rating Scale. The draft was forwarded to 15 psychiatrists and one assessment and evaluation specialist and their opinions were collected. The second draft, prepared in response to their feedback, was then forwarded to a language expert for language evaluation. Subsequently, the necessary final arrangements were made, and the draft was finalized.

2.3 Data Collection Phase

A website created by DNB Analytics was used during the data collection phase. A total of 676 people who came to a psychiatry clinic were registered on this website by an expert and a CPDDT was distributed to them. Subjects completed their tests by clicking on a link sent to them via text message. Artificial intelligence analyzed the test results and sent a report to the expert. The information and test results were kept confidential and never shared, and their data were protected by recording all details in the system according to protocol numbers.

2.4 The Optimized LASSO Logistic Regression Model

The goal of the proposed model was to optimize the logistic regression (LR) coefficients by using a combination evolutionary strategy (ES) and simulated annealing (SA) algorithm. SA, a random search technique that uses single-base optimization, explores the neighborhoods of the primary solutions and searches for the appropriate solution space. Although the starting point can be determined randomly in this algorithm, it is trapped in the local optima because it scans the primary solutions at nearby points.

In the model we propose an ES meta-heuristic optimization that is used to determine the primary solution. Unlike SA, when ES is used to find the primary solution, it is possible for the algorithm to go beyond the local optimum, allowing for more accurate solutions. Thus, the best model can be found by optimizing the coefficients with this hybrid meta-heuristic optimization approach.

Regularization methods have been proven effective at resolving the overfitting problem that exists with traditional LR models.

$$F_x = \frac{1}{1 + e^{-(\beta_{n+1}+\beta_1 x_1+\beta_2 x_2+\beta_3 x_3+\cdots+\beta_n x_n)}} \tag{1}$$

The x values in Eq. (1) represent each question on the test. Since there were 314 questions, the value of n is 314. The β variable is a value between 0 and 1, indicating the severity of each question. In this equation, β is unknown and the algorithm determines the value. For example, if as a result of the algorithm the value of β_1 is 0, x_1, the first question, does not contribute to the test and can be excluded. A value of β close to 1 indicates that the importance of the question is high. The ES algorithm was used when first determining the ß values in this formula. The values that were not attached to the local optima given by SA were later developed with LR and finalized. The importance of each question was determined in the most optimal way.

$$min_{\beta_0,\beta_1,\beta_2,\beta_3,\ldots\beta_n}\left(\frac{1}{2N}\sum_{i=1}^{N}(Y_i-(F_{Xi}))^2+\lambda\sum_{j=1}^{p}\left|\beta_j\right|\right. \tag{2}$$

The mathematical formula of the LASSO algorithm is given in Eq. (2). Here, N is the number of test questions, Yi is the response in the test, and Xi is the data point. While λ is a non-negative regression parameter, β is the coefficient value of the regression model. Since the formulation as an objective function is not linear with absolute and square values, the ES-based SA algorithm is used to optimize the formulation.

To summarize the proposed model, feature selection is done first, and the best feature subset is selected by using the filter and wrapper feature selection methods together. After determining the LASSO-LR formulation for the problem, the SA model is begun with the help of the ES algorithm. Then, as the model is optimized, the coefficients of the LASSO model are adjusted using the SA-based hybrid evolution strategy. In the end, the most suitable solution is chosen and using the LASSO model, the most distinctive items on the test are estimated with optimal coefficients [17].

3 Results

This research is an initial study of the proposed algorithm. Two separate results can be obtained from the algorithm: the severity of each question and the probability of the patient suffering from a disorder. In the present work, the first two-thirds of the 676 data points were used to train the model. The remaining data were used in the test phase to determine whether the algorithm worked. During the training phase, the accuracy was 0.93 for 450 data points. The 226 data points not included in the training were used in the test phase. The algorithm was found to predict if respondents suffered from a disorder at an accuracy level of 0.71.

The β value in Eq. (1) was calculated separately for each question to determine the importance. Questions with an importance value of 0.000 were removed because they did not create a discriminatory effect on the scale. The weight values of the remaining 147 questions are given in Table 3.

In summary, as a result of the algorithm, the CPDDT was reduced from 314 to 147 questions, with an accuracy level of 0.93. In addition, the model would be found to predict at an accuracy level of 0.71 whether an individual suffered from a disorder.

It is also important to note that this study reflects only a preliminary example of the proposed system. Although the test currently offers expert information on 48 different diagnoses, the algorithm does not examine individuals with regards to all of these. Since this is a preliminary study, the algorithm shortened the scale by determining the significance of each problem. Also, the algorithm is currently only able to determine if someone is suffering from a disorder by calculating the probability of that person being unwell. Moreover, while the accuracy level was 0.93 in the training phase (where 450 data points were used), it was 0.71 in the test phase (which utilized the remaining 226 data points). The data collection phase is currently ongoing. When the body of data increases to a sufficient extent, the accuracy of the test phase is expected to exceed 0.90. In future work employing a sufficient body of data, individuals found to be "sick" will be further examined for each of the 48 sub-diagnoses and a precise diagnosis delivered.

4 Discussion and Future Work

In a world where digitalization continues to increase on a global scale, modernization of the application and analysis of psychiatric tests is inevitable. Of course, experts will always be needed to evaluate the analysis results presented by artificial intelligence. The goal is not to remove experts from the system, but rather to provide mental health services to more people by offering a practical, helpful system that will reduce

Table 3 Distinct question severity levels of the 147 questions

Question number	Weight value	Question number	Weight value	Question number	Weight value	Question number	Weight value	Question number	Weight value	Question number	Weight value	Question number	Weight value	Question number	Weight value
2	0.010	51	0.002	86	0.007	142	0.003	180	0.004	225	0.002	259	0.004	296	0.003
8	0.013	53	0.020	90	0.001	143	0.005	181	0.007	228	0.007	260	0.004	297	0.012
15	0.004	55	0.017	98	0.019	149	0.018	184	0.007	230	0.027	261	0.005	299	0.016
16	0.007	57	0.002	107	0.002	150	0.028	185	0.008	231	0.020	262	0.002	301	0.013
20	0.010	60	0.006	110	0.002	153	0.008	186	0.005	232	0.002	265	0.002	302	0.001
21	0.006	61	0.004	113	0.004	154	0.001	190	0.016	233	0.006	266	0.001	304	0.008
22	0.010	63	0.017	115	0.002	156	0.006	192	0.010	235	0.004	267	0.003	306	0.003
23	0.005	64	0.003	116	0.002	158	0.013	199	0.004	236	0.011	272	0.006	307	0.008
26	0.004	66	0.009	117	0.006	160	0.006	200	0.018	238	0.005	273	0.013	309	0.001
28	0.007	68	0.005	121	0.006	163	0.001	202	0.008	239	0.003	275	0.006	311	0.002
30	0.002	69	0.015	122	0.011	165	0.015	203	0.002	242	0.004	279	0.005	312	0.005
31	0.005	71	0.004	125	0.002	169	0.006	205	0.001	245	0.007	280	0.002	313	0.008
33	0.005	75	0.007	126	0.015	170	0.012	207	0.003	246	0.005	281	0.005	317	0.011
35	0.001	79	0.003	129	0.012	171	0.005	210	0.007	247	0.003	283	0.006	319	0.004
40	0.004	80	0.003	131	0.010	172	0.003	215	0.002	248	0.004	284	0.008		
42	0.004	81	0.001	132	0.004	173	0.016	216	0.001	249	0.002	285	0.012		
46	0.003	83	0.006	137	0.002	176	0.007	217	0.007	252	0.001	286	0.004		
47	0.019	84	0.005	139	0.004	177	0.008	219	0.014	255	0.008	290	0.004		
48	0.11	85	0.013	140	0.002	178	0.006	221	0.010	258	0.006	293	0.002		

experts' workloads. In a system in which the number of patients is high and experts are few, it is essential in terms of both time and cost to offer tests online and analyze the results automatically. The digital advancement of psychiatric tests will also eliminate the need for certain types of applications and analyzes and create a common level of use at the national level, making more accurate results and comparisons possible.

One drawback of both digital and traditional methods is that Likert-type scales are used to quantify individual responses. In contrast to performance measures, on psychiatric scales, it is generally accepted that the respondent is correct. On a digital platform, recording the time spent per question, selections changed, and mouse movement through the website are useful means of overcoming this weakness. These records will automatically provide experts with information such as the person's tendency to lie, provide haphazard responses, or spend excessive time on the test.

Moreover, when paper tests are used, test results must manually be individually entered into the system. In a well-structured study, the higher the number of participants, the greater the workload. In the proposed system, test results from tens of thousands of respondents can remain anonymous and ready for analysis, without the need for extra data entry. The coexistence of many test results about a particular person also makes it possible to evaluate that person more integrally. It is also very important for epidemiological research that tests be easy to deliver and the results interpreted automatically. The goal of epidemiology is to improve health and reduce disease by interpreting and applying large bodies of information [18]. This system is capable of breaking new ground in epidemiology research by providing a practical means of collecting and analyzing substantial bodies of data.

The literature review revealed that scales for psychiatric disorders are generally specific to a single disease, and thus there is a need for a more comprehensive scale. This study is pioneering in terms of providing a holistic perspective and means of evaluating diagnoses with factors affecting treatment, such as functionality. However, it should be noted that although many diagnosis and sub-diagnosis groups are included in this test, there are diagnoses that have been omitted so as not to increase the number of questions to an unreasonable level. In the first draft, the total number of questions was 314. The current version has 147 questions. Determining which diagnoses were not added to the draft, creating a second scale that includes all diagnoses in the DSM are opportunities for development in this field. Creating a more complete body of diagnoses will close the current gap, and a CPDDT 2 is planned in which these diagnoses will be added.

Finally, a portion of the data collection process overlapped with the onset of the Coronavirus pandemic, which may have affected the answers given to the questions related to obsessive–compulsive and anxiety disorders. For example, one item was: "I don't want to directly touch an object somewhere because I think other people have touched it before." In response to this question, someone who might have responded with "Never" before the pandemic could possibly answer "Often" today, considering that doing so would protect against the virus. For this reason, it is inevitable that Covid affected the data collected during this period.

5 Conclusion

This system is recommended as means of assisting experts by providing a comprehensive screening test for use in the field of psychiatry. The test comprehensively examines respondents' mental health and this system can be used both alone and with other tests that will be integrated in the future. While the primary purpose is to assist experts, the sampling process makes it possible for health systems to digitalize their data, making the system more practical and capable of reaching more people. Thus, it is adaptable for use in various health areas in the future.

References

1. Beck J (n.d.) The Rorschach Test and Personality Diagnosis. 72–75
2. Burns A, Lawlor B, Craig S (2002) Rating scales in old age psychiatry. Br J Psychiatry 180(2):161–167. https://doi.org/10.1192/bjp.180.2.161
3. Derogatis LR, Rickels K, Rock AF (1976) The SCL 90 and the MMPI: a step in the validation of a new self report scale. Br J Psychiatry 128(3):280–289. https://doi.org/10.1192/bjp.128.3.280
4. Dingemans PM (1990) The brief psychiatric rating scale (BPRS) and the nurses' observation scale for inpatient evaluation (NOSIE) in the evalution of positive and negative symptoms. J Clin Psychol 46(2):168–174. https://doi.org/10.1002/1097-4679(199003)46:2%3c168::AID-JCLP2270460207%3e3.0.CO;2-L
5. Fydrich T, Dowdall D, Chambless DL (1992) Reliability and validity of the beck anxiety inventory. J Anxiety Disord 6(1):55–61. https://doi.org/10.1016/0887-6185(92)90026-4
6. Kessler RC, Adler L, Ames M, Demler O, Faraone S, Hiripi E, Howes MJ, Jin R, Secnik K, Spencer T, Ustun TB, Walters EE (2005) The World Health Organization adult ADHD self-report scale (ASRS): a short screening scale for use in the general population. Psychol Med 35(2):245–256. https://doi.org/10.1017/S0033291704002892
7. Pina-Camacho L, Parellada M, Kyriakopoulos M (2016) Autism spectrum disorder and schizophrenia: boundaries and uncertainties. BJPsych Adv 22(5):316–324. https://doi.org/10.1192/apt.bp.115.014720
8. Lilienfeld SO, Wood JM, Garb HN (2000) The scientific status of projective techniques. Psychol Sci Public Interes 1(2):27–66. https://doi.org/10.1111/1529-1006.002
9. Mathias R (1978) The Minnesota multiphasic personality inventory (Book). J Pers Assess 42(3):332–333. https://doi.org/10.1207/s15327752jpa4203_28
10. Mennin DS, Fresco DM, Heimberg RG, Schneier FR, Davies SO, Liebowitz MR (2002) Screening for social anxiety disorder in the clinical setting: using the Liebowitz Social Anxiety Scale. J Anxiety Disord 16(6):661–673. https://doi.org/10.1016/S0887-6185(02)00134-2
11. National Council for Behavioral Health (2017) The psychiatric shortage: causes and solutions. National Council for Behavioral Health, 1–66. https://www.thenationalcouncil.org/wp-content/uploads/2017/03/Psychiatric-Shortage_National-Council-.pdf
12. Pawlby S, Sharp D, Hay D, O'Keane V (2008) Postnatal depression and child outcome at 11 years: the importance of accurate diagnosis. J Affect Disord 107(1–3):241–245. https://doi.org/10.1016/j.jad.2007.08.002
13. Quevedo AS (2017) Occurence of dermoid cyst in the FOM—the importance of differential diagnosis in pediatric patients 25(3):341–345
14. Selzer ML (1971) The Michigan alcoholism screening test: the quest for a new diagnostic instrument. Am J Psychiatry 127(12):1653–1658. https://doi.org/10.1176/ajp.127.12.1653

