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Assessment of Material Selection Problem for Aircraft Parts Using the GRA method

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Abstract. *Composites can simultaneously enhance materials and designs while having superior mechanical qualities. Composites can have notably better "strength, stiffness, corrosion, wear, and fatigue resistance" than typical composites, which is important for developing aviation constituent parts. The mechanical qualities of the composite fabric must be crafted to fit its intended application or the exploited circumstances. For "the manufacture of aeroplanes", many metals and synthetic fibres are preferred today. Thousands of people of polymers must be chosen by engineers, but only 0.05 per cent of those may be used in the aerospace sector and still have the desired properties. The choice of proper raw materials from tens of thousands of components has grown to be a significant problem. In a "Multi-criteria decision-making (MCDM)" situation, the optimal material for an aeroplane must be selected from a range of alternatives. The finest components for aeroplane parts are chosen in this study using strategies focused on "the Grey Relational Analysis (GRA) method". rank for Al 2024-T3 is 8, Al 2524-T3 is 1, Al 5052-H32 is 6, Al 6061-T6 is 7, Al 7075-T6 is 5, AISI 4130 is 2, Ti-6Al-4V is 3 and AZ31B is 4. The ranking order is "Al 2524-T3 > AISI 4130 > Ti-6Al-4V > AZ31B > Al 7075-T6 > Al 5052-H32 > Al 6061-T6 > Al 2024-T3". "Aluminum alloy (Al 2524-T3) and steel alloy (AISI 4130)" were discovered to be the first two most appropriate components for aircraft parts, respectively, per the GRA technique.*
Keywords: *Composites, Aircraft Wings, Natural Fibres, Material Selection, Multi-Criteria, MCDM.*

1. INTRODUCTION

In recent years, it has been revealed that biopolymers can be used in a variety of technological fields. The polymers' capacity to degrade is most likely what is to blame. Natural fibre's worth can be demonstrated in its minimal price and simplicity of processing. When contrasted with their individual properties, fibre-reinforced polymer composites have indeed been found to have more advantages than traditional materials. These eco-friendly composite materials are used in many aerospace industries and related fields [1]. The use of natural fibre composites has some advantages, but there are not only some drawbacks that have an impact on implementations in the aeronautics and automobile industries. These drawbacks include "gradual uptake of water, reduced fire resistance, microbe infection, low-temperature limitations, poor mechanical properties, and, most importantly, price fluctuations during the annual harvest" [2]. Existing research has demonstrated that the integrity of natural fibres can be enhanced for better fibre matrix adhesion by applying chemical methods, such as surface therapy. Additionally, natural fibre composites can suit human demands and offer appealing ecological and economic perspectives. Green fibre composites have a lot of potential applications in the automotive and aerospace industries [3]. "The suitable selection of volume concentration, fibre orientation, layer sequence, and fibre distribution in the matrix" greatly influences the mechanical characteristics of fibre-reinforced polymer composite. As a result, a sturdy and lightweight material is produced that can be used in a variety of fields, including construction management. It is well recognised that the aviation industry is the dominant sector with the execution of innovative materials, and two different methods are being used in the advancement of aerospace applications [4]. Whereas the second alternative suggests the use of recently discovered synthetic structures, the first method, which is favoured by many scientists, focuses on the enhancement of current materials and techniques. The materials used in the construction of aircraft components must be strong and stiff enough to support the expected load. To guarantee the secure and lengthy usage of aircraft structures, an accurate assessment of composites' mechanical properties is crucial [5]. It is generally accepted that the fabrication processes used to produce natural fibre composites require a shorter time, requires fewer resources, and put less strain on the equipment than those used to produce synthetic fibre composites in the aircraft and automotive industries. When particularly in comparison to natural fibre composites, the costs of producing synthetic fibre composites rises by more than 30% [6]. In aerospace applications, "titanium alloys" are economical and provide fuel savings due to their unique physical and mechanical characteristics. Whenever different "temperatures and other service circumstances" are taken into account, it also exhibits distinctive characteristics. Titanium is employed in many different areas of an aircraft because of all these benefits [7]. Although their consumption rates are declining, aluminium-based alloys continue to be the most popular materials in airline materials. Compared to "steel and titanium", they are lightweight alloys. Super strength Aluminum alloys have been created thanks to the effects of various alloying components and thermal treatment, even when "the mechanical and physical properties of pure aluminium" are not at the acceptable level [8]. Additionally, "alloying uses magnesium". Mg alloys' rigidity and shock-absorbing qualities are important in material choice. Additionally, because magnesium alloys have a very lower density, they are lightweight. The use of synthetic structures in the aviation industry has increased recently. " The high strength, high elastic modulus, and lightweight" are to blame for this [9]. This will not be appropriate to utilise the very same fabric in each area of the aircraft due to the loads on it and potential flight hazards (bird strikes, etc.). For instance, there are variations in the loads applied to "the wings, fuselage, and nose". In addition to "static loads, dynamic loads" will also be applied to the wings throughout flying [10]. The nose, meanwhile, cannot be discussed to the very same dynamic response. Engineers often have trouble deciding the material to employ for a particular aeroplane component. At about this point, among the potential materials that can demonstrate the desired level of performance, the best choice can be made using "multi-criteria decision-making (MCDM) methodologies". The versatility and resilience of MCDM approaches allow them to handle a variety of selection difficulties [11]. The fabric that satisfies the preferred physicochemical characteristics at the best rate can be identified by a variety of MCDM processes depending on the character traits of the choice of suitable materials. As a result, technicians will be able to choose the best material before wasting time and money on time-consuming and costly methods like development and testing and different mechanical experiments [12].

