Grey Relational Analysis Approach In Academic Performance Comparison Of University: A Case Study Of Turkish Universities

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Abstract

Universities, serve humanity with either the people that educate or their scientific activities. Therefore, students for a quality education and better career and scientists for the advancement of humanity by contributing to the science world need to prestigious universities. To be considered as a reputable university it must be one of the best performing universities in the area. Each year, the data about the ranking of universities are published and shared by various organizations, as worldwide or regional. Grey System theory, has been used successfully in cases where uncertainty or partial information exists. Grey Relational Analysis (GRA) is a part of Grey System theory. In this method, the correlation between reference sequence and comparability sequences is obtained and then ranking is made according to this correlation. In the study 10 Turkish University were analyzed with Grey Relational Analysis and the results of this method were interpreted.

Keywords: Performance Measurement, Education, Grey Relational Analysis, Multi Criteria Decision Making

Introduction:

If any living or any organization wants to survive in an environment where resources are scarce, it must be better than its competitors. It is also possible perform better. However, few people can agree on what that means for performance. The term of performance can have a different meaning from the efficiency, to robustness, resistance or the return on investment (Lebas, 1995: 23). Whereas a system's performance is analyzed, quantitative performance measurement are preferred to the qualitative assessments because of the uncertainty and difficulties (Beamon, 1999: 275).

Performance measurement is a term which contains program input, output, intermediate outcomes and end outcomes (Newcomer, 1997: 7). In this study performance of universities is compared so that, it will be useful that looking from organization's aspect. When asked why an organization needs to measure performance, the answer may be as identifying success, whether customer needs are met or not, understanding its processes, the ability to determine where the problem or the bottleneck etc. (Parker, 2000: 63). Due to these characteristics, performance measurement is very important for organizations and the executives of the organizations monitor their performance constantly. In literature, the performance of universities is measured with data envelopment analysis (Kuah & Wong, 2011; Warning, 2004), Malmquist indices (Worthington & Lee, 2008), DEMATEL, ANP and VIKOR methods (Wu, Lin & Chang, 2011), financial performance ratios (Pursglove & Simpson, 2007), AHP and VIKOR (Wu, Chen, Chen & Zhuo, 2012) etc. methods. In this study performance comparison was made with Grey Relational Analysis.

Grey Relational Analysis

Grey System theory was introduced to science world in 1982 (Ju-Long, 1982). The systems which lack information, such as structure message, operation mechanism and behavior document are referred to as Grey Systems. The goal of Grey System theory and its applications is bridge to the gap existing between social science and natural science. So that it can be said that Grey System theory is interdisciplinary (Julong, 1989: 1). The "grey" word in the name of the theory can be explained as characteristic between black and white. Hereby, "black" means needed information is not exactly available, conversely "white" means needed information is exactly available. "Grey" system proposition establishes a connection between black with white. With the established connection, correct properties of systems are discovered under poorly-informed situations. Therefore, Grey System theory seeks only the intrinsic structure of the system given such limited data (Huang, Chiu & Chen, 2008: 899). Grey System theory has five major components. These are Grey Prediction, Grey Relational Analysis, Grey Decision, Grey Programming and Grey Control (Wei, 2011: 672).

Grey Relational Analysis which used for analyzing relations between the discrete data sets is one of the popular methods. Grey Relational Analysis is also used for decision making in multi attribute cases. The major advantages of Grey Relational Analysis are based on original data, easy calculations and being straightforward and one of the best methods to decide in business environment (Wei, 2011: 672). Grey Relational Analysis compares the factors quantitatively in a dynamic way using information from the Grey System. This approach contacts establish relations among the

factors based on level of similarity and variability (Chang, Tsai & Chen, 2003: 54).