15. Sternberger LG, Burns GL (1990) Compulsive activity checklist and the maudsley obsessional-compulsive inventory: Psychometric properties of two measures of obsessive-compulsive disorder. Behav Ther 21(1):117–127. https://doi.org/10.1016/S0005-7894(05)80193-5
16. Teri L (1982) The use of the beck depression inventory with adolescents. J Abnorm Child Psychol 10(2):277–284. https://doi.org/10.1007/BF00915946
17. Tutun S, Khanmohammadi S, He L, Chou CA (2020) A meta-heuristic LASSO model for diabetic readmission prediction. In: Proceedings of the 2016 Industrial and Systems Engineering Research Conference, ISERC 2016, 2228–2233
18. Van Der Flier WM, Scheltens P (2005) Epidemiology and risk factors of dementia. J Neurol Neurosurg Psychiatry 76:2–7. https://doi.org/10.1136/jnnp.2005.082867
19. Walton-Moss B, Gerson L, Rose L (2005) Effects of mental illness on family quality of life. Issues Ment Health Nurs 26(6):627–642. https://doi.org/10.1080/01612840590959506
20. Wittchen HU, Jacobi F (2005) Size and burden of mental disorders in Europe—A critical review and appraisal of 27 studies. Eur Neuropsychopharmacol 15(4):357–376. https://doi.org/10.1016/j.euroneuro.2005.04.012
21. Zimmerman M (2012) Broadening the concept of bipolar disorder: What should be done in the face of uncertainty? Postep Psychiatr I Neurol 21(2):88–90
22. Zimmerman M, Mattia JI (2001) A self-report scale to help make psychiatric diagnoses: the psychiatric diagnostic screening questionnaire. Arch Gen Psychiatry 58(8):787–794. https://doi.org/10.1001/archpsyc.58.8.787

A Two-Echelon Pharmaceutical Supply Chain Optimization via Genetic Algorithm

Elif Yıldırım and Berrin Denizhan

Abstract The two-echelon supply chain model consists of two separate components that have diverse objectives. In this study, a supply chain (SC) is modeled as a two-echelon supply chain consisting of one supplier, one retailer, and one product at a pharmaceutical supply chain (P-SC). The purpose of optimization is to maximize the total profit generated during sales and distribution of the product. Sales take place at the pharmaceutical retailer, and the demand encountered is stochastic, and order periods are determined by the frequency of visits by the drug supplier. Considering this visit frequency, the pharmaceutical retailer follows a periodic review inventory model. For the retailer, the decision variable is the safety factor determined according to the stated order level. It determines the pharmaceutical supplier's profitableness by influencing the sales volume of the P-SC. The problems were optimized with two different scenarios and two different models: the traditional SC model and the two-echelon supply chain model. The heuristic model of these problems provides more profitability for both echelons.

Keywords Two-echelon inventory · Pharmaceutical supply chain · Genetic algorithm

1 Introduction

A significant part of healthcare spending is pharmaceutical costs, including the distribution of pharmaceutical supplies—ninety-two percent of the drug sales sold throughout SC with distributors [1]. The inefficient coordination between the P-SC members creates a loss in profitability [2]. Despite the industry's scale around the world, the healthcare SC management has received comparatively little coverage.

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Among those cycles with development potential, P-SC configuration has a significant measure of assets, costs, and impact on the service level of the medical services frameworks. Privett and Gonzalves [3] have listed and prioritized ten significant problems in the SC of pharmaceuticals. They noted that the absence of synchronization with their choices was recognized as the key challenge that could lead to poor results.

A supply chain can be described as an organization of customers and facilities who work together to maximize their mutual profitability using some management strategies and seek to achieve transportation, replenishment, and production functions. Though separate associates in the supply chain are bound only by loyalty, common purposes bring them together [4]. The SC structure consists of members such as retailers, suppliers, buyers, products, also replenishment methods, inventory handling, and inventory distribution across the members. There is a movement of inventory from the supplier to the retailer or vice versa. This flow creates some stages to plan at one or more SC facilities [5]. When an SC is designed, the outline of the SC becomes a crucial decision-making process that affects all members. The architecture of the SC is the primary decision affecting the entire supplier chain and, due to increased competition on the markets, it has lately become significant. The design problem decides the number of facilities and location of facilities, the capacity at all facilities, the distribution of all locations to one or more regions, and the distributors for retailers and goods [6–8]. Retailers are forced to get high satisfaction from customers across all the SCs. Moreover, they need to reduce their costs and increase their profit simultaneously. The flow of inventory affects the total cost of the system and service level; according to that, distribution of products became a fundamental decision for profitability [9].

The two-echelon inventory optimization represents an advanced approach to optimizing inventory throughout the SC. Modeling multiple stages allows for accurate estimation of many types of inventories and provisioning due to demand placed at specific times. As a part of inventory optimization, distributor performance, customer service, and units related to inventory can be monitored continuously to ensure continuous improvement [10].

There is some literature that aims to optimize an SC over a two-echelon model dealing with stochastic demand [11], Cachon and Zipkin [12] and Cachon [13] expanded the literature by producing a game-theoretical model of continuous and periodic review problems with competitive models. Moses and Seshadri [14] studied a lost sales model with a periodic review viewpoint. Netessine and Rudi [15] developed relationship models between a wholesaler and an individual retailer for SCs where the wholesaler does not store an inventory of goods sold on demand for the future. Lariviere and Porteus [16] investigated how a supplier leads the supply price, and a retailer reacts from the point of view on quantities. Panda, Modak, and Cardenas-Barron [17] studied the teamwork issue of a two-echelon closed-loop SC by commodity recycling and considered social responsibility. To eliminate the channel dispute, an RS contract was used. Hosseini-Motlagh et al. [18] in conjunction with manufacturer's quality effort, Socially Responsible decisions, and periodic review decisions explore collaboration among participants of a two-echelon P-SC with the social decision-making process.

Using the base-stock review strategy to refine inventory handling policies a heuristic approach suggested by Sakulsom and Tharmmaphornphilas [19] included the first step that is deciding the starting purchasing strategy and the second step to the establishment of the safety stock. They examined optimal pricing and quality decisions, taking into account members' fairness preferences and negotiating competencies. Li et al. [20] have investigated a two-echelon SC, in which the producer delivers the products with some consistency to the final retailer. They examined optimum price and efficiency choices concerning the fairness of the participants and their negotiating forces. Taleizadeh, Alizadeh-Basban, and Sarker [21] studied the two-echelon SC with cooperation problem in the games Stackelberg and Nash where consumer demand is price carbon emission rate cognizant.

2 Model Formulation

This work is about both inventory control and collaboration in a supply chain and GA model building. Using GA optimization makes it easy to adapt this model to any business. Model is about the visit interval between echelons and optimum stock control to ensure a particular service level. In this model, the pharmacy is the retailer that fulfills customer orders, and the supplier fulfills the retailer's replacement orders.

Figure 1 shows the distribution of medication and cash flow through two-echelon SC. The stock is exported at wholesale price w (Dollars per unit) from the pharmaceutical supplier to the pharmaceutical retailer. In the two-echelon SC problem examined in this study, the decision variables are the visit interval for the supplier, the supply multiplier, and the delivery time, which is a safety factor for the retailer. The visit interval of the supplier is a decision variable T, and delivery takes a certain amount of time LT reaches the customer's premises. The travel time and order costs are regardless of the quantities of the order, and the carrier is capable of any quantity. The safety factor k is used to determine the service level. Specifying the pharmaceutical supplier's visit interval and the retailer's service level not only directly affects their profitability but also their mutual profitability. Besides, these decisions also affect patients. In this system, if the service level is determined incorrectly, the system is faced with a drug shortage, which will affect the health system negatively. Therefore, a social contribution model of the problem is taken into account for a preferable strategy for patients.

The pharmaceutical supplier is the leader of the Stackelberg game. In this game, the order of events is as follows. First, the supplier decides his optimum profit parameters as his decision variables for a commodity unit. The second decision is that the retailer takes the parameters from the supplier and chooses its optimum parameters for a maximum profit on sale prices.

In this paper, a search-optimization technique was used to apply the concept of two-echelon supply chain design using the artificial intelligence field, GA. GA is an

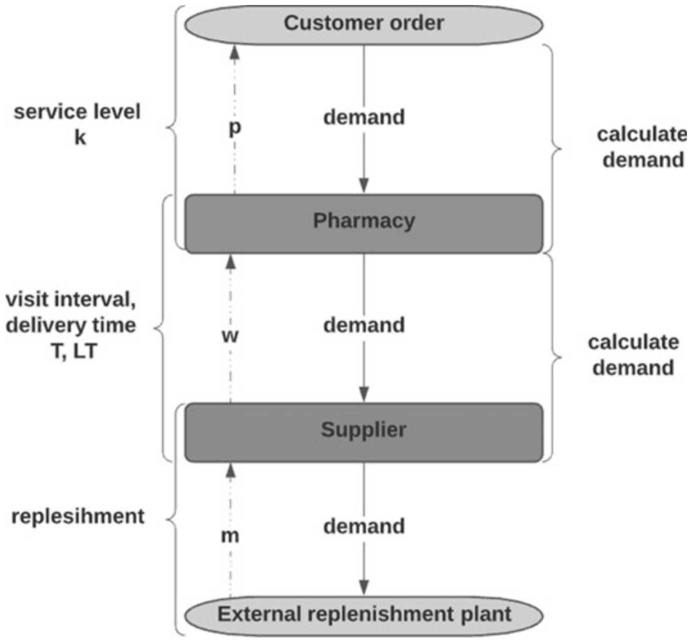


Fig. 1 The SC model

operation that relies freely on Darwinian ideas of fittest survival where operators of selection and recombination are used in high-performance solutions [22].

In this study, notations with the following signs are used (Table 1).

The following assumptions were considered in this study: The drug market is probabilistic per unit time and has a normal distribution. The pharmacy is facing no sales related to partial pre-order. There is a loss of reputation sh for every missing inventory unit, whether lost or not. The interval between two consecutive visits by the drug supplier is T, assumed to be a fixed number. The drug pharmacy uses a periodic review inventory policy based on the drug distributor's visit interval (T, S). When the drug distributor arrives, the inventory position at the pharmacy is equal to s, which is equal to the difference between inventory and pre-orders. The drug supplier delivers the received order to the pharmacy after a fixed delivery time LT has expired. There are generally one or several pending orders. The cost of the drug supplier's visit is independent of s and T variables. There is no product variety in the system, and the lead time length LT is less than the cycle length T for avoiding multiple pending orders in any cycle.

Table 1 Notations of the model

T visit interval of drug supplier Tmax = 14.0, the maximum period length allowed by the government administration.
LT order waiting time
μ Average demand follows normal distribution/time
σ Standard deviation with the normal distribution of demand/time
hr inventory holding cost at retailer/time
hs inventory holding cost at supplier/time
cs pharmaceutical supplier crashing cost. Cost for each order./Distribution and shipping cost of the drug supplier for each visit
a rate of lost sales
p selling price at retailer/unit drug
w Wholesale price/unit drug
m supply price/unit drug
sh Pharmaceutical retailer's shortage cost
A order cost at the drug supplier/order
n the drug supplier has a supply multiplier for replenishments
S order-up-to level at the pharmaceutical retailer
s reorder point at the pharmaceutical retailer
k the safety factor at the pharmaceutical retailer
SL Te pharmaceutical retailer's service level
CSR compensation transferred to drug supplier
X For drug following normal distribution having $\mu(T + LT)$ and std deviation σsqrt(T + LT), the request for protection interval
EP The expected profit/time

2.1 SC Model

The assumption of demand to the pharmacist is calculated by the demand following the normal distribution. D is equal to $\mu(T + LT)$ standard deviation $\sigma\sqrt{T + LT}$. Standard deviation over the protection interval.

S is a function of the order-up-to level that includes safety stock. It is calculated as S = SS + D, which can be shown in the equation below:

$$S = \mu(T + LT) + k\sigma\sqrt{T + LT} \qquad (1)$$

Considering that the protection gap demand X follows a normal distribution, the expected product shortage between two consecutive replenishments can be approximately calculated as

$$E(X - S) = G(k)\sigma\sqrt{T + LT} \qquad (2)$$

Here G(x) is called the unit normal loss function that is calculated as

$$\begin{aligned} G(\mathrm{x}) &= \int_{\mathrm{x}}^{\infty} (\mathrm{z}-\mathrm{x})\mathrm{f}(\mathrm{z})\mathrm{dz} \\ &= \mathrm{f}(\mathrm{x}) - \mathrm{x}[1-\mathrm{F}(\mathrm{x})] \end{aligned} \tag{3}$$

f(x) is the standard normal distribution function, calculated in the literature as $\mathrm{f}(\mathrm{x}) = \frac{1}{\sqrt{2\pi}}\mathrm{e}^{\frac{-\mathrm{x}^2}{2}\mathrm{dx}}$.

F(x) is the total distribution function, computed with $\mathrm{F}(\mathrm{x}) = \int_{\mathrm{x}}^{\infty} \mathrm{f}(\mathrm{x})\mathrm{dx}$.