2. MATERIALS AND METHODS

One approach to examining uncertainty that performs best at arithmetically assessing systems with sketchy insights is called "The grey system concept". " The grey system concept" states that while a black scheme has all of the knowledge unsure, a white system seems to have all the accessible information [13]. "A grey system" is one that only has the least part of recognised details. " Grey relational analysis (GRA), grey decision, grey programming, and grey control" are the five main components of the grey systems approach. GRA is part of the grey systems approach, which helps tackle challenges with intricate interconnections between various components and quantities [14]. Therefore, the GRA technique has been extensively employed to address uncertainty issues arising from discontinuous data and partial knowledge. Additionally, the GRA approach is one of the most widely used techniques for examining numerous associations between discrete data collections and for making conclusions when dealing with several attributes. The main benefits of the GRA technique are that it is some of the best ways to make judgments in a corporate context, the computations are easy to understand, and the conclusions are dependent on the raw data [15]. Widespread use of "Deng's (1982) grey systems approach" in a variety of domains. It has been demonstrated to be practical for coping with inaccurate, insufficient, and ambiguous info. " Grey relational analysis (GRA)" is a branch of the grey systems approach, which can be used to solve issues involving complex interactions between several different elements and elements [16]. Numerous MADM issues, including "hiring decisions (Olson & Wu, 2006), restoration planning for power distribution systems (Chen, 2005), an inspection of integrated-circuit marking processes (Jiang, Tasi, & Wang, 2002), modelling of quality function deployment (Wu, 2002), defect detection in silicon wafer slicing (Lin et al., 2006)", etc., have been effectively addressed by the use of GRA [17]. By incorporating all of the achievement similarity measures taken into account for each option into a fixed value, GRA can help address MADM troubles. As a result, the original issue is reduced to a judgement issue involving a single attribute. As a result, following the GRA procedure, solutions with numerous characteristics can be simply evaluated [18]. Furthermore, a comparison sequence is created by converting the behaviour of each possibility into the primary step of GRA. The term "grey relational generating" refers to this phase. Based on those sequences, "a standard sequence (ideal target sequence)" is defined. Finally, the grey relational correlation between all similarity variants and the benchmark pattern is determined [19]. "The grey relational grade" between each comparable pattern and the benchmark pattern is then generated based on those "grey relational coefficients". The optimal variant will be the one whose converted comparable sequence has the greatest grey relational grade among "the reference sequence and itself" [20].