Grey Relational Analysis is used such as areas: behavior effect on energy consumption (Yu, Fung, Haghighat, Yoshino & Morofsky, 2011), decision making with intuitionistic fuzzy methods (Hou, 2010), supplier selection (Yang & Chen, 2006), stock market forecasting and portfolio selection (Huang & Jane, 2009), performance analysis of software project (Song & Shepperd, 2011), e-commerce system safety assessment (Liu, 2011), evaluation of business performance of wealth management banks (Wu, Lin & Tsai, 2010), analyzing of medical data (Xuerui & Yuguang, 2004) etc.

The method proposes theoretically a dependence to measure the correlation degree of factors. Accordingly, this means the more similarity the more factor correlation. Grey Relational Analysis uses Grey Relational grade to measure relation degree of factors (Kung & Wen, 2007: 843). In this respect Grey Relational theory provides efficiently management of uncertainty (Kao & Hocheng, 2003: 256).

Firstly, all alternatives are transformed to a comparability sequence in Grey Relational Analysis. This transformation is called Grey Relational generating. In this step data are normalized and transformed to values in 0-1 interval. Considering this sequence a reference (ideal target) sequence is defined. Then, Grey Relational coefficient is calculated between reference sequence and all comparability sequences. Finally, Grey Relational grade between reference sequence and comparability sequences is calculated according to grey relational coefficient. The highest Grey Relational grade among the alternatives will be the best choice (Kuo, Yang & Huang, 2008: 81; Wei, 2010: 244; Lin, Lin & Ko, 2002: 272). The steps of method are as follows.

Data Preprocessing

In this step, in order to compare correctly the data which have different measurement unit, a transformation operation is made and after this process the data values are obtained in 0-1 interval. $x_0^{(O)}(k)$ and $x_i^{(O)}(k)$ ($i = 1,2,\dots,m; k = 1,2,\dots,n$) ($m$ alternative, n criteria) show that original reference sequence and comparable sequence respectively. Normalization method can be made in four ways (Fung, 2003: 299).

i) If the data have “the larger-the better” characteristic:

$$x_i^*(k) = \frac{x_i^{(O)}(k) - \min x_i^{(O)}(k)}{\max x_i^{(O)}(k) - \min x_i^{(O)}(k)} \quad (1)$$

ii) If the data have “the smaller-the better” characteristic:

$$x_i^*(k) = \frac{\max x_i^{(O)}(k) - x_i^{(O)}(k)}{\max x_i^{(O)}(k) - \min x_i^{(O)}(k)} \quad (2)$$

iii) If there is a target value to be reached for the original data (OB means target value in Eq. 3):

$$x_i^*(k) = 1 - \frac{\left|x_i^{(O)}(k) - OB\right|}{\max\left(\max x_i^{(O)}(k) - OB, OB - \min x_i^{(O)}(k)\right)} \quad (3)$$

iv) Finally, as the simplest method normalization can be made dividing sequence values by the first value of sequence.

$$x_i^*(k) = \frac{x_i^{(O)}(k)}{x_i^{(O)}(1)} \quad (4)$$

Calculating of Grey Relational Coefficient and Grey Relational Grade

After data preprocessing, Grey Relational Coefficient is calculated based on normalized sequences (Yang, 2006: 771).

$$\gamma\left[(x_0^*(k), x_i^*(k)\right] = \frac{\Delta_{\min} + \xi\Delta_{\max}}{\Delta_{0i}(k) + \xi\Delta_{\max}}, \quad 0 < \gamma\left[(x_0^*(k), x_i^*(k)\right] \le 1 \quad (5)$$

Hereby, $\Delta_{0i}(k)$is deviation sequence between $x_0^*(k)$ reference sequence and $x_i^*(k)$ comparable sequence. This deviation sequence is calculated as in Eq. 6.

$$\Delta_{0i}(k) = \left|x_0^*(k) - x_i^*(k)\right| \quad (6)$$

Similarly, the biggest deviation and the smallest deviation are calculated as in Eq. 7 and Eq. 8.

$$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \left|x_0^*(k) - x_j^*(k)\right| \quad (7)$$

$$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \left|x_0^*(k) - x_j^*(k)\right| \quad (8)$$

The term in Eq. 5 ξ is distinguishing coefficient in [0, 1] and its value is usually 0.5 in literature.