2.1.1 Decentralized SC Problem

Profit model of the pharmaceutical retailer

The pharmaceutical retailer's profit is derived from the sales revenue by subtracting retention costs and lost sales costs [23]. The pharmaceutical retailer first decides how much to order. When R is divided, and the safety factor is taken as a decision variable, based on Nematollahi [24], the new objective function becomes

$$\begin{aligned} EP_{ret}^{dec} =& (p-w)\mu - h_r\left[\frac{\mu T}{2} + k\sigma\sqrt{T+LT} + aG(k)\,\sigma\sqrt{T+LT}\right] \\ & - \frac{sh + a(p-w)}{T}G(k)\sigma\sqrt{T+LT} \end{aligned} \tag{4}$$

In the decentralized model, the drug supplier predetermines the T visit interval and the drug retailer decides a service-level decision.

Profit model of the pharmaceutical supplier.

The objective function of the problem is modeled by subtracting the cost of holding and stock-free, lost sales, and order costs from the profit generated from the product. With this model, the expected profit of the pharmaceutical retailer can be calculated approximately as follows:

$$\begin{aligned} EP_{\text{sup}}^{dec} =& (w-m)\left(\mu - \frac{a\sigma\sqrt{T+LT}G(k)}{T}\right) - \frac{C_s + A/n}{T} \\ & - \frac{h_s(n-1)(\mu T - aG(k)\,\sigma\sqrt{T+LT})}{2} \end{aligned} \tag{5}$$

s.t.

$$EP_{ret}^{dec} = (p-w)\mu - h_r\left[\frac{\mu T}{2} + k\sigma\sqrt{T+LT} + aG(k)\,\sigma\sqrt{T+LT}\right]$$

$$-\frac{sh + a(p-w)}{T}G(k)\,\sigma\sqrt{T+LT} \tag{6}$$

$$0 \le \mathrm{T} \le \overline{\mathrm{T}} \tag{7}$$

2.1.2 Social Collaboration SC Problem

Nematollahi et al. [24] used a Social Collaboration model to ensure that members of the socially collaborated supply chain are involved in the provision of critical drug sales services to patients. The optimal quality of operation for the occupancy rate limit compared to the maximum permitted medicine deficiency rates for a period is taken into consideration in the proposed model. As with Uthayakumar and Priyan [25], the supply chain management assumes that the fill rate for the particular product is set according to the demand that the existing stock is supposed to have in a period separated by the expected average demand per cycle.

$$\begin{aligned} EP^{soc} =& (p-m)\mu - \frac{1}{T}\left(C_s + \frac{A}{n}\right) - \frac{G(k)\sigma\sqrt{T+LT}}{T}(sh + a(p-m) \\ & - \frac{h_s a(n-1)T}{2}) - \frac{\mu T}{2}[(n-1)h_s + h_r] \\ & - h_r\left[k\sigma\sqrt{T+LT} + aG(k)\sigma\sqrt{T+LT}\right] - err \end{aligned} \tag{8}$$

s.t.

$$\begin{aligned} & (p-w)\mu - \frac{sh + a(p-w)G(k)\sigma\sqrt{T+LT}}{T} \\ & - h_r\left[\frac{\mu T}{2} + k\sigma\sqrt{T+LT} + aG(k)\sigma\sqrt{T+LT}\right] \\ & \le (p-w)\mu - \frac{sh + a(p-w)G(k)\sigma\sqrt{T+LT}}{T} \\ & -h_r\left[\frac{\mu T}{2} + k\sigma\sqrt{T+LT} + aG(k)\sigma\sqrt{T+LT}\right] \end{aligned} \tag{9}$$

$$(w-m)\left(\mu-\frac{aG(k)\sigma\sqrt{T+LT}}{T}\right)-\frac{C_s+A/n}{T}$$
$$-\frac{h_s(n-1)G(k)\left(\mu T-a\sigma\sqrt{T+L}\right)}{2}\leq$$
$$(w-m)\left(\mu-\frac{aG(k)\sigma\sqrt{T+LT}}{T}\right)-\frac{C_s+A/n}{T}$$
$$-\frac{h_s(n-1)G(k)\left(\mu T-a\sigma\sqrt{T+L}\right)}{2}+err \tag{10}$$

$$0\leq T\leq\overline{T} \tag{11}$$

$$0\leq k\overline{T} \tag{12}$$

Equation (8) aims at maximizing overall profitability minus the moved compensation within the framework of social collaboration decision-making. Constraint (9) has been drawn up to ensure that when the establishment of the partnership is modeled, the viability of a pharmaceutical retailer is greater than for the decentralized situation. Constraint (10) notes that the profitability of the drug supplier after the distribution of payments is superior to the decentralized structure. The constraint (11) ensures that the supplier must not cross a certain threshold between two consecutive visits.

2.2 Algorithm Parameters

GA (genetic algorithm) is a global stochastic search that represents the natural selection process. The method is iterative and produces the ideal solution. The parameter values used in GA are in Table 2. The algorithm is coded in Python programming language using Python 3.9 and PyCharm 2.3. the parameters wanted in the algorithm are as follows: Max number of iterations is stopping criteria of the GA. Population size, mutation probability, number of elitists, crossover probability, parents' portion, the maximum number of iterations without improvement, which means the

Table 2 Value of the GA model parameters

Parameter	Type/value
Max generation	1000
Population size	100
Mutation	0.5
Crossover	0.5 uniform
Selection	elitism

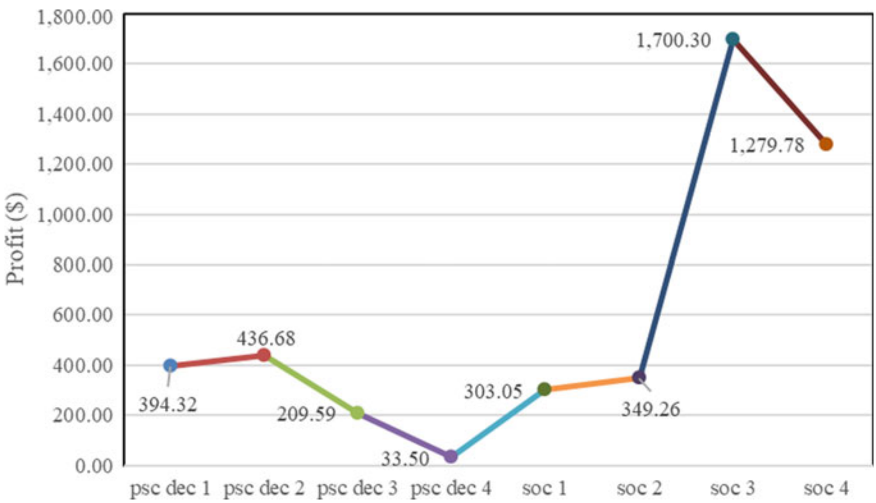
maximum number of successive iterations without improvement, and crossover-type can be 'uniform', 'one point' or 'two point'.

3 Results

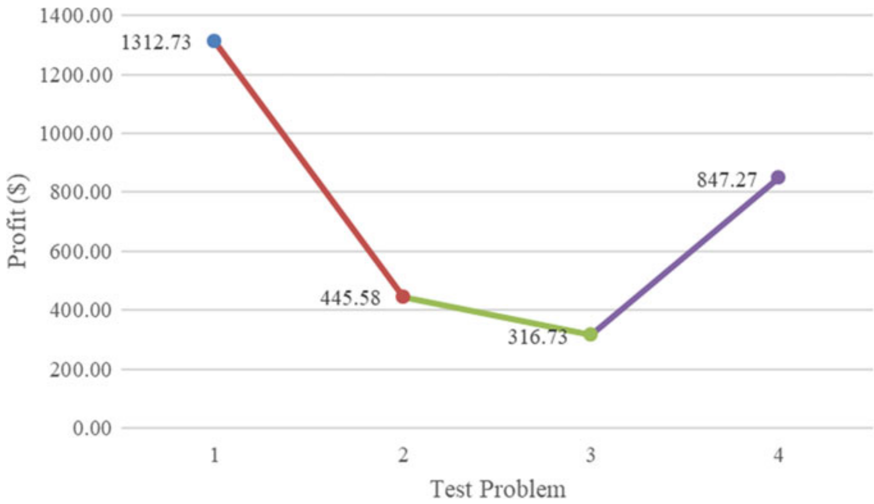
This article used GA for a two-echelon P-SC and compared the results with the mathematical model of a case study. Having GA on a two-echelon supply chain structure provides a better solution; also, the GA is easier to understand and faster than the mathematical model. Even mathematical model considered giving the best results, GA gave more reliable answers than the original model Nematollahi, Hosseini-Motlagh, and Heydari [24]. Test problems used in this article were taken from Nematollahi [24].

The difference between the mathematical model and the GA is shown in Graph 1. The genetic algorithm provided more profit for all scenarios in dollars. *Psc dec* and *soc* correspond to the profit gained from the decentralized model and social cooperation model, respectively.

Graph 2 shows the difference between the social collaboration model and the decentralized model solved by using GA. The social, collaborative model gives better results than the decentralized model.



Graph 1 Shows the difference between mathematical and GA model's solutions



Graph 2 The difference between the social collaboration model and the decentralized model

4 Conclusion

The supply chain network consists of different nodes that need to plan their cash and commodity flow continuously. The decentralized model showed the struggle haven to model two times for an SC having two echelons. When the echelons were programmed corresponding to the two-echelon model, the profit raised, and planning time was reduced accordingly. The GA gives better results than the mathematical model even without changing any parameter. Heuristics are easy to implement and can be adjusted to a large number of problems comfortably.

The program written in Python programming language can be used to solve all kinds of optimization models with limitless decision variables.

For future research, the algorithm written would be adapted to solve multi-objective optimization problems.

References

1. HiseyT, Jacoby R (2019) The role of distributors in the US health care industry. Available: https://www2.deloitte.com/us/en/pages/life-sciences-and-health-care/articles/the-role-of-distributors-in-the-us-health-care-industry.html
2. Nasrollahi M, Razmi J (2019) A mathematical model for designing an integrated pharmaceutical supply chain with maximum expected coverage under uncertainty. Oper Res 1–28
3. Privett N, Gonsalvez D (2014) The top ten global health supply chain issues: perspectives from the field. Oper Res Heal Care 3(4):226–230. https://doi.org/10.1016/j.orhc.2014.09.002

4. Denizhan B, Arslankaya S, Polat TK (2009) Knowledge Leverage Approach for Stronger Supply Chain. Eur MediterrEan Conf Inf Syst
5. Sabri EH, Beamon BN (2000) A multi-objective approach to simultaneous strategic and operational planning in supply chain design. Omega 28(5):581–598
6. Thomas DJ, Griffin PM (1996) Coordinated supply chain management. Eur J Oper Res 94:1–15
7. Simchi-Levi D, Kaminsky P, Simchi-Levi E (2004) Managing the Supply Chain: The Definitive Guide for the Business Professional. McGraw-Hill, New York
8. Chopra S, Meindl P (2013) Supply chain management: strategy, planning, and operation. Chapter 1, 5th edn. Harlow: Pearson. www.pearson.com. [Google Scholar]
9. Chopra S (2003) Designing the distribution network in a supply chain. Transp Res Part E 39:123–140
10. Spratt S, Company SO, Harrity C, Choate C, (2011) Inventory optimization: balancing the asset versus. pp 1–3
11. Johari M (2016) Coordinating pricing and periodic review replenishment decisions in a two-echelon supply chain using quantity discount contract. J Ind Eng Manag Stud 3(2):58–87
12. Cachon GP, Zipkin PH (1999) Competitive and cooperative inventory policies in a two-stage supply chain. Manage Sci 45(7):936–953
13. Cachon GP (2001) Stock wars: inventory competition in a two-echelon supply chain with multiple retailers. Oper Res 49(5):658–674. https://doi.org/10.1287/opre.49.5.658.10611
14. Moses M, Seshadri S (2000) Policy mechanisms for supply chain coordination. IIE Trans 32:245–262
15. Netessine S, Rudi N (2001) Supply chain structures on the Internet: Marketing operations coordination. Working paper, Wharton School, University of Pennsylvania, Philadelphia, PA. http://omg.simon.rochester. edu/omgHome/Rudi/Serguei/dropship.pdf, M. A
16. Lariviere E, Porteus L (2001) Selling to the newsvendor: an analysis of price-only contracts. Manufact Serv Oper Manag 3(4):293–305
17. Panda S, Modak NM, Cárdenas-Barrón LE (2017) Coordinating a socially responsible closed-loop supply chain with product recycling. Int J Prod Econ 188:11–21
18. Hosseini-Motlagh SM, Nematollahi M, Johari M, Choi T-M (2019) Reverse SC systems coordination across multiple links with duopolistic third-party collectors. IEEE Trans Syst Man Cybern Syst 3(3):1–12. https://doi.org/10.1109/TSMC.2019.2911644
19. Sakulsom N, Tharmmaphornphilas W (2019) Heuristics for a periodic-review policy in a two-echelon inventory problem with seasonal demand. Comput Ind Eng
20. Li JC, Lu JH, Wang QL, Li C (2018) Quality and pricing decisions in a two-echelon SC with bargaining fairness concerns. Discret Dyn Nat Soc
21. Taleizadeh AA, Alizadeh-Basban N, Sarker BR (2018) Coordinated contracts in a two-echelon green supply chain considering pricing strategy. Comput Ind Eng 124:249–275
22. Goldberg DE (1989) Genetic Algorithm in Search, Optimization, and Machine Learning. Boston, MA: Addison-Wesley Publishing Company
23. Ouyang LY, Chuang BR (2000) A periodic review inventory model involving variable leadtime with a service level constraint. Int J Syst Sci 31(10):1209–1215. https://doi.org/10.1080/00207720050165717
24. Nematollahi M, Hosseini-Motlagh SM, Heydari J (2017) Economic and social collaborative decision-making on visit interval and service level in a two-echelon pharmaceutical supply chain. J Clean Prod 142:3956–3969. https://doi.org/10.1016/j.jclepro.2016.10.062
25. Uthayakumar R, Priyan S (2013) Pharmaceutical supply chain and inventory management strategies: Optimization for a pharmaceutical company and a hospital. Oper Res Heal Care 2(3):52–64. https://doi.org/10.1016/j.orhc.2013.08.001

Meta-Heuristical Constrained Optimization Based on a Mechanical Design Problem

Bengü Güngör

Abstract Mechanical design optimization is a crucial part of engineering and manufacturing problems, according to the literature. Dealing with constraints is amongst the most challenging parts of this form of problem. Many studies have been presented to concern with infeasible solutions in process optimization, especially those based on genetic algorithms. The application step is carried out in this study with a chosen problem that is investigated by a Group Search Optimizer (iGSO) for resolving mechanical design optimization problems and an algorithm that uses both subsets and cooperative evolutionary strategies to enhance swarm intelligence capabilities and optimization accuracy. The selected pressure vessel design from this study aims to minimize the total cost of materials, forming and welding of the pressure vessel. By this aim, the pressure vessel design optimization problem was implemented with Simulated Annealing and Great Deluge Algorithms via MATLAB R2020b software. The parameters and constraints were specified in two distinct functions to compute the fitness function using an inverse tangent approach and even to obtain a penalty function that decreases the fitness values of infeasible solutions in accordance with the degree of constraint violation. Since it has a tiny area and performs in a restricted period, the Simulated Annealing Algorithm offered a reasonable result despite violating any constraints, according to MATLAB outputs.