Step 1. Design of decision matrix and weight matrix

For an MCDM problem consisting of "m alternatives and n criteria, let $D = x_{ij}$ be a decision matrix, where $x_{ij} \in R$"

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad 1$$

Step 2. "Normalization of decision matrix"

Formulae 2 and 3 are used, respectively, to analyse whether normalising two data sets is better whenever the higher type is assessed or stronger when the lesser type is. The information after normalisation varies from zero to one.

$$M_{ij} = \frac{N_{ij} - \min(N_{ij})}{\max(N_{ij}) - \min(N_{ij})} \quad 2$$

$$M_{ij} = \frac{\max(N_{ij}) - N_{ij}}{\max(N_{ij}) - \min(N_{ij})} \quad 3$$

Where $i, j = 1,2,3, \cdots, n$

Step 3. "$Deviation = the \max value\ after\ normalization - value\ of\ the\ current\ row$" 4

Step 4. Computation of "Gray relation coefficient"

$$C_{ij} = \frac{\Delta_{min} - \xi\Delta_{max}}{Current\ value - \xi\Delta_{max}}, where\ zeta\ (\xi)\ is\ distinguishing\ coefficient \quad 5$$

Step 5. Computation of "Gray relation grade"

It represents the Gray Relation Coefficient on averages. After that, options are ordered using the "Gray Relation Coefficient's average" [21,22]. "While takeoff, flight, landing, and taxiing", aircraft are subjected to a variety of loads. " The aircraft's wings and nose" are also subjected to various stress and strain. Consequently, the requirements are established by taking into account the loads and obstacles that an aeroplane may experience during delivery and by reviewing the related kinds of literature for the choice of materials for "aeroplane nose and wings", which have been the topics of this study. "Density, cost, tensile strength, fatigue, thermal expansion, modulus of elasticity, and percentage elongation" are the established criteria for analysis. " Density and cost" have minimum desirable values, whereas the other factors have minimum desirable values. Taking into account the aforementioned material characteristics, the following options were selected: "aluminium alloys (Al 2024-T3, Al 2524-T3, Al 5052-H32, Al 6061-T6, and Al 7075-T6), steel alloy (AISI 4130), titanium alloy (Ti-6Al-4V) and magnesium alloy (AZ31B)".

3. ANALYSIS AND DISCUSSION

TABLE 1. Quantitative data for alternative materials

Materials	TS [MPa]	E [GPa]	%EL	S [MPa]	αl [10^{-6} °C]	C [$US/kg]	D [g/cm^3]
Al 2024-T3	485	72.4	18	143	23.6	16	2.77
Al 2524-T3	483	73.1	18	138	24.1	3.01	2.78
Al 5052-H32	228	70.3	18	117	23.7	4.98	2.68
Al 6061-T6	310	69	17	95	23.6	7.55	2.7
Al 7075-T6	572	71	11	160	23.4	13	2.8
AISI 4130	560	209	28	285	12.3	1.95	7.85
Ti-6Al-4V	900	114	14	548	8.6	105	4.43
AZ31B	290	45	15	110	26	36.8	1.77

Table 1 shows the initial decision matrix for Quantitative data for alternative materials for aircraft nose and wing. Here we consider ten materials "(Al 2024-T3, Al 2524-T3, Al 5052-H32, Al 6061-T6, and Al 7075-T6, AISI 4130, Ti-6Al-4V and AZ31B" as alternate. After consideration, "Density (D), Cost [C], Tensile Strength (TS), Fatigue (S), Thermal Expansion (αl), Modulus of Elasticity € and Percentage Elongation (%EL)" is to be used as evaluation parameters for aircraft parts material selection. Here "Tensile Strength (TS), Fatigue (S), Thermal Expansion (αl), Modulus of Elasticity € and Percentage Elongation (%EL)" are beneficial criteria. "Density and Cost" are taken as non-beneficial criteria.