Grey Relational grade is weighted sum of Grey Relational coefficients and it can be shown as in Eq. 9.

$$\gamma(x_0^*, x_i^*) = \sum_{k=1}^{n} \beta_k \gamma\left[x_0^*(k), x_i^*(k)\right] \quad (9)$$

$$\sum_{k=1}^{n} \beta_k = 1 \quad (10)$$

In Eq. 9 $\gamma(x_0^*, x_i^*)$ Grey Relational grade represents the level of correlation between the reference sequence and comparable sequences. If two series are identical to each other Grey Relational grade equals to 1. Grey

Relational grade also shows that level of influence applied to reference sequence by comparable sequence.

Performance Indicators of Universities

Details of performance indicators of universities were used in this study as follows.

i) **Article Score for 2014 (AS):** Scientific activities are announced to the scientific world with help of articles carried out in universities. Thus, humanity's knowledge thanks to the finding of these new articles, is cumulatively increasing. In this study data on 2014 were used so that because of 2015 not available.

ii) **Total Citation Score (TC):** Publications of scientists, in scientific terms how innovative or valuable is directly related to the number of citations they receive. For instance, the article *"Control Problems of Grey Systems"* written by Deng Ju-Long in 1982 was cited 3116 times citations by the date this study prepared according to Google Scholar. Therefore, as far as the number of published papers, the number of citations of these articles determine the performance of the universities.

iii) **Total Scientific Document Score (TSD):** As a result of scientific activities carried out in the universities not only the articles but also books, journals, papers and related to artistic activities documents can be obtained. For this reason, these documents are indicator of the performance of universities.

iv) **PhD Student Score (PhD):** One of the important missions of universities is raising equipped people to carry forward the torch of science. These people have the scientific competence with the doctoral programs, they will raise new students and carry out scientific activities.

v) **Lecturer/Student Score (L/S):** In terms of students the performance of universities depends on the quality of the education they take. The most important factor in determining the quality of education is the number of lecturer per student. The higher this ratio, the higher performance of the students will be. Therefore, the ratio is also an indicator of university performance.

Performance Comparison of Turkish Universities with Grey Relational Analysis

Indicators on the performance of Turkish Universities were obtained from the website of Middle East Technical University, University Ranking by Academic Performance (URAP) research laboratory (2016). Performance data of the first 10 universities as shown in Table 1.

Table 1: Performance data on universities

Rank	University	Est. Year	AS	TC	TSD	PhD	L/S	Total
1	U1	1956	167.35	188.66	171.91	183.61	55.83	767.35
2	U2	1967	155.16	159.88	165.24	155.13	69.88	705.3
3	U3	1933	153.51	154.97	157.59	175.13	56.75	697.95
4	U4	1985	169.62	187.63	156	114.17	50.27	677.69
5	U5	1946	146.15	141.29	147.72	184.99	57.17	677.32
6	U6	1944	150.92	149.33	151.09	168.19	55.33	674.88
7	U7	2014	139.72	164.13	136.73	154.8	62.56	657.94
8	U8	1955	147.15	145.92	151.92	144.86	66.44	656.29
9	U9	1982	148.95	136.87	148.14	164.3	53.61	651.87
10	U10	1996	152.49	166.62	157.65	107.95	63.57	648.29

The performance of universities may be misleading to consider the criteria by the total score. Because of the level of development of each university, physical facilities, time difference from the establishment to the present time, the number of staff and number of students can show very large differences. For instance, the first and fourth universities in the ranking show very close performance on AS and TC criteria. But the universities were established in 1956 and 1985 respectively. For this reason the first university has more lecturers and students ahead in total score due to having. Hence, by using Gray Relational Analysis, measuring the correlation between the reference sequence and comparable sequences a different approach will be adopted for the comparison of university performance. Reference sequence and comparable sequences necessary for Grey Relational Analysis are as in Table 2.