Keywords Constrained optimization · Great Deluge Algorithm · Mechanical design problem · Simulated Annealing Algorithm

1 Introduction

Swarm-based evolutionary algorithms have garnered considerable attention in recent decades, and a lot of them have indeed been suggested, including genetic algorithms (GAs), evolutionary programming (EP), and evolution strategies (ES). Swarm intelligence (SI) algorithms that are nature-inspired have recently been created. There are

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two main types of SI algorithms: particle swarm optimization (PSO) and ant colony optimization (ACO) [1]. Heuristic methods have proved to become more versatile and effective than deterministic approaches, and they minimize the amount of time it takes to overcome an optimization problem. Although, the result obtained is really not assured to be a feasible or globally optimal solution [2]. Numerous researchers have proposed different algorithm to overcome constrained design optimization problems in the literature. Despite the widespread use of meta-heuristic approaches in a variety of engineering fields, their use in mechanical design optimization problems is still limited [3]. Within this context, there are several studies presenting these approaches. When it regards the most cited studies, at first, Goldberg (1989) mentioned Genetic Algorithms and its metaphors, especially in the machine learning field [4]. Another study presented by Kennedy and Eberhart (1995) described the evolution of numerous paradigms of particle swarm which approaches to optimize nonlinear functions and explained benchmark tests in neural network training [5]. Parsopoulos and Vrahatis (2002) explore the performance of the Unified Particle Swarm Optimization approach by using a penalty function technique [6]. Dorigo and Stützle (2004) provide an overview of ant colony optimization as well as a list of its most prominent applications [7]. Lee and Geem's study (2005) introduce a new harmony search meta-heuristic algorithm-based technique for engineering optimization problems involving continuous design variables, which is inspired by the musical practice of looking for the optimal state of harmony [8]. For improving multivariable functions, the Artificial Bee Colony algorithm presented by Karaboga and Basturk (2005) is a multivariable optimization technique based on the intelligent behavior of honeybee swarms [9]. Grenade Explosion Method, a new optimization technique developed by Ahrari and Atai (2010) is a simple and robust algorithm capable of discovering all global and some local optima of multimodal functions [10]. As another applied algorithm in engineering design problems, Eskandar et al. (2012) present the Water Cycle Algorithm is inspired by nature and is based on real-world observations of the water cycle and how rivers and streams flow into the sea [11]. Many additional swarm-based algorithms, such as Grey Wolf Optimizer (GWO) [12], Adaptive Firefly Algorithm (AFA) [13], Moth-flame Optimization Algorithm (MFO) [14], Ant Lion Optimization Algorithm (ALO) [15], Whale Optimization Algorithm (WOA) [16], Grey Relational Analysis (GRA) [17] and Salp Swarm Optimization Algorithm (SSO) [18] are utilized to solve constraint optimization issues in addition to these.

According to the literature review, the use of Simulated Annealing and Great Deluge Algorithms in engineering design problem has a poor amount than the others listed above. Therefore, this study aims to integrate both algorithms to solve a selected mechanical design optimization problem via using MATLAB R2020b software. In this case, the problem for the implementation phase was identified from the literature, based on [1]. Paper's "An improved group search optimizer for mechanical design optimization problems" published in Progress in Natural Science 19 (2009), 91–97. This paper introduces an improved group search optimizer (iGSO) for solving mechanical design optimization problems, as well as an algorithm that improves global search capability and convergence efficiency by using both subpopulations and a cooperative evolutionary strategy. The iGSO is tested on two classical mechanical design optimization problems: spring and pressure vessel. Within the application step, the pressure vessel design optimization problem was preferred based on Shen et al.'s study and Simulated Annealing and Great Deluge Algorithms were used to solve it.

2 Methodology

In this section, the applied algorithms for solving the selected pressure vessel design optimization problem are briefly represented.

2.1 Great Deluge Algorithm

The Great Deluge Algorithm (GDA) was created by Dueck [19] to solve complex optimization problems. "An individual climbing a hill will try to move in some direction that does not get his or her feet wet in the hope of finding a way up as the water level rises" according to the GDA analogy [20]. GDA has a significant advantage over the other related meta-heuristics in that it only requires the correction of a few parameters. It only requires the adjustment of one key parameter, the decay rate, or ΔL that is a search parameter that controls whether non-improving solutions are accepted. GDA will accept a non-improving solution if its quality is less than or equal to a predefined standard, which is reduced by ΔL in each iteration. Great Deluge Algorithm controls candidate solutions, and if a new candidate solution is superior or similar to the current solution, it is accepted [21].

Figure 1 (adopted from Baykasoğlu (2012)) shows the pseudocode for the GDA as implemented in this study.

The key parameter to configure in GDA is the decay rate calculated by Eq. 1. The initial and final values of the objective function are represented by F(S) and $F(S^f)$, respectively. $F(S^f)$ can be set to a reasonable lower bound.

Step-1. Generate an initial solution *S*
Step-2. Calculate initial cost function *F*(*S*) and set *Level, L*= *F*(*S*)
Step-3. **Repeat until** a stop criterion is satisfied;
    Step-2.1. Employ **chaotic maps** and **neighbor generation functions** to generate a neighbor within neighborhood of *S*, *S**⍰ *N*(*S*)
    Step-2.2. If *F*(*S**) ≤ *F(S)* **then** *S* = *S** **else if** *F*(*S**) ≤ *L* **then** *S* = *S**
    Step-2.3. *L* = *L* – Δ*L*
Step-4. Return *S**

Fig. 1 Pseudocode of Great Deluge Algorithm by Baykasoğlu (2012)

$$\Delta L = \frac{F(S) - F(S^f)}{\text{iteration number}} \tag{1}$$

Within a pre-specified neighbouring set, neighbourhood generation is essentially deciding new values for decision variables. To integrate GDA, Eqs. 2 and 3 were used for generating neighbourhood solutions in this study. $\Psi()$ is a chaotic number generator that assigns chaotic numbers within the range of zero and one.

$$x_i^* = x_i + integer[(2 * \Psi() - 1) * stepi_i] \tag{2}$$

$$x_i^* = x_i + (2 * \Psi() - 1) * stepc_i \tag{3}$$

The step sizes are specified in this method in relatively large numbers at the start of the search process, and they are decreased as the search progresses and the search finds a successful solution, where a more intensive search is more useful. This method has proven to be very useful and successful in our computational research. Baykasoğlu (2012) presented Eq. 4 to calculate step sizes as a new approach. According to Eq. 4, k is iteration counter, φ is parameter, which is set to $\varphi = 0.001$ in the present study.

$$step_i = step_i - e^{(-mod(k/k+1),1))} * \varphi * step_i \tag{4}$$

2.2 Simulated Annealing Algorithm

Simulated Annealing (SA) is a general optimization technique that is based on the statistical mechanics of solid annealing [22]. The implementation attempts to reduce a given objective, f, by making a small variation to the predictors while considering the objective's change in value, Δk [23]. The ability to stop being stuck in local minima is SA's big advantage over other approaches.

The algorithm generates a random search that allows variations that both minimize and maximize the objective function k. The algorithm begins with a random solution as the initial solution, and the process temperature ($T = T_0$) will be the same. Any iteration yields a solution that is near the current one. The proper idea is recognized with probability if the resultant adjustment produces an increase in the objective; Eq. 5, T is a control parameter related to as the system's temperature.

$$\exp(-\Delta k/T) \tag{5}$$

The neighbourhood search process is repeated until the number of iterations exceeds a fixed threshold. The device temperature is reduced after this stage.

```
Initialize parameters;
S=generate initial solution ( );
T = T_0;
While (T < T_final)
{
   Until (N ≤ I − Iter)
    {
        Generate solution S′ in the neighborhood of S
                 if f(S′′) < (f(S)
                           S ← S′
                 else
                           Δ = f(S′) − f(S)
                           r = random( );
                           if(r < exp(−Δ / k * T))
                           S ← S′
    }
        T = a × T;
}
Return the best solution found;
```

Fig. 2 Pseudocode of simulated annealing algorithm by Hosseinabadi et al. (2017)

This procedure is repeated until the termination criteria have been met [23]. This algorithm's pseudocode is shown in Fig. 2.

Within the neighbourhood generation and the step size part of this algorithm, Eqs. 2, 3 and 4 were used to implement on MATLAB software. Initial solutions for both GDA and SA algorithms were generated based on Eq. 6.

$$x_i^* = x_{min}^i + rand * \left(x_{max}^i - x_{min}^i\right) \tag{6}$$

After the algorithm coding section in MATLAB, codes were integrated with the selected pressure vessel design problem which is given in Sect. 3.

3 Application

Shen et al. (2009) developed an integrated group search optimizer (iGSO) for solving mechanical design optimization problems, as well as an algorithm that uses both subpopulations and a cooperative evolutionary strategy to enhance global search

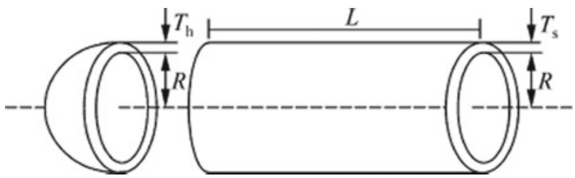

Fig. 3 Pressure vessel illustration by Shen et al. (2009)

Table 1 Pressure vessel design variables

Shell thickness	$T_s = x_1$
Thickness of the head	$T_h = x_2$
The inner radius	$R = x_3$
Length of cylindrical section	$L = x_4$

capability and convergence efficiency. The iGSO is put to the test on two classic mechanical design optimization problems: springs and pressure vessels.

Mechanical design problems can be expressed as constrained optimization problems in general, as shown below:

$$mink(X) \tag{7}$$

$$\text{Subject to } h_i(X) = 0 \quad i = 1, 2, ..., \ m \tag{8}$$

$$g_i(X) \geq 0i = 1, 2, \ldots, P \tag{9}$$

where X is an n-dimensional vector of mixed variables and k(X) is the objective function. The equality and inequality constraints are $h_i(X)$ and $g_i(X)$, respectively, and p is the number of inequality constraints.

This selected pressure vessel design (see Fig. 3) seeks to reduce the pressure vessel's overall cost of materials, forming, and welding. Design variables are given in Table 1.

x_1 and x_2 are discrete integer multiples of 0.0625 in, while x_3 and x_4 are continuous.

The mathematical model of Shen's pressure vessel design problem is stated as follows:

3.1 Pressure Vessel Design Problem Integration with MATLAB R2020b Software

Figure 5 shows how the problem was modelled using both Simulated Annealing and Great Deluge Algorithms. For MATLAB integration of this selected problem, the parameters and constraints were defined under two separated functions which

$$\text{Minimize} \quad f_{(x)} = 0.0624x_1x_3x_4 + 1.7781x2x_3^3 + 3.1661x_1^2x_4 + 19.84x_1^3x_3$$

subject to

$$g_1(X) = 0.0193x_3 - x_1 \leqslant 0$$
$$g_2(X) = 0.00954x_3 - x_2 \leqslant 0$$
$$g_3(X) = 1,296,000 - \pi x_3^2x_4 - \tfrac{4}{3}\pi x_3^3 \leqslant 0$$
$$g_4(X) = x_4 - 240 \leqslant 0$$
$$\text{and} \quad 0.0625 \leqslant x_1 \leqslant 6.1875, 0625 \leqslant x_2 \leqslant 6.1875, 10 \leqslant x_3 \leqslant 200, 10 \leqslant x_4 \leqslant 200$$

Fig. 4 Mathematical model of Shen's pressure vessel

```
function y=obj_func(x)
 y=(0.0624*x(1)*x(3)*x(4))+(1.7781*(2*(x(3)^3)))+(3.1661*(x(1)^2)*x(4))+(19.84*(x(1)^3)*x(3));
 %constraints
 g(1)=(0.0193*x(3))-x(1);
 g(2)=(0.00954*x(3))-x(2);
 g(3)=(1296000-(pi*(x(3)^2)*x(4))-((4/3)*pi*(x(3)^3)));
 g(4)=x(4)-240;

 g(5)=0.0625-x(1);
 g(6)=x(1)-6.1875;

 g(7)=0.625-x(2);
 g(8)=x(2)-6.1875;

 g(9)=10-x(3);
 g(10)=x(3)-200;

 g(11)=10-x(4);
 g(12)=x(4)-200;
```

Fig. 5 MATLAB modelling of objective function and constraints

are obj_func_tan to calculate objective function with inverse tangent approach, and obj_func_pen to create a penalty function that is generated for infeasible solutions by reducing their fitness values in proportion to their degrees of constraint violation. The co-evolutionary penalty form was coded as a penalty feature, as seen in an article by Yeniay (2005). This type of penalty divides the penalty into two values, providing enough detail to the Genetic Algorithms about the sum of restriction violations and the severity of the violations [24].