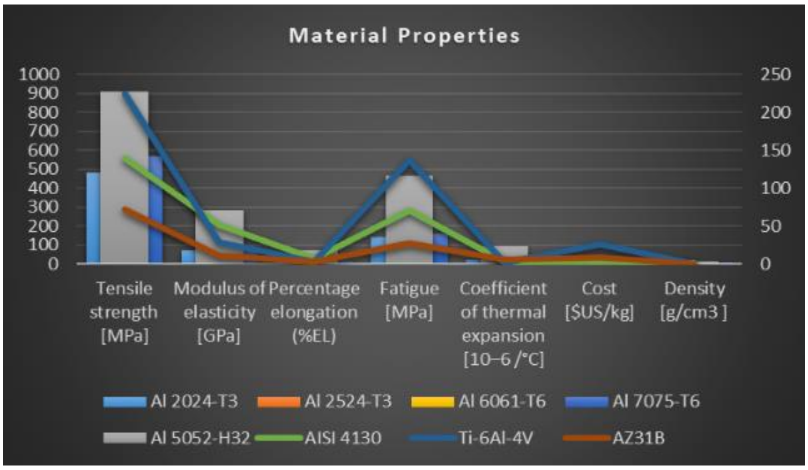

FIGURE 1. Quantitative data for alternative materials

Figure 1 illustrates the initial decision matrix for Quantitative data for alternative materials for aircraft nose and wing. Here we consider ten materials "(Al 2024-T3, Al 2524-T3, Al 5052-H32, Al 6061-T6, and Al 7075-T6, AISI 4130, Ti-6Al-4V and AZ31B" as alternate. After consideration, "Density (D), Cost [C], Tensile Strength (TS), Fatigue (S), Thermal Expansion (αl), Modulus of Elasticity € and Percentage Elongation (%EL)" is to be used as evaluation parameters for aircraft parts material selection. Here "Tensile Strength (TS), Fatigue (S), Thermal Expansion (αl), Modulus of Elasticity € and Percentage Elongation (%EL)" are beneficial criteria. "Density and Cost" are taken as non-beneficial criteria.

TABLE 2. Normalized matrix

0.3824	0.1671	0.1060	0.8621	0.8637	0.8355
0.3795	0.1713	0.0949	0.8908	0.9897	0.8339
0.0000	0.1543	0.0486	0.8678	0.9706	0.8503
0.1220	0.1463	0.0000	0.8621	0.9457	0.8470
0.5119	0.1585	0.1435	0.8506	0.8928	0.8306
0.4940	1.0000	0.4194	0.2126	1.0000	0.0000
1.0000	0.4207	1.0000	0.0000	0.0000	0.5625
0.0923	0.0000	0.0331	1.0000	0.6618	1.0000

Table 2 shows the normalized array for material properties of alternative materials for aircraft wings and noses. This is calculated using equation 2 for beneficial criteria ("Tensile Strength (TS), Fatigue (S), Thermal Expansion (αl), Modulus of Elasticity € and Percentage Elongation (%EL)") and equation 3 for non-beneficial criteria ("Density and Cost").

TABLE 3. Deviation sequence

0.6176	0.8329	0.8940	0.1379	0.1363	0.1645
0.6205	0.8287	0.9051	0.1092	0.0103	0.1661
1.0000	0.8457	0.9514	0.1322	0.0294	0.1497
0.8780	0.8537	1.0000	0.1379	0.0543	0.1530
0.4881	0.8415	0.8565	0.1494	0.1072	0.1694
0.5060	0.0000	0.5806	0.7874	0.0000	1.0000
0.0000	0.5793	0.0000	1.0000	1.0000	0.4375
0.9077	1.0000	0.9669	0.0000	0.3382	0.0000

Table 3 shows the Deviation sequence matrix for material properties of alternative materials for aircraft nose and wing. This value is calculated using equation 4, that is Maximum value of the column of normalized value is subtracted from the current value of the normalized matrix.