Table 2: Reference sequence and comparable sequences

	University	AS	TC	TSD	PhD	L/S
0	Reference Sequence	169.62	188.66	171.91	184.99	69.88
1	U1	167.35	188.66	171.91	183.61	55.83
2	U2	155.16	159.88	165.24	155.13	69.88
3	U3	153.51	154.97	157.59	175.13	56.75
4	U4	169.62	187.63	156	114.17	50.27
5	U5	146.15	141.29	147.72	184.99	57.17
6	U6	150.92	149.33	151.09	168.19	55.33
7	U7	139.72	164.13	136.73	154.8	62.56
8	U8	147.15	145.92	151.92	144.86	66.44
9	U9	148.95	136.87	148.14	164.3	53.61
10	U10	152.49	166.62	157.65	107.95	63.57

There is no standard of what should be the value of the $x_0^{(O)}$ reference sequence shown on university performance indicators in Table 2. Therefore, while creating the reference sequence has benefited from the original values of the comparable sequences. All the criteria have “the larger-the better” characteristic, so that reference sequence values equal to the maximum of the column values.

The data in Table 2 don't allow for comparison because of have measurement differences. For this reason values must be transformed [0, 1] interval by normalization operation. Normalized comparable sequences are shown in Table 3.

Table 3: Normalized comparable sequences

	University	AS	TC	TSD	PhD	L/S
0	Reference Sequence	1.0000	1.0000	1.0000	1.0000	1.0000
1	U1	0.9241	1.0000	1.0000	0.9821	0.2835
2	U2	0.5164	0.4443	0.8104	0.6124	1.0000
3	U3	0.4612	0.3495	0.5930	0.8720	0.3304
4	U4	1.0000	0.9801	0.5478	0.0807	0.0000
5	U5	0.2151	0.0853	0.3124	1.0000	0.3519

Normalized comparable sequences (continued)

6	U6	0.3746	0.2406	0.4082	0.7819	0.2580
7	U7	0.0000	0.5264	0.0000	0.6081	0.6267
8	U8	0.2485	0.1747	0.4318	0.4791	0.8246
9	U9	0.3087	0.0000	0.3243	0.7314	0.1703
10	U10	0.4271	0.5744	0.5947	0.0000	0.6782

The values in Table 2 have "the larger-the better" characteristic, so that normalized values were obtained by using Eq. 1. For instance, AS for U1 $x_1^*(1)$ was calculated as follows.

$$x_1^*(1) = \frac{x_1^{(O)}(1) - \min x_1^{(O)}(1)}{\max x_1^{(O)}(1) - \min x_1^{(O)}(1)} = \frac{167.35 - 139.72}{169.62 - 139.72} = 0.9241$$

Similarly, other values were obtained by Eq. 1. After normalized sequence obtained, firstly the deviation sequence is calculated between reference sequence and comparable sequences to calculate Grey Relational coefficient. The calculated values are as in Table 4.

Table 4: Deviation Sequence

	University	AS	TC	TSD	PhD	L/S
0	Reference Sequence	1.0000	1.0000	1.0000	1.0000	1.0000
1	U1	0.0759	0.0000	0.0000	0.0179	0.7165
2	U2	0.4836	0.5557	0.1896	0.3876	0.0000
3	U3	0.5388	0.6505	0.4070	0.1280	0.6696
4	U4	0.0000	0.0199	0.4522	0.9193	1.0000
5	U5	0.7849	0.9147	0.6876	0.0000	0.6481
6	U6	0.6254	0.7594	0.5918	0.2181	0.7420
7	U7	1.0000	0.4736	1.0000	0.3919	0.3733
8	U8	0.7515	0.8253	0.5682	0.5209	0.1754
9	U9	0.6913	1.0000	0.6757	0.2686	0.8297
10	U10	0.5729	0.4256	0.4053	1.0000	0.3218

The values in Table 4 equal to absolute value of the difference between reference sequence and comparable sequence. For instance, TC for U2 was calculated as follows using Eq. 6.

$$\Delta_{02}(2) = \left|x_0^*(2) - x_2^*(2)\right| = \left|1 - 0.4443\right| = 0.5557$$

When the values of deviation sequence taken from this perspective, the deviation sequence measures the values of comparable sequences how far away to the values of reference sequence. If the value of deviation is close to 1, it is commented that comparable sequence is remote to reference sequence, vice versa if the value of deviation is close to 0, they are close to each other.