In this model, individuals are evaluated by Eq. 10 where f(X) is the objective function's value, w_1 and w_2 are two penalty parameters, and coef (see Eq. 11) is the number of the values by which the constraints are violated. viol starts at zero and increases by one for each restriction violated. As shown in Fig. 6, the co-evolutionary penalty function was coded in MATLAB under the name obj_func_pen.

```
%apply co-evolutionary penalty
penalty=0;
coef=counter;
for i=1:12
   penalty=y-(coef+(coef*100/g(i)));
end
L=y+12*penalty;

y=L;
```

Fig. 6 Co-evolutionary penalty function implementation on MATLAB

$$\text{eval}(\overline{x}) = f(x) - (\text{coefw}_1 + \text{violw}_2) \tag{10}$$

$$coef = \sum_{i=1}^{q} g_i(\overline{x}), \quad \forall g_i(\overline{x}) > 0 \tag{11}$$

In this part of the code, the infeasible constraints were counted, and the number was stored under the counter variable. The penalty equation was calculated for 12 different constraints so, it was written in a for loop having an index i from 1 to 12. The second part of the equation which is coef*100/g(i) calculates the number of violated constraints based on the number of infeasible constraints divided by the overall number of constraints.

4 Results

After the analyzing defined mechanical design optimization problem, the outputs of Simulated Annealing (SA) and Great Deluge Algorithms (GDA) were given in Table 2.

The developed iGSO algorithm within the Shen's study gives the best solution as: $x_1 = 0.812500$ $x_2 = 0.437500$ $x_3 = 42.098446$ $x_4 = 176.636596$%fitness = 6059.714. According to SA and GDA algorithms, it can be observed that both give feasible

Table 2 Output table of SA and GDA

	X1	X2	X3	X4	Y	Fitness
SA	1.55655	2.58282	75.2264	74.2178	− 6.57619e-07	1.5206e + 06
GDA	−0.130212	0.360365	4.47167	4.75327	− 13,936.6	317.8624

solutions because y values are negative. Additionally, even though both algorithms have given closer to an optimal solution than iGSO algorithm fitness value; however, Simulated Annealing Algorithm has provided a better solution with a smaller fitness value for the pressure vessel design constrained minimization problem. Furthermore, the objective function plots of the SA and GDA algorithms are shown in Figs. 7 and 8. Both plots show that objective functions converge to near to optimum solution so, it can be confirmed that the analyzes give a feasible solution for the designed problem.

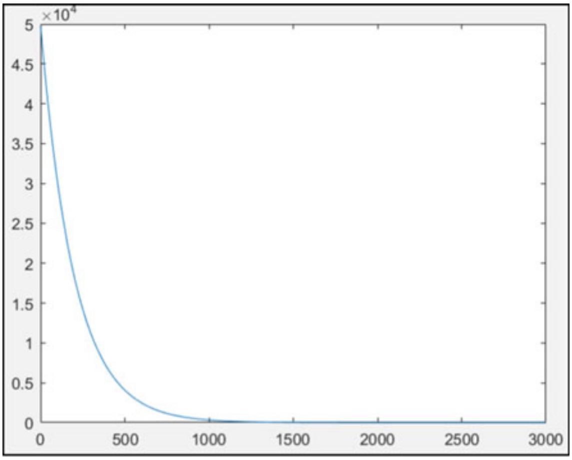

Fig. 7 Objective function plot of Simulated Annealing Algorithm

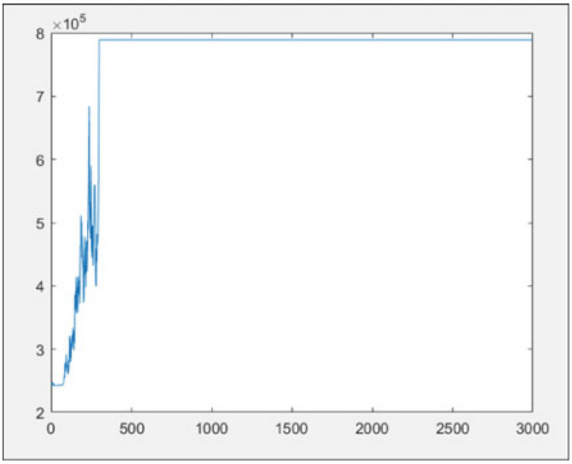

Fig. 8 Objective function plot of Great Deluge Algorithm

5 Conclusion

This research uses two separate meta-heuristic algorithms to solve a constrained optimization problem in the engineering design field: Simulated Annealing and Great Deluge Algorithm. First and foremost, a literature-based issue, pressure vessel design, was chosen. Following that, the pseudocodes were used to code each SA and GDA algorithm in the MATLAB R2020b software. Since it has a small population and operates in a small number of generations, the Simulated Annealing Algorithm gives a stable solution without violating the constraints, according to MATLAB outputs. A further successful algorithm is the Great Deluge Algorithm, which avoids getting stuck in local optima by using simple neighbourhood search heuristics to find solutions in a short period of time. According to the outputs of this study, it was seen that both algorithms applied to the problem were more successful in solving the engineering design problem minimization model than the iGSO algorithm. As a future research direction of the study, different algorithms can be implemented by embedding learning algorithms in them.

References

1. Shen H, Zhu Y, Niu B, Wu QH (2009) An improved group search optimizer for mechanical design optimization problems. Prog Nat Sci 19(1):91–97. https://doi.org/10.1016/j.pnsc.2008.06.007
2. Rao RV, Waghmare GG (2017) A new optimization algorithm for solving complex constrained design optimization problems. Eng Optim 49(1):60–83. https://doi.org/10.1080/0305215X.2016.1164855
3. Yildiz AR, Abderazek H, Mirjalili S (2020) A comparative study of recent non-traditional methods for mechanical design optimization. Arch Comput Methods Eng 27(4):1031–1048. https://doi.org/10.1007/s11831-019-09343-x
4. Goldberg DE (1989) Genetic algorithms in search. Optim Mach Learn
5. Kennedy J, Eberhart R (1995) Particle swarm optimization. IEEE, 1942–1948. https://doi.org/10.1002/9780470612163
6. Parsopoulos KE, Vrahatis MN (2002) Hybrid particle swarm optimizer for constrained optimization problems. Intell Technol-Theory Appl: New Trends Intell Technol 76(1):214–220
7. Dorigo M, Stützle T (2004) Ant colony optimization theory. IEEE, 121–152
8. Lee KS, Geem ZW (2005) A new meta-heuristic algorithm for continuous engineering optimization: harmony search theory and practice. Comput Methods Appl Mech Eng 194(36–38):3902–3933. https://doi.org/10.1016/j.cma.2004.09.007
9. Karaboga D, Basturk B (2007) A powerful and efficient algorithm for numerical function optimization: artificial bee colony (ABC) algorithm. J Glob Optim 39:459–471
10. Ahrari A, Atai AA (2010) Grenade explosion method - a novel tool for optimization of multimodal functions. Appl Soft Comput J 10(4):1132–1140. https://doi.org/10.1016/j.asoc.2009.11.032
11. Eskandar H, Sadollah A, Bahreininejad A, Hamdi M (2012) Water cycle algorithm - a novel metaheuristic optimization method for solving constrained engineering optimization problems. Comput Struct 110–111:151–166. https://doi.org/10.1016/j.compstruc.2012.07.010
12. Mirjalili S, Mirjalili SM, Lewis A (2014) Grey wolf optimizer. Adv Eng Softw 69:46–61. https://doi.org/10.1016/j.advengsoft.2013.12.007

13. Baykasoglu A, Ozsoydan FB (2015) Adaptive firefly algorithm with chaos for mechanical design optimization problems. Appl Soft Comput J 36:152–164. https://doi.org/10.1016/j.asoc.2015.06.056
14. Mirjalili S (2015) Moth-flame optimization algorithm: a novel nature-inspired heuristic paradigm. Knowl-Based Syst 89:228–249. https://doi.org/10.1016/j.knosys.2015.07.006
15. Mirjalili S (2015) The ant lion optimizer. Adv Eng Softw 83:80–98. https://doi.org/10.1016/j.advengsoft.2015.01.010
16. Mirjalili S, Lewis A (2016) The whale optimization algorithm. Adv Eng Softw 95:51–67. https://doi.org/10.1016/j.advengsoft.2016.01.008
17. Shinde AB, Pawar PM (2017) Multi-objective optimization of surface textured journal bearing by Taguchi based Grey relational analysis. Tribol Int 114(April):349–357. https://doi.org/10.1016/j.triboint.2017.04.041
18. Mirjalili S, Gandomi AH, Mirjalili SZ, Saremi S, Faris H, Mirjalili SM (2017) Salp Swarm Algorithm: a bio-inspired optimizer for engineering design problems. Adv Eng Softw 114:163–191. https://doi.org/10.1016/j.advengsoft.2017.07.002
19. Dueck G (1993) New optimization heuristics: the great deluge algorithm and the record-to-record travel. J Comput Phys 104(1):86–92
20. Baykasoglu A (2012) Design optimization with chaos embedded great deluge algorithm. Appl Soft Comput J 12(3):1055–1067. https://doi.org/10.1016/j.asoc.2011.11.018
21. Landa-Silva D, Obit JH (2008) Great deluge with non-linear decay rate for solving course timetabling problems. In: Proceedings of 2008 4th Int. IEEE Conf. Intell. Syst. IS 2008. Vol 1, pp 811–818. https://doi.org/10.1109/IS.2008.4670447
22. Busetti F (2003) Simulated annealing overview. World Wide Web URL www.geocities.com (1):1–10
23. Hosseinabadi AAR, Alavipour F, Shamshirbnd S, Balas VE (2017) A novel meta-heuristic combinatory method for solving capacitated vehicle location-routing problem with hard time windows. Adv Intell Syst Comput 454(October):707–728. https://doi.org/10.1007/978-3-319-38789-5_77
24. Yeniay Ö (2005) Penalty function methods for constrained optimization with genetic algorithms. Math Comput Appl 10(1):45–56. https://doi.org/10.3390/mca10010045

A Case Study of Shape Optimization Using Grasshopper Optimization Algorithm

Faik Fatih Korkmaz, Mert Subran, and Ali Rıza Yıldız

Abstract Structural optimization is a popular topic in today's engineering and industry to reduce costs and obtain more ideal designs. In the structural optimization problem, the lightest design under conditions is investigated. Increasing studies in recent years have proven the success of metaheuristic optimization algorithms in structural optimization problems. Unlike the traditional method, metaheuristic methods use stochastic methods and do not need derivative information of the problem. This makes them more flexible and easy to use. In this study, a solid part's shape optimization is performed by using the Grasshopper Optimization Algorithm (GOA). The design values and results found by the algorithm are discussed.

Keywords Structural Optimization · Shape optimization · Constrained optimization · Metaheuristic · GOA

1 Introduction

The product design process and product cost are important topics in today's industrial world. Design optimization methods have been an expert way to develop more efficient, lighter, and lower-cost designs. The purpose of structural design optimization is to determine the best shape of the structure by changing the design variables [1, 2]. Today, there are many structural optimization software available, both commercial such as Hypermesh [3], optiSLang [4], solidThinking Inspire [5], and open-source such as OpenMDAO [6], OpenLSTO [7].

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The first type of optimization algorithms is based on gradient. This type of algorithm uses the derivative vectors of functions that are modeled by the problem. The second type is based on stochastic approaches. These algorithms apply more than one solution in each iteration. Metaheuristic algorithms also use this approach and become known as a powerful instrument to determine the best solution to design problems [2, 8]. Today, there are not only many studies using metaheuristic algorithms inspired by nature [9–18], but also hybrid studies increasing day by day [19–25]. Additionally, these algorithms have given a different perspective to engineering design problems [26–40].

Metamodeling has been used in many studies [41, 42] due to a large number of function evaluations and the weakness of commercially used structural optimization software to use meta-heuristic artificial intelligence algorithms. The basic concept is to obtain an approximate model of the system by using samples. The responses to the problem are approximately obtained with this type of modeling.

Like other optimization techniques, shape optimization is an essential method of structural optimization [43]. In this study, using the Hypermorph tool and Grasshopper Optimization Algorithm (GOA), shape optimization of a three-dimensional part is completed without metamodeling. The objective is the mass, and the constraint of the problem is the maximum von Mises stress of the structure.

GOA is such a nature-inspired optimization algorithm that models grasshopper swarms' behavior in nature [44]. Pseudocodes for the GOA and more detailed information can be found in reference [44].

2 Case Study

The finite element model was created to determine the mechanical behavior of the part under working conditions. The finite element model includes mesh elements describing the part's geometry and loading conditions. In this study, the linear static analysis was preferred because it properly describes the mechanical behavior and it has analysis time which is at a reasonable level.