TABLE 4. Grey Relation Coefficient

0.4474	0.3751	0.3587	0.7838	0.7857	0.7525
0.4462	0.3763	0.3559	0.8208	0.9798	0.7506
0.3333	0.3715	0.3445	0.7909	0.9445	0.7696
0.3629	0.3694	0.3333	0.7838	0.9020	0.7657
0.5060	0.3727	0.3686	0.7699	0.8234	0.7469
0.4970	1.0000	0.4627	0.3884	1.0000	0.3333
1.0000	0.4633	1.0000	0.3333	0.3333	0.5333
0.3552	0.3333	0.3409	1.0000	0.5965	1.0000

Table 4 shows the Grey Relation Coefficient matrix for material properties of alternative materials for aircraft parts. This value is calculated using equation 5 and the zeta value is 0.5. Table 3 Deviation sequence matrix is for calculating Grey Relation Coefficient.

TABLE 5. Grey Relation Grade

Materials	GRG
Al 2024-T3	0.58386
Al 2524-T3	0.62160
Al 5052-H32	0.59239
Al 6061-T6	0.58617
Al 7075-T6	0.59793
AISI 4130	0.61358
Ti-6Al-4V	0.61055
AZ31B	0.60432

Table 5 shows the Grey Relation Grade value for alternate materials taken for this paper. Its average values of the Grey Relation Coefficient using table 4. Here Grey Relation Grade value for Al 2024-T3 is 0.58386, Al 2524-T3 is 0.62160, Al 5052-H32 is 0.59239, Al 6061-T6 is 0.58617, Al 7075-T6 is 0.59793, AISI 4130 is 0.613581, Ti-6Al-4V is 0.61055 and AZ31B is 0.60432.

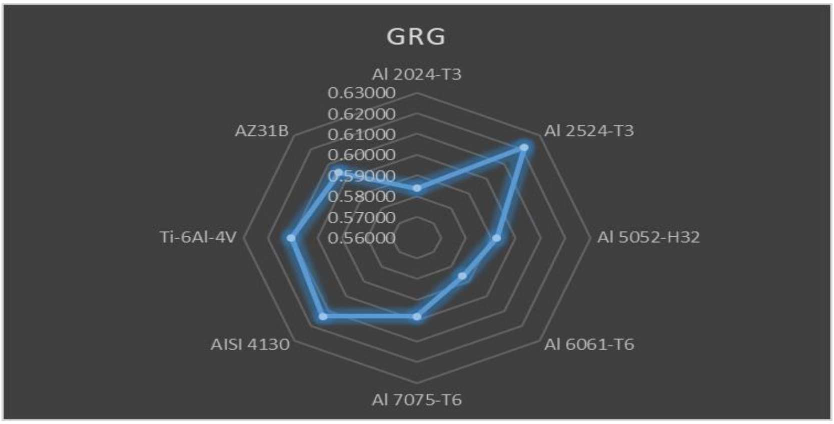

FIGURE 2. Grey Relation Grade

Figure 2 shows the graphical representation of the Grey Relation Grade value for alternate materials taken for this paper. Its average values of the Grey Relation Coefficient using table 4. Here Grey Relation Grade value for Al 2024-T3 is 0.58386, Al 2524-T3 is 0.62160, Al 5052-H32 is 0.59239, Al 6061-T6 is 0.58617, Al 7075-T6 is 0.59793, AISI 4130 is 0.613581, Ti-6Al-4V is 0.61055 and AZ31B is 0.60432.

TABLE 6. The rank

Materials	Rank
Al 2024-T3	8
Al 2524-T3	1
Al 5052-H32	6
Al 6061-T6	7
Al 7075-T6	5
AISI 4130	2
Ti-6Al-4V	3
AZ31B	4

Table 5 shows the rank of the alternate materials taken for this paper by ranking Grey Relation Grade values using table 5. Here rank for Al 2024-T3 is 8, Al 2524-T3 is 1, Al 5052-H32 is 6, Al 6061-T6 is 7, Al 7075-T6 is 5, AISI 4130 is 2, Ti-6Al-4V is 3 and AZ31B is 4. The ranking order is “Al 2524-T3 > AISI 4130 > Ti-6Al-4V > AZ31B > Al 7075-T6 > Al 5052-H32 > Al 6061-T6 > Al 2024-T3”.