Grey Relational coefficients are calculated using Eq. 5, Eq. 7 and Eq. 8 after the deviation sequence obtained. Calculated Grey Relational coefficients are as in Table 5.

Table 5: Grey Relational Coefficients

	University	AS	TC	TSD	PhD	L/S
0	Reference Sequence	1.0000	1.0000	1.0000	1.0000	1.0000
1	U1	0.8682	1.0000	1.0000	0.9654	0.4110
2	U2	0.5083	0.4736	0.7251	0.5633	1.0000
3	U3	0.4813	0.4346	0.5512	0.7962	0.4275
4	U4	1.0000	0.9617	0.5251	0.3523	0.3333
5	U5	0.3891	0.3534	0.4210	1.0000	0.4355
6	U6	0.4443	0.3970	0.4580	0.6963	0.4026
7	U7	0.3333	0.5135	0.3333	0.5606	0.5726
8	U8	0.3995	0.3773	0.4681	0.4898	0.7403
9	U9	0.4197	0.3333	0.4253	0.6506	0.3760
10	U10	0.4660	0.5402	0.5523	0.3333	0.6084

When calculating Grey Relational coefficients, the coefficient ξ in Eq. 5 was chosen as 0.5. As an example to calculating of Grey Relational coefficient PhD for U6 firstly, the biggest deviation and the smallest deviation are needed.

$$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \left|x_0^*(4) - x_j^*(4)\right| = 1$$

$$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \left|x_0^*(4) - x_j^*(4)\right| = 0$$

After that, by the help of Eq. 5, Grey Relational coefficient was calculated as follows.

$$\gamma\left[(x_0^*(4), x_3^*(4)\right] = \frac{\Delta_{\min} + \xi\Delta_{\max}}{\Delta_{03}(4) + \xi\Delta_{\max}} = \frac{0 + (0.5)\times 1}{0.1280 + (0.5)\times 1} = 0.7962$$

The other values were obtained similarly. Grey Relational grade is calculated after all Grey Relational coefficients obtained. Grey Relational

grade is calculated by Eq. 9. For this calculation the importance of each criteria was selected equal. Obtained Grey Relational grades are shown in Table 6.

Table 6: Grey Relational Grade

	University	Grey Relational Grade
0	Reference Sequence	1.0000
1	U1	0.8489
2	U2	0.6541
3	U3	0.5382
4	U4	0.6345
5	U5	0.5198
6	U6	0.4796
7	U7	0.4627
8	U8	0.4950
9	U9	0.4410
10	U10	0.5001

Grey Relational grades equal to weighted sum of the values in Table 5. These grades represent correlation between reference sequence and comparable sequence. For this reason, the alternative with highest correlation is selected the best choice/decision. An example of calculation Grey Relation grade for U5 is,

$$\gamma(x_0^*, x_5^*) = \sum_{k=1}^{n} \beta_k \gamma\left[x_0^*(5), x_5^*(k)\right]$$

$$= 0.20 \times (0.3891 + 0.3534 + 0.4210 + 1 + 0.4355) = 0.5198$$

The reason of selecting β_k as 0.2 is 1/5=0.2 according to Eq. 10. When Grey Relational grade of alternatives is ranked from the biggest to the smallest academic performance comparison of the universities is done. The comparison of universities according to the total score and Grey Relational Analysis is shown in Table 7.