The optimization problem defines the design values, purpose, and constraints of the problem. One of the equations used in the optimization process is the linear static analysis of the model. In this section, the finite element model of the part and optimization problem is explained.

2.1 Model

The front view of the part is given in Fig. 1. There is a round hole and a rectangular hole on the part to change the shape and size. The changes to be made on the part are explained in the optimization problem header.

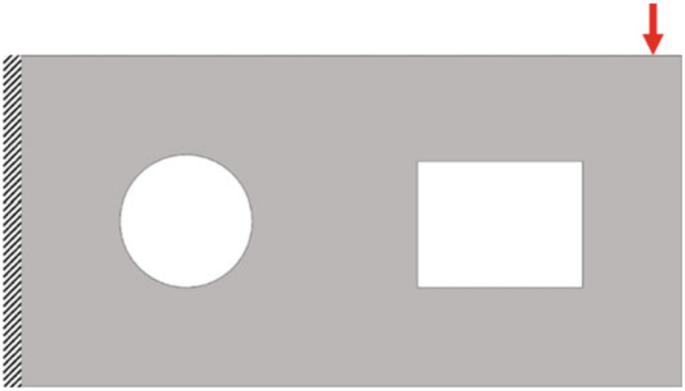

Fig. 1 Front view of the part

Geometry has been meshed using CTRIA3, CQUAD4, CPENTA, and CHEXA elements using Hypermesh software. The total element number is 6447, and the total node number is 4921. Material properties referenced steel. The elasticity modulus is 210000 MPa, and the Poisson ratio is 0.3, density is 7.9e-9 kg/mm^3. The total distributed force is 9600 N at the corner of the left edge.

2.2 *Optimization Problem*

Ensuring that the part is lightened without losing its reliability under boundary conditions can be expressed as a constrained optimization problem. In this optimization problem, the design variables are the dimensions of the part. The damage hypothesis suitable for the part is defined in the problem as a constraint. The objective function is defined using the mass.

In this study, design values were selected as the multiplier of perturbation vectors that change geometry points (Fig. 2). These shape perturbations are user-defined vectors and they are defined in Hypermesh software by using the Hypermorph tool. In this way, the shape of the part is changed by changing the multipliers.

Design values:

$$x_j = multiplier\ of\ p_j \tag{1}$$

$$0 \leq x_j \leq 1 \tag{2}$$

Objective function:

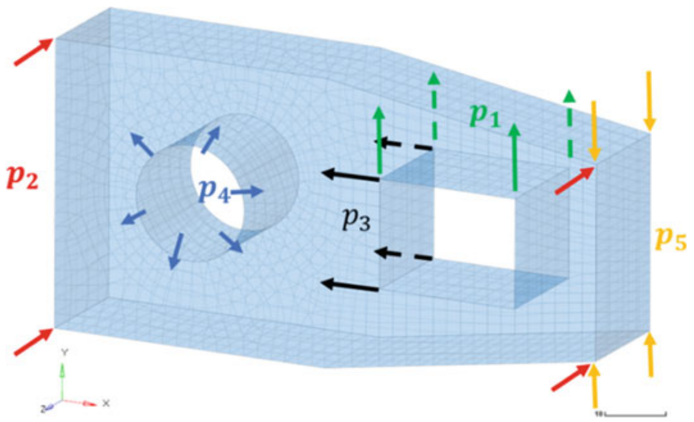

Fig. 2 The visualization of shape perturbations on geometry

$$\min\left(\sum_{k=1,2,3,\ldots}^{N} \rho \Delta V_k\right) \tag{3}$$

Constraints:

$$\sigma_k(x) \leq 200 \tag{4}$$

x is the vector that contains the perturbation multipliers. The objective function is the sum of the mass. N is the total number of elements, k is the element number, and ΔV_k is the volume of the number k element. $\sigma_k(x)$ refers to the von mises stress of the k numbered element.

Initial design values, in Eq. (1), are determined by GOA. Geometry is regenerated by this initial design. After the static analysis using Optistruct software, objective and constraint violation values are obtained. If the constraints are above zero, penalty scores apply—the penalty score is calculated by using Eq. (5) and (6).

$$C(x) = M(x) + 10^{10} \times \mathrm{V(x)}^2 \tag{5}$$

$$V(x) = \sum \max(\sigma_k(x) - 200,\ 0) \tag{6}$$

Here, V shows the violation value, M is the mass function which is calculated using density and volume of geometry, and C is the cost value. If any elements with a von Mises stress above 200 MPa, the violation is penalized in the cost. Design values, static analysis, and calculating the cost values repeat during optimization for each iteration.

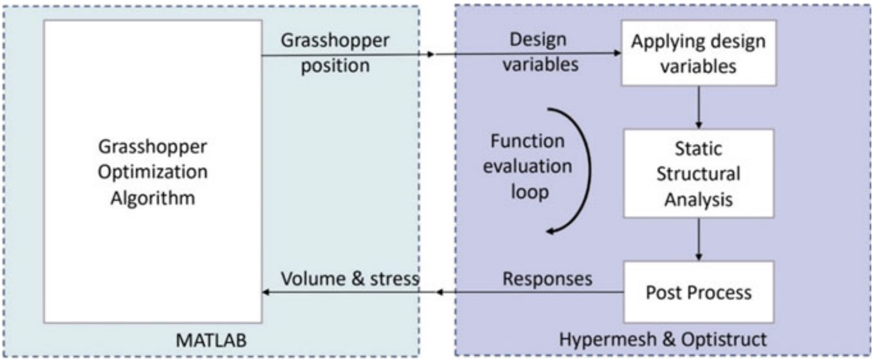

Fig. 3 Function evaluation flow diagram

2.3 Method

The flowchart used in the solution of the design problem is given in Fig. 3. The diagram follows a closed-loop path and applies the design values determined by the algorithm to the problem and transfer the necessary responses to the algorithm. This approach was used instead of the metamodeling method, in which the problem was modeled approximately.

Detailed information on the algorithm documentation for GOA is described in reference [44]. The GOA algorithm used in the study has been run in the MATLAB software environment. The algorithm randomly determines the initial population. The position of each grasshopper in the population is equivalent to the design values in the physical problem. Design values are applied to geometry with Hypermesh software. In the finite element model, structural analysis is performed in the Optistruct environment without any changes except geometry. Structural analysis results include data of parameters such as stress distribution and displacement values. Response data are transferred to the algorithm in the MATLAB environment, and the fitness values of the population are obtained. This cycle is followed in all objective function runs, and the optimization process continues with the cooperation of many different platforms.

3 Results and Conclusion

This section includes optimization results. The number of search agents is 15, the number of maximum iterations is 350. The dimension of the problem is 5. The results of the 3 independent runs are listed in Table 1.

As a result of 3 independent runs using the same optimization parameters, 3 different design concepts were obtained. When the design value named X1 is compared for 3 different results, it is observed that it takes different values. Also, it

Table 1 Run summary table

Run ID	Mass (kg)	X1	X2	X3	X4	X5
Run 1	**0.000394266**	0.132912	0.620637	0.182769	0.150604	0.418107
Run 2	0.000405558	0.298307	0.584310	0.315859	0.363608	0.263748
Run 3	0.000406024	0.941332	0.579465	0.000000	0.370795	0.255130

is similar to other design values. This shows that the GOA algorithm can be used as a tool to find the optimum design and search for different concepts.

The convergence curve of the best solution is shown in Fig. 4. The plot gives the values of the minimum cost with respect to iteration. Additionally, the fitness history curve shows cost with respect to iteration. The convergence curve and the fitness history curve show the best cost value in each iteration. While the fitness history curve shows the best value in the current iteration, the convergence curve shows the cost value of the best design in the whole optimization process.

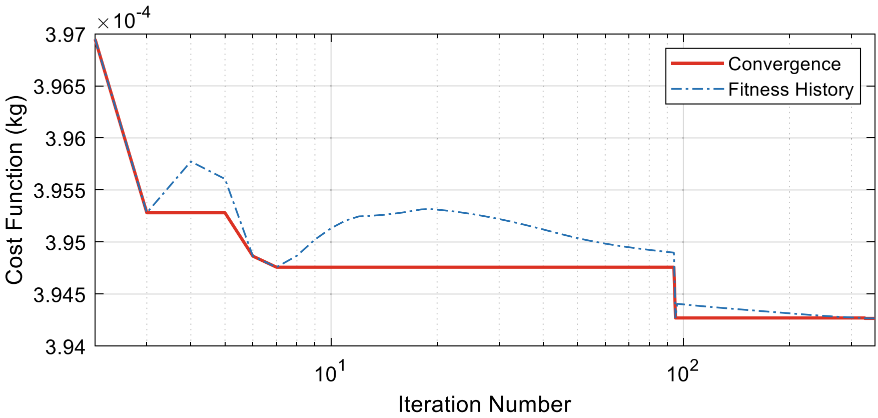

Fig. 4 Convergence curve and fitness history

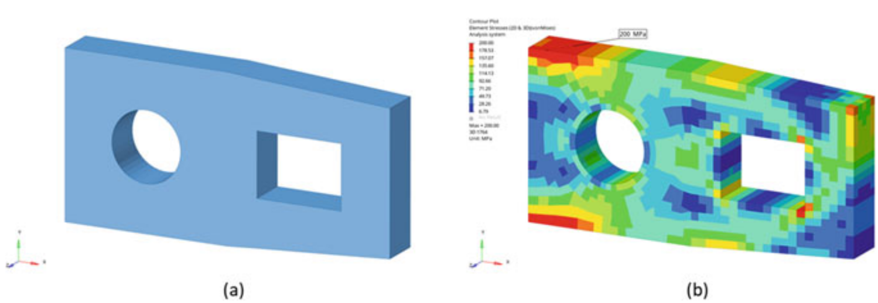

Fig. 5 Optimal design, **a** geometry, **b** static analysis result

As a result of the design values, the shape changes are visualized in Fig. 5a. The linear static analysis results of the shape optimization are shown in Fig. 5b for the best running. GOA has found a feasible design that the maximum von Mises stress is 200 MPa and does not violate the constraints.

In summary, instead of the metamodeling method, which has many examples in the literature and can be used in structural optimization problems, a connection has been made between MATLAB and Hypermesh software. In this way, the freedom to choose the optimization algorithm has been obtained, and shape optimization has been performed using the GOA algorithm. The shape-optimized part is a simple three-dimensional geometry in which 5 different perturbation vectors are defined. Optimization algorithm parameters have been adjusted considering the optimization time and convergence, and the part was subjected to 3 independent optimizations. The results show that the GOA and the method used in the study yielded successful results that do not violate the problem constraints. In addition, the method used in the study includes collaboration between software and allows shape optimization for different structural parts by using metaheuristic optimization algorithms. This advantage offers the idea that optimizations in different techniques or software without optimization tools can also be included in the optimization.

References

1. Yildiz BS, Yildiz AR (2018) Comparison of grey Wolf, whale, water cycle, ant lion and sine-cosine algorithms for the optimization of a vehicle engine connecting rod. Mater/Mater Test 60(3):311–315. https://doi.org/10.3139/120.111153
2. Yildiz AR (2013) Comparison of evolutionary-based optimization algorithms for structural design optimization. Eng Appl Artif Intell 26(1):327–333. https://doi.org/10.1016/j.engappai.2012.05.014
3. Hypermesh. Altair Engineering, Inc., Troy MI, United States, [Online]. Available: https://altairhyperworks.com/product/HyperMesh
4. ANSYS Inc (2021) Ansys optiSLang: design optimization. https://www.ansys.com/products/platform/ansys-optislang (accessed Mar. 05)
5. Altair Inspire (2021) https://www.altair.com/inspire/ (accessed Mar. 05)
6. Gray JS, Hwang JT, Martins JRRA, Moore KT, Naylor BA (2019) OpenMDAO: an open-source framework for multidisciplinary design, analysis, and optimization. Struct Multidiscip Optim 59(4):1075–1104. https://doi.org/10.1007/s00158-019-02211-z
7. M. M. D. O. Laboratory (2021) Welcome to OpenLSTO. http://m2do.ucsd.edu/software/ (accessed Mar. 05)
8. De Leon-Aldaco SE, Calleja H, Alquicira JA (2015) Metaheuristic optimization methods applied to power converters: a review. IEEE Trans Power Electron 30(12):6791–6803. https://doi.org/10.1109/TPEL.2015.2397311
9. Erdal F, Doğan E, Saka MP (2011) Optimum design of cellular beams using harmony search and particle swarm optimizers. J Constr Steel Res 67(2):237–247. https://doi.org/10.1016/j.jcsr.2010.07.014
10. Tejani GG, Savsani VJ, Patel VK, Savsani PV (2018) Size, shape, and topology optimization of planar and space trusses using mutation-based improved metaheuristics. J Comput Des Eng 5(2):198–214. https://doi.org/10.1016/j.jcde.2017.10.001