FIGURE 3. The rank of alternate materials

Figure 3 shows a graphical representation of the alternate materials taken for this paper by ranking Grey Relation Grade values using table 5. Here rank for Al 2024-T3 is 8, Al 2524-T3 is 1, Al 5052-H32 is 6, Al 6061-T6 is 7, Al 7075-T6 is 5, AISI 4130 is 2, Ti-6Al-4V is 3 and AZ31B is 4. The ranking order is “Al 2524-T3 > AISI 4130 > Ti-6Al-4V > AZ31B > Al 7075-T6 > Al 5052-H32 > Al 6061-T6 > Al 2024-T3”. "Aluminum alloy (Al 2524-T3) and steel alloy (AISI 4130)" were discovered to be the first two most acceptable materials for aeroplane noses, correspondingly, as per the GRA technique.

4. CONCLUSION

In recent times, the globalization of people and cultures has been facilitated by the growth of the air transportation industry. The impact of aero planes "on emissions and global warming", which are two of the biggest issues facing us presently and, in the future, cannot be refuted when taking into account the percentage of aircraft travel and total energy demand. The global aviation industry is responsible for around 2.5% of all carbon dioxide emissions caused by humans. These pollutants are anticipated to rise by 300 per cent, far quicker than anticipated, as this segment, which transported 2.4 billion travelers in 2010, is predicted to transit 16 billion people in 2050. The importance and complexity of the choice of composites in the aviation industry have increased along with materials variety. An aeronautical engineer can select from more than 120,000 raw materials, according to estimates, for the motor and aerostructures. With the creation of new metals or the enhancement of existing materials' qualities, this quantity is growing. Between all these components, composites including "GFRP, CFRP, and sandwich composites, as well as steel and Al, Ti, and Mg alloys", distinguish noteworthy. The optimum materials for "aviation wings and the nose" were chosen for this study using a process known as "the Grey Relational Analysis (GRA) method". "Aluminum alloy (Al 2524-T3) and steel alloy (AISI 4130)" were discovered to be the first two more acceptable materials for aeroplane noses, respectfully, per the GRA technique.

REFERENCE

[1]. Khan, Tabrej, Mohamed Thariq Bin Hameed Sultan, and Ahmad Hamdan Ariffin. "The challenges of natural fibre in manufacturing, material selection, and technology application: A review." *Journal of Reinforced Plastics and Composites* 37, no. 11 (2018): 770-779.

[2]. Calado, Elcin Aleixo, Marco Leite, and Arlindo Silva. "Selecting composite materials considering cost and environmental impact in the early phases of aircraft structure design." *Journal of Cleaner Production* 186 (2018): 113-122.

[3]. Kastratović, Gordana, Aleksandar Grbović, Aleksandar Sedmak, Ž. Božić, and Simon Sedmak. "Composite material selection for aircraft structures based on experimental and numerical evaluation of mechanical properties." *Procedia Structural Integrity* 31 (2021): 127-133.

[4]. Hao, Xuelong, Chen Wen, Ning Zhao, Lu Lu, Kai Zhang, and Donghui Zhang. "Prototype of an Expert System for the Selection of Aircraft Structural Materials." *International Journal of Photoenergy* 2020 (2020): 1-7.

[5]. Jawalkar, C. S., and Suman Kant. "A review on use of aluminium alloys in aircraft components." *i-Manager's Journal on Material Science* 3, no. 3 (2015): 33.