Table 7. Results of the methods

Ranking	Original Ranking	Proposed Method
1	U1	U1
2	U2	U2
3	U3	U4
4	U4	U3
5	U5	U5
6	U6	U10
7	U7	U8
8	U8	U6
9	U9	U7
10	U10	U9

According to proposed method, the first two and the fifth universities remain unchanged but the ranking of other universities subject to changes. U4, U8 and U10 are rising universities, U3, U6 and U9 are falling universities in the ranking. Ranking according to total score does not consider differences of universities too much. Grey Relational Analysis considers the correlation with the ideal value, it measures relative performance of alternatives. Therefore, the results assessed reasonable.

Conclusion

Using Gray System Theory on systems that do not have full knowledge of available data, valuable information about the system is obtained. Grey Relational Analysis is also part of Grey System Theory. Firstly, reference sequence is generated in this method. Then, normalization, calculating of Grey Relational coefficient and Grey Relational Grade is made on comparable sequences. After these operations, the correlation between reference sequence and comparable sequences can be determined. A sequence with higher correlation is determined as more ideal sequence so that, ranking is needed.

In this study 10 Turkish Universities were compared under 5 criteria with data were obtained from Middle East Technical University Ranking by Academic Performance (URAP) Research Laboratory. In comparison, URAP's total score and Grey Relational Analysis method were used. It has been observed that there are differences in the ranking of two methods. Grey Relational Analysis that measures the relative performance represents more accurately the characteristics of the alternatives. In this study, weights of criteria were considered as equal to each other. In the later studies, it is considered that different weights specific to the system can be selected for Grey Relational Analysis using the Multi Criteria Decision Making Methods (MCDM).

References:

Beamon, B. M. (1999). Measuring Supply Chain Performance. *International Journal of Operations & Production Management*, 19(3), 275-292.

Chang, C. L., Tsai, C. H., & Chen, L. (2003). Applying Grey Relational Analysis to the Decathlon Evaluation Model. *International Journal of The Computer, The Internet and Management*, 11(3), 54-62.

Fung, C. P. (2003). Manufacturing Process Optimization for Wear Property of Fiber-reinforced Polybutylene Terephthalate Composites with Grey Relational Analysis. *Wear*, 254(3-4), 298-306.

Hou, J. (2010). Grey Relational Analysis Method for Multiple Attribute Decision Making in Intuitionistic Fuzzy Setting. *Journal of Convergence Information Technology*, 5(10), 194-199.

Huang, K. Y., & Jane, C. J. (2009). A Hybrid Model for Stock Market Forecasting and Portfolio Selection Based on ARX, Grey System and RS Theories. *Expert Systems with Applications*, 36(3), 5387-5392.
Huang, S. J., Chiu, N. H., & Chen, L. W. (2008). Integration of the Grey Relational Analysis with Genetic Algorithm for Software Effort Estimation. *European Journal of Operational Research*, 188(3), 898-909.
Ju-Long, D. (1982). Control Problems of Grey Systems. *Systems & Control Letters*, 1(5), 288-294.
Julong, D. (1989). Introduction to Grey System Theory. *The Journal of Grey System*, 1(1), 1-24.
Kao, P. S., & Hocheng, H. (2003). Optimization of Electrochemical Polishing of Stainless Steel by Grey Relational Analysis. *Journal of Materials Processing Technology*, 140(1-3), 255-259.
Kuah, C. T., & Wong, K. Y. (2011). Efficiency Assessment of Universities through Data Envelopment Analysis. *Procedia Computer Science*, 3, 499-506.
Kung, C. Y., & Wen, K. L. (2007). Applying Grey Relational Analysis and Grey Decision Making to Evaluate the Relationship between Company Attributes and its Financial Performance-A Case Study of Venture Capital Enterprises in Taiwan. *Decision Support Systems*, 43(3), 842-852.
Kuo, Y., Yang, T., & Huang, G. W. (2008). The Use of Grey Relational Analysis in Solving Multiple Attribute Decision-Making Problems. *Computers & Industrial Engineering*, 55(1), 80-93.
Lebas, M. J. (1995). Performance Measurement and Performance Management. *International Journal of Production Economics*, 41(1-3), 23-35.
Lin, C. L., Lin, J. L., & Ko, T. C. (2002). Optimisation of the EDM Process Based on the Orthogonal Array with Fuzzy Logic and Grey Relational Analysis Method. *The International Journal of Advanced Manufacturing Technology*, 19(4), 271-277.
Liu, D. (2011). E-Commerce System Security Assessment Based on Grey Relational Analysis Comprehensive Evaluation. *JDCTA: International Journal of Digital Content Technology and its Applications*, 5(10), 279-284.
Middle East Technical University, University Ranking by Academic Performance (URAP) Research Laboratory. (2016). *2015-2016- Tablo 9: Tüm Üniversitelerin Genel Puan Tablosu*. Retrieved from http://tr.urapcenter.org/2015/2015_t9.php.
Newcomer, K. E. (1997). Using Performance Measurement to Improve Programs. *New Directions for Evaluation*, 1997(75), 5-14.
Parker, C. (2000). Performance Measurement. *Work Study*, 49(2), 63-66.