11. Dhiman G et al (2021) EMoSOA: a new evolutionary multi-objective seagull optimization algorithm for global optimization. Int J Mach Learn Cybern 12(2):571–596. https://doi.org/10.1007/s13042-020-01189-1
12. Ficarella E, Lamberti L, Degertekin SO (2021) Comparison of three novel hybrid metaheuristic algorithms for structural optimization problems. Comput Struct 244:106395. https://doi.org/10.1016/j.compstruc.2020.106395.
13. Biswas K, Vasant P, Vintaned JAG, Watada J, Roy A, Sokkalingam R (2021) A hybrid metaheuristic algorithm for truss structure domain's optimization problem. Theoretical, modelling and numerical simulations toward industry 4.0. Springer, pp 21–34
14. Karagöz S, Yıldız AR (2017) A comparison of recent metaheuristic algorithms for crashworthiness optimisation of vehicle thin-walled tubes considering sheet metal forming effects. Int J Veh Des 73(1/2/3):179. https://doi.org/10.1504/IJVD.2017.082593
15. Yıldız BS, Yıldız AR (2017) Moth-flame optimization algorithm to determine optimal machining parameters in manufacturing processes. Mater Test 59(5):425–429. https://doi.org/10.3139/120.111024
16. Pholdee N, Bureerat S, Yıldız AR (2017) Hybrid real-code population-based incremental learning and differential evolution for many-objective optimisation of an automotive floor-frame. Int J Veh Des 73(1/2/3):20. https://doi.org/10.1504/IJVD.2017.082578
17. Yıldız BS (2017) A comparative investigation of eight recent population-based optimisation algorithms for mechanical and structural design problems. Int J Veh Des 73(1/2/3):208. https://doi.org/10.1504/IJVD.2017.082603
18. Gholizadeh S, Ebadijalal M (2018) Performance based discrete topology optimization of steel braced frames by a new metaheuristic. Adv Eng Softw 123:77–92. https://doi.org/10.1016/j.advengsoft.2018.06.002
19. Panagant N, Pholdee N, Wansasueb K, Bureerat S, Yildiz AR, Sait SM (2019) Comparison of recent algorithms for many-objective optimisation of an automotive floor-frame. Int J Veh Des 80(2–4):176–208. https://doi.org/10.1504/IJVD.2019.109863
20. Yıldız AR, Erdaş MU (2021) A new Hybrid Taguchi-salp swarm optimization algorithm for the robust design of real-world engineering problems. Mater Test 63(2):157–162. https://doi.org/10.1515/mt-2020-0022
21. Yildiz AR (2019) A novel hybrid whale–Nelder–Mead algorithm for optimization of design and manufacturing problems. Int J Adv Manuf Technol 105(12):5091–5104. https://doi.org/10.1007/s00170-019-04532-1
22. Kurtuluş E, Yıldız AR, Sait SM, Bureerat S (2020) A novel hybrid Harris hawks-simulated annealing algorithm and RBF-based metamodel for design optimization of highway guardrails. Mater Test 62(3):251–260. https://doi.org/10.3139/120.111478
23. Yıldız BS, Pholdee N, Panagant N, Bureerat S, Yildiz AR, Sait SM (2021) A novel chaotic Henry gas solubility optimization algorithm for solving real-world engineering problems. Eng Comput. https://doi.org/10.1007/s00366-020-01268-5
24. Özkaya H, Yıldız M, Yıldız AR, Bureerat S, Yıldız BS, Sait SM (2020) The equilibrium optimization algorithm and the response surface-based metamodel for optimal structural design of vehicle components. Mater Test 62(5):492–496. https://doi.org/10.3139/120.111509
25. Yildiz BS, Pholdee N, Bureerat S, Yildiz AR, Sait SM (2021) Robust design of a robot gripper mechanism using new hybrid grasshopper optimization algorithm. Expert Syst. https://doi.org/10.1111/exsy.12666
26. Abderazek H, Yildiz AR, Sait SM (2019) Mechanical engineering design optimisation using novel adaptive differential evolution algorithm. Int J Veh Des 80(2–4):285–329. https://doi.org/10.1504/IJVD.2019.109873
27. Abderazek H, Sait SM, Yildiz AR (2019) Optimal design of planetary gear train for automotive transmissions using advanced meta-heuristics. Int J Veh Des 80(2–4):121–136. https://doi.org/10.1504/IJVD.2019.109862
28. Karaduman A, Yıldız BS, Yıldız AR (2019) Experimental and numerical fatigue-based design optimisation of clutch diaphragm spring in the automotive industry. Int J Veh Des 80(2–4):330–345. https://doi.org/10.1504/IJVD.2019.109875

29. Sarangkum R et al (2019) Automated design of aircraft fuselage stiffeners using multiobjective evolutionary optimisation. Int J Veh Des 80(2–4):162–175. https://doi.org/10.1504/IJVD.2019.109864
30. Panagant N, Pholdee N, Bureerat S, Kaen K, Yıldız AR, Sait SM (2021) Seagull optimization algorithm for solving real-world design optimization problems. Mater Test 62(6):640–644. https://doi.org/10.1515/mt-2020-620615
31. Yıldız BS (2020) The spotted hyena optimization algorithm for weight-reduction of automobile brake components. Mater Test 62(4):383–388. https://doi.org/10.1515/mt-2020-620409
32. Champasak P, Panagant N, Pholdee N, Bureerat S, Yildiz AR (2020) Self-adaptive many-objective meta-heuristic based on decomposition for many-objective conceptual design of a fixed wing unmanned aerial vehicle. Aerosp Sci Technol 100:105783. https://doi.org/10.1016/j.ast.2020.105783.
33. Aye CM, Pholdee N, Yildiz AR, Bureerat S, Sait SM (2019) Multi-surrogate-assisted meta-heuristics for crashworthiness optimisation. Int J Veh Des 80(2–4):223–240. https://doi.org/10.1504/IJVD.2019.109866
34. Panagant N, Pholdee N, Bureerat S, Yildiz AR, Mirjalili S (2021) A comparative study of recent multi-objective metaheuristics for solving constrained truss optimisation problems. Arch Comput Methods Eng No. 0123456789. https://doi.org/10.1007/s11831-021-09531-8
35. Yıldız BS, Pholdee N, Bureerat S, Yıldız AR, Sait SM (2020) Sine-cosine optimization algorithm for the conceptual design of automobile components. Mater/Mater Test 62(7):744–748. https://doi.org/10.3139/120.111541
36. Yıldız BS, Yıldız AR, Pholdee N, Bureerat S, Sait SM, Patel V (2020) The Henry gas solubility optimization algorithm for optimum structural design of automobile brake components. Mater/Mater Test 62(3):261–264. https://doi.org/10.3139/120.111479
37. Yıldız BS (2020) Optimal design of automobile structures using moth-flame optimization algorithm and response surface methodology. Mater/Mater Test 62(4):371–377. https://doi.org/10.3139/120.111494
38. Yıldız BS (2020) The mine blast algorithm for the structural optimization of electrical vehicle components. Mater Test 62(5):497–501. https://doi.org/10.3139/120.111511
39. Yıldız BS, Yıldız AR, Albak Eİ, Abderazek H, Sait SM, Bureerat S (2020) Butterfly optimization algorithm for optimum shape design of automobile suspension components. Mater Test 62(4):365–370. https://doi.org/10.3139/120.111492
40. Meng Z, Li G, Wang X, Sait SM, Yıldız AR (2020) A comparative study of metaheuristic algorithms for reliability-based design optimization problems. Arch Comput Methods Eng. https://doi.org/10.1007/s11831-020-09443-z
41. Jin R, Du X, Chen W (2003) The use of metamodeling techniques for optimization under uncertainty. Struct Multidiscip Optim 25(2):99–116. https://doi.org/10.1007/s00158-002-0277-0
42. Wang GG, Shan S (2007) Review of metamodeling techniques in support of engineering design optimization. J Mech Des 129(4):370–380. https://doi.org/10.1115/1.2429697
43. Zhou M, Pagaldipti N, Thomas HL, Shyy YK (2004) An integrated approach to topology, sizing, and shape optimization. Struct Multidiscip Optim 26(5):308–317. https://doi.org/10.1007/s00158-003-0351-2
44. Saremi S, Mirjalili S, Lewis A (2017) Grasshopper optimisation algorithm: theory and application. Adv Eng Softw 105:30–47. https://doi.org/10.1016/j.advengsoft.2017.01.004

Quality 4.0 in Research and Development by Using Blockchain Technology

Erhan Baran and Tülay Korkusuz Polat

Abstract Today, the factors affecting the competition between businesses in the global world are increasing more and more over the years. Using the latest technology alone is not enough to stay ahead of the competition. The effect of Research & Development (R&D) activities is quite high in increasing the efficiency of the enterprises in the market. In this study, it is emphasized that using technologies in R&D to increase quality in every activity and every process of the enterprise can provide a more competitive advantage. The concept of Quality 4.0 has been explained and how it can be applied in R&D has been investigated. Blockchain technology is used to store data in R&D. There is no similar study in the literature on Quality 4.0 efficiency in R&D activities. The study is also unique in this respect. In the study, it can be seen that the Quality 4.0 technologies can be used for R&D.

Keywords Research and development · Quality 4.0 · Industry 4.0 · Blockchain technology

1 Introduction

Today, companies attach great importance to improving themselves in order to compete with each other. In order to realize this development, it is very important that the R&D department of the companies work correctly. R&D can be defined as the department where the information in a company is compiled, the knowledge base is increased and it is used to design a new process, system, and applications.

R&D is innovative activities carried out by companies or governments to develop new products or services or to improve existing ones [1]. The first stage in the development of a product or production process takes place in R&D.

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With the developing technologies in R&D studies, the studies have gained speed. With the industrial revolution we are in, Industry 4.0 has also increased the development of technologies. Industry 4.0 technologies can be used in many areas of an enterprise. In this study, it has been focused on which Industry 4.0 technologies can be used for what purposes in R&D. It has been examined how the use of these technologies can increase the quality.

The concept of Industry 4.0 first appeared in Germany in 2011. Inspired by other industrial revolutions, the widespread use of computers in production is based on [2]. Industry 4.0 will provide quite a lot of durability and flexibility in engineering, planning, production, operational and logistics processes [3]. Among the main features of Industry 4.0 are interoperability, virtualization, reproduction, real-time capability, platform-oriented services and modularity [4]. With Industry 4.0, new advanced technologies have started to be used. The main ones of these technologies are; Internet of Things, cloud computing technology, big data and blockchain technology [5]. With the use of technologies, new concepts such as smart factories and smart robots have emerged [6].

With the integration of the use of developing new technologies into production, continuous improvement and increasing business performance in the enterprise has become important. Continuous improvement can be achieved by integrating these technologies into the quality management system. Thus, the concept of Quality 4.0 emerged as a result of this integration. Quality 4.0 can be explained as the use of Industry 4.0 technologies to increase quality performance at every stage of production. The challenges for Quality 4.0 are similar to Industry 4.0. It is necessary to have good digital skills and skills for both. Unlike Industry 4.0, Quality 4.0 is not just a concept for the cost and the amount of output in the production result. It is also a holistic data-oriented approach to the quality of the products, the quality level of all services affecting the products, and the quality of the processes.

In this study, Quality 4.0, which is a new subject has been studied. It is emphasized that using technologies in R&D to increase quality in every activity and every process of the enterprise can provide a more competitive advantage.

2 Quality 4.0

Quality is how well a product or service can meet its features or possible requirements. In order to increase quality, employees must be involved in all stages of the process. [7]. Participation as a team is required at all stages, only the involvement of senior management employees is not enough. Determining a common goal and working in that direction will increase the quality of the business in every process [8].

Quality 4.0 is closely related to Industry 4.0. It shows the digitization of quality and how digital tools can affect technology, processes and people. Changes that occur with digitalization; should be considered as organizational issues that quality work will be associated with to find new sources of data that can be analyzed to provide insights for people, suppliers and customers to do their jobs more efficiently [9].

Industry 4.0 focuses on the use of technologies, but not on how they make a difference to different stakeholders, changes within the organization, and how to get quality work done. Businesses can benefit from a move to Quality 4.0 by being more effective at controlling expenses and allocating resources. Managing expenses and allocating resources will be done more efficiently [10].

By integrating the use of new technologies, which are constantly moving forward, into manufacturing, continuous improvement and increase in business performance have become essential. Continuous improvement can be achieved by integrating these technologies into the quality management system. As a result of this integration, the concept of Quality 4.0 has emerged. Quality 4.0 can be defined as the use of Industry 4.0 technologies to increase quality performance in all processes of production [11].

The challenges for Quality 4.0 are similar to Industry 4.0. It is necessary to have good digital skills and skills for both. Unlike Industry 4.0, Quality 4.0 is not just a concept for the cost and the amount of output in the production result. It is also a holistic data-oriented approach to the quality of the products, the quality level of all services affecting the products, and the quality of the processes.

3 Quality 4.0 in R&D

Research and Development (R&D) is an innovative activity where efforts are made to develop new products and services for businesses or to improve existing ones [12]. Research and development activities constitute the first step in the development of a service or production process [13]. R&D studies can follow a different process for each business. With R&D studies, profit is not made quickly, it is an activity that spreads throughout the process [14]. However, it is very important to launch new products developed in R&D in order for businesses to gain higher income from their market share. Because businesses that cannot design new products or develop their existing products will have difficulty competing with their competitors. With the developing technologies, businesses should constantly renew themselves and increase their quality level. At this point, the concept of Quality 4.0 is encountered in R&D studies. By using the developed services, products or processes in an integrated manner with Industry 4.0 technologies, it will be possible to increase and improve the quality levels. Thanks to Quality 4.0, the efficiency of R&D activities will increase. In general, R&D activities can be examined under three headings. These activities are; basic research is applied research and experimental development [15]. In basic research; Observations are used for research. It is mostly a preliminary work based on experiments and theoretical knowledge. A goal should be set for applied research and an original study should be produced in line with that goal. Unlike the first two activities, experimental development, it includes a systematic study for the development of existing products and the use of the information obtained from research in the production of new products or services.