[6]. Huda, Zainul, and Prasetyo Edi. "Materials selection in design of structures and engines of supersonic aircrafts: A review." *Materials & Design* 46 (2013): 552-560.
[7]. Singh, Paramjit, Harish Pungotra, and Nirmal S. Kalsi. "On the characteristics of titanium alloys for the aircraft applications." *Materials today: proceedings* 4, no. 8 (2017): 8971-8982.
[8]. Lan, Yuanpei, Zhidong Guan, Qixiang Jiao, and Guangxing Xu. "A web-based computer-aided material-selection system for aircraft design." In *2010 WASE International Conference on Information Engineering*, vol. 3, pp. 109-113. IEEE, 2010.
[9]. Hodonou, C., M. Balazinski, M. Brochu, and C. Mascle. "Material-design-process selection methodology for aircraft structural components: application to additive vs subtractive manufacturing processes." *The International Journal of Advanced Manufacturing Technology* 103 (2019): 1509-1517.
[10]. Schijve, Jaap. "Fatigue damage in aircraft structures, not wanted, but tolerated?" *International Journal of Fatigue* 31, no. 6 (2009): 998-1011.
[11]. Yavuz, Hande. "Materials selection for aircraft skin panels by integrating multiple constraints design with computational evaluations." *Procedia Structural Integrity* 21 (2019): 112-119.
[12]. Boyacı, Aslı Çalış, and Mehmet Çağrı Tüzemen. "Multi-criteria decision-making approaches for aircraft-material selection problem." *International Journal of Materials and Product Technology* 64, no. 1 (2022): 45-68.
[13]. Sallehuddin, Roselina, Siti Mariyam Hj Shamsuddin, and Siti Zaiton Mohd Hashim. "Application of grey relational analysis for multivariate time series." In *2008 Eighth International Conference on Intelligent Systems Design and Applications*, vol. 2, pp. 432-437. IEEE, 2008.
[14]. Suvvari, Anandarao, and Phanindra Goyari. "Financial performance assessment using Grey relational analysis (GRA): An application to life insurance companies in India." *Grey Systems: Theory and Application* (2019).
[15]. Wu, Hsin-Hung. "A comparative study of using grey relational analysis in multiple attribute decision making problems." *Quality Engineering* 15, no. 2 (2002): 209-217.
[16]. Yüksel, Serhat, Hasan Dinçer, and Şenol Emir. "Comparing the performance of Turkish deposit banks by using DEMATEL, Grey Relational Analysis (GRA) and MOORA approaches." *World Journal of Applied Economics* 3, no. 2 (2017): 26-47.
[17]. Liang, Z. H. O. U., Tai-hua MU, Ruo-fang ZHANG, Qing-hua SUN, and Yan-wen XU. "Nutritional evaluation of different cultivars of potatoes (Solanum tuberosum L.) from China by grey relational analysis (GRA) and its application in potato steamed bread making." *Journal of integrative agriculture* 18, no. 1 (2019): 231-245.
[18]. Huang, Sun-Jen, Nan-Hsing Chiu, and Li-Wei Chen. "Integration of the grey relational analysis with genetic algorithm for software effort estimation." *European Journal of Operational Research* 188, no. 3 (2008): 898-909.
[19]. Škrinjarić, Tihana. "Dynamic portfolio optimization based on grey relational analysis approach." *Expert systems with applications* 147 (2020): 113207.
[20]. Xu, Guoping, Weifeng Tian, Li Qian, and Xiangfen Zhang. "A novel conflict reassignment method based on grey relational analysis (GRA)." *Pattern Recognition Letters* 28, no. 15 (2007): 2080-2087.
[21]. Noorul Haq, A., and G. Kannan. "An integrated approach for selecting a vendor using grey relational analysis." *International Journal of Information Technology & Decision Making* 5, no. 02 (2006): 277-295.
[22]. Yamaguchi, Daisuke, Guo-Dong Li, Kozo Mizutani, Takahiro Akabane, Masatake Nagai, and Masatoshi Kitaoka. "On the generalization of grey relational analysis." *Journal of Grey System* 9, no. 1 (2006): 23-33.
[23]. Santos, Celise Villa dos, Daniel Rodrigo Leiva, Fábio Rodrigues Costa, and José Angelo Rodrigues Gregolin. "Materials selection for sustainable executive aircraft interiors." *Materials Research* 19 (2016): 339-352.