Pursglove, J., & Simpson, M. (2007). Benchmarking the Performance of English Universities. *Benchmarking: An International Journal*, 14(1), 102-122.
Song, Q., & Shepperd, M. (2011). Predicting Software Project Effort: A Grey Relational Analysis Based Method. *Expert Systems with Applications*, 38(6), 7302-7316.
Warning, S. (2004). Performance Differences in German Higher Education: Empirical Analysis of Strategic Groups. *Review of Industrial Organization*, 24(4), 393-408.
Wei, G. (2011). Grey Relational Analysis Model for Dynamic Hybrid Multiple Attribute Decision Making. *Knowledge-Based Systems*, 24(5), 672-679.
Wei, G. W. (2010). GRA Method for Multiple Attribute Decision Making with Incomplete Weight Information in Intuitionistic Fuzzy Setting. *Knowledge-Based Systems*, 23(3), 243-247.
Worthington, A. C., & Lee, B. L. (2008). Efficiency, Technology and Productivity Change in Australian Universities, 1998-2003. *Economics of Education Review*, 27(3), 285-298.
Wu, C. R., Lin, C. T., & Tsai, P. H. (2010). Evaluating Business Performance of Wealth Management Banks. *European Journal of Operational Research*, 207(2), 971-979.
Wu, H. Y., Chen, J. K., Chen, I. S., & Zhuo, H. H. (2012). Ranking Universities Based on Performance Evaluation by a Hybrid MCDM Model. *Measurement*, 45(5), 856-880.
Wu, H. Y., Lin, Y. K., & Chang, C. H. (2011). Performance Evaluation of Extension Education Centers in Universities Based on the Balanced Score Card. *Evaluation and Program Planning*, 34(1), 37-50.
Xuerui, T., & Yuguang, L. (2004). Using Grey Relational Analysis to Analyze the Medical Data. *Kybernetes*, 33(2), 355-362.
Yang, C. C., & Chen, B. S. (2006). Supplier Selection Using Combined Analytical Hierarchy Process and Grey Relational Analysis. *Journal of Manufacturing Technology Management*, 17(7), 926-941.
Yang, Y. K. (2006). Optimization of Injection-Molding Process for Mechanical and Tribological Properties of Short Glass Fiber and Polytetrafluoroethylene Reinforced Polycarbonate Composites with Grey Relational Analysis: A Case Study. *Polymer-Plastics Technology and Engineering*, 45(7), 769-777.
Yu, Z., Fung, B. C. M., Haghighat, F., Yoshino, H., & Morofsky, E. (2011). A Systematic Procedure to Study the Influence of Occupant Behavior on Building Energy Consumption. *Energy and Buildings*, 43(6), 1409-1417.