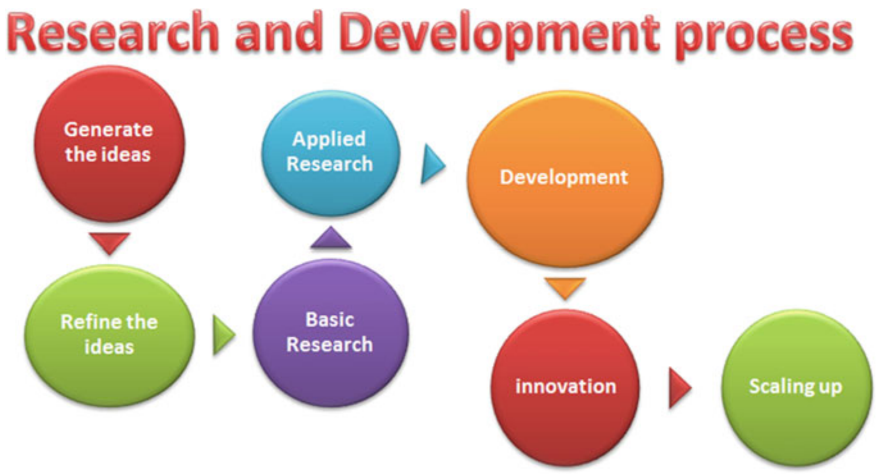

Fig. 1 Process of R&D [16]

An effective system must be created and processes must be classified in order to carry out development studies in R&D. The processes of R&D are given in detail in Fig. 1.

In order to realize the processes, it is necessary to benefit from advanced technologies. With the integration of Industry 4.0 technologies into these processes, the efficiency of R&D activities will also increase. Quality 4.0 is needed to increase the quality of the processes and the developed products. In the first process, it will be possible to make observations and research by using Quality 4.0 technologies in synthesis and theory formation. Big data, internet of things and blockchain technologies can be effective in obtaining and evaluating data at the first stage. In the second stage, in the exploration part, internet of things technology can also have an effect on product-based evaluation. In the third stage, augmented reality technology can be used in the design, development and testing stage. In the fourth stage, big data, cloud technology and blockchain technologies can be used for implementation and improvement. In measuring the effectiveness of the last stage studies, augmented reality technologies with big data can be used to obtain experimental findings. In this study, blockchain technology is chosen to use in the research and development department.

Blockchain technology is a system of storing information in a way that makes it difficult or impossible to modify, hack or cheat the system. A blockchain is essentially a digital ledger of transactions that are incremented and distributed across the entire network of computer systems on the blockchain [17].

As a result, we can group all fields and applications in 4 main ways: [18]

(1) Literally Permissionless Blockchain Networks,
(2) Partially Permissionless Blockchain Networks,
(3) Partially Permissioned Blockchain Networks,

(4) Fully Permitted Blockchain Networks.

The data in blockchain technology is recorded not only by a center or a group of centers, but by everyone involved in the system. For this, these employees do not need to have information about each other, but the rules of the system and the distribution of the record chain produced within these rules are distributed to everyone, not the relationships between the people who provide the trust [19].

All points to which blockchain records are transmitted are in communication with each other, ensuring that the system is working. If a connection is lost or the data log structure is changed, the chain is broken and the system usually removes the point of disconnection from the distributed logging network. Thus, the rest agree on the point that the chain continues without interruption and continues to use the system [20].

Activities in R&D should be carried out with great confidentiality. It is necessary to plan systematically which employees will be informed about the processes. In this privacy, it would be appropriate to use blockchain technology for data security. Blockchain is a technology that can grow as blocks and connect these blocks together with its cryptographic structure [21]. This structure is shown below in Fig. 2 [22].

Each of the blocks in the blockchain contains a cipher summary of the previous block. All transaction data and time frames are included. Once a blockchain is created, data is very difficult to change. Because it is not allowed to change the blocks retrospectively [23].

Technologies that can be used for Quality 4.0 can be adapted to R&D. It is necessary to use blockchain technology for information security and secure access to this information, which is one of the most important elements for studies in R&D. With Blockchain technology, the control of departments in the enterprise where other technologies are used can also be performed. Interactions of blockchain technology are shown in Fig. 3 [24].

Research and development (R&D) is the creation of new knowledge of existing products or processes or the creation of an entirely new product. This is systematic

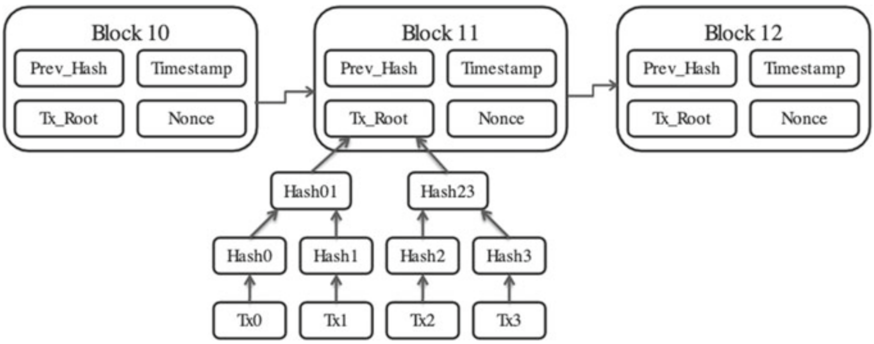

Fig. 2 Structure of Blockchain [22]

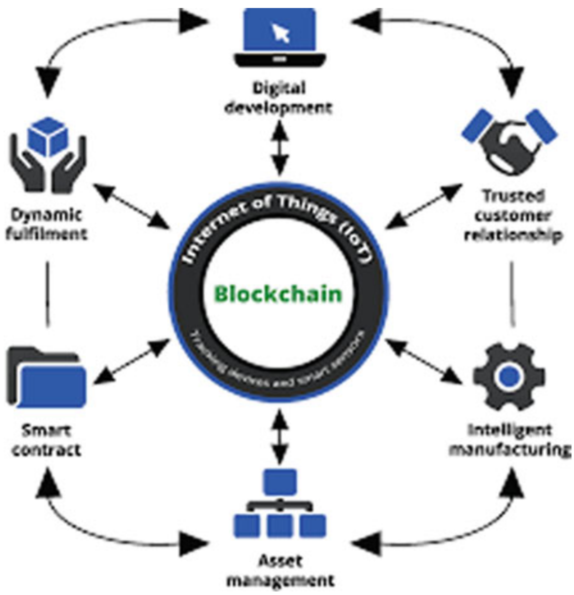

Fig. 3 Blockchain Technology [15]

creative work and the new knowledge discovered is then used to formulate new materials or all new products and to modify and improve existing ones [25].

Research and Development is used to achieve two main objectives:

(1) Launching a new product
(2) To reveal new scientific and technical knowledge.

R&D engineers design and test product concepts and also revise existing products. They may work in a variety of industries where they collaborate with R&D personnel on product design concepts, develop new products, and redesign existing products to industry standards [26].

In this study, the blockchain structure has five components that exhibit a degree of interconnectedness and would assist in creating a blockchain-based R&D system that can be examined in future research. The structure is shown in Fig. 4.

Registered transactions in Research and Development are now created and managed at multiple levels through networks with partner industries such as smart devices, collaborating vendors and innovators, materials evaluation and research. They act as key inputs to the architecture of the blockchain system and must be managed in accordance with legal and regulatory guidelines. With the integration of newer technologies, such as smart devices for monitoring team metrics, future research needs to focus on managing such data sources to improve the comprehensiveness of R&D record databases.

As blockchain technology advances, we will witness noticeable changes and advances in the factors whose architecture is incorporated into the blockchain system.

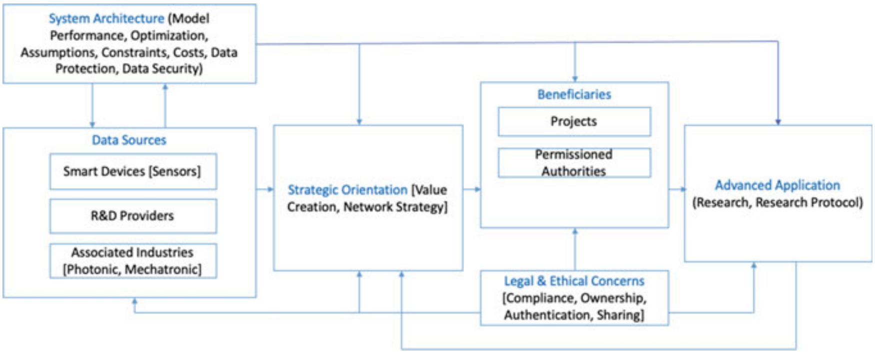

Fig. 4 Blockchain Structure

Future work should focus on developing strategies to control advanced system architectures, especially with regard to issues that may affect performance and efficiency, such as node control and key transport techniques.

Based on the studies, we reveal whether blockchain will be a value creation or value enhancement technology and how it should be implemented by addressing the specific issues identified in this study. These include strategic issues such as resource constraints and technical details such as performance uncertainty and system requirements.

Blockchain-based databases can bring the necessary documentation for those who hold ownership of their personal data, the definitive beneficiary on the R&D bill. It should be able to explain the perspectives of educators and designers that are not included in a blockchain-based system. It may be suitable for simple use and may be easy to use.

4 Conclusion

Businesses must be in continuous development in order to increase their market share. Taking advantage of the technologies brought by Industry 4.0, the industrial revolution we are in, to ensure continuous improvement, will accelerate the development of enterprises. However, it is necessary to increase not only the improvement of product development but also the improvement of processes and product quality. In this study, it was emphasized that Quality 4.0 should be integrated into R&D activities in order to achieve this goal. Quality 4.0 will not only increase the quality of businesses in terms of management but also increase the quality of products. It has been determined as to which Quality 4.0 technology can be effective in the R&D stages. This study can be a guide to researchers for the effective use of technologies in R&D activities. In the study, "Blockchain Technology", one of the Quality 4.0 technologies, was used. Data transfer between employees in R&D processes has been carried out more securely with the special cryptographic structure of Blockchain. With the use of Blockchain Technology in R&D, R&D activities will become closed to external intervention and cannot be changed. The data will not be linked to any center or individual. People who are authorized to share data will have access with a password. Information about the blocks can be distributed to all people on the network in the desired way. Due to the transparency of the blockchain system, blocks can be examined when desired. Nobody will be able to know which employee has access to how much information.

References

1. Staff Investopedia (2017) Research and Development-R&D. Investopedia
2. Banger G (2016) Endüstri 4.0 ve akıllı işletme. Dorlion Yay, Ankara
3. Acatech (2013) Acatech: recommendations for implementing the strategic
4. Schwab K (2016) Dördüncü sanayi devrimi. Çev.:Zülfü Dicleli, Optimist Yay, İstanbul
5. Ghobakhloo M (2020) Industry 4.0, digitization, and oppurtinities for sustainability. J Clean Prod 252:119869
6. Büchi G, Cugno M, Castagnoli R (2020) Smart factory performance and industry 4.0. Technol Forecast Soc Chang 150:119790
7. Budianto A (2019) Customer loyalty: quality of service. J Manag Rev 3(1):299–305
8. Othman I, Ghani SNM, Choon SW (2020) The total quality management (TQM) journey of Malaysian building constractors. Ain Shams Eng J 11:697–704
9. Kauffman R, Dougles Z, (1993) Quality management plus. The Continous Improvement of Education Press
10. Barreto L, Amaral A, Pereira T (2017) Industry 4.0 implications in logistics: an overview. Procedia Manuf 13:1245–1252
11. Baumann Z (1999) Küreselleşme-Toplumsal Sonuçları. çev. A. Yılmaz, İstanbul
12. Ortega-Argiles R, Potters L, Vivarelli M (2011) R&D and productivity: testing sectoral peculiarities using micro data. Empir Econ 41(3):817–839
13. Ortega-Argiles R, Piva M, Vivarelli M (2011) Productivity gains from R&D investment: are high-tech sectors still ahead? IZA Discuss Pap 5975:1–22
14. Chiesa V (2001) R&D strategy and organisation. Imperial College Press
15. Javaid M, Haleem A (2019) Industry 4.0 applications in medical field: a brief review. Curr Med Res Pract 9(3):102–109
16. Research ad Evaluation on Education in Science and Engineering (REESE) (2009) NSF 09–601, National Science Foundation
17. Risius M, Spohrer K (2017) A blockchain research framework. Business & information systems engineering, pp 1–25
18. Chen G, Xu B, Lu M, Chen NS (2018) Exploring blockchain technology and its potential applications for education. Smart Learn Environ 5(1)
19. Ducas E, Wilner A (2017) The security and financial implications of blockchain technologies: regulating emerging technologies in Canada. Int J 72(4):538–562
20. Nakamoto S (2017) Bitcoin: a peer-to-peer electronic cash system
21. Morris DZ (2016) Leaderless, blockchain-based venture capital fund raises $100 million, and counting. Fortune
22. Wander M (2013) Graphic of data fields in bitcoin blockchain. Creative Commons Attribution-Share Alike 3.0
23. Narayanan A, Bonneau J, Felten E, Miller A, Goldfeder S (2016) Bitcoin and cryptocurrency technologies: a comprehensive introduction. Princeton University Press, Princeton
24. Subic A, Xiang Y, Pai S, De La Serve E (2018) Blockchain and industry 4.0. Swinburne University, Capgemini

25. Vieira AAC, Dias LMS, Santos MY, Pereira GAB, Oliveira JA (2018) Setting an industry 4.0 research and development agenda for simulation–a literature review. Int J Simul Model 17(3):377–390
26. Hall BH, Lerner J (2009) The financing of research and development and innovation. National Bureau of Economic Research