Applying Grey Relational Analysis to Find Interactions between Manufacturing and Logistics Industries in Taiwan

Yi-Chung Hu1[[1]](#footnote-1) **, Peng Jiang**1,[[2]](#footnote-2)\* **,** Ghi-Feng Yen1, K. Caleb Chan2

1*Department of Business Administration, Chung Yuan Christian University, Chung Li Dist., Taoyuan City, Taiwan*

2 *Gainey School of Business, Spring Arbor University, Michigan, USA*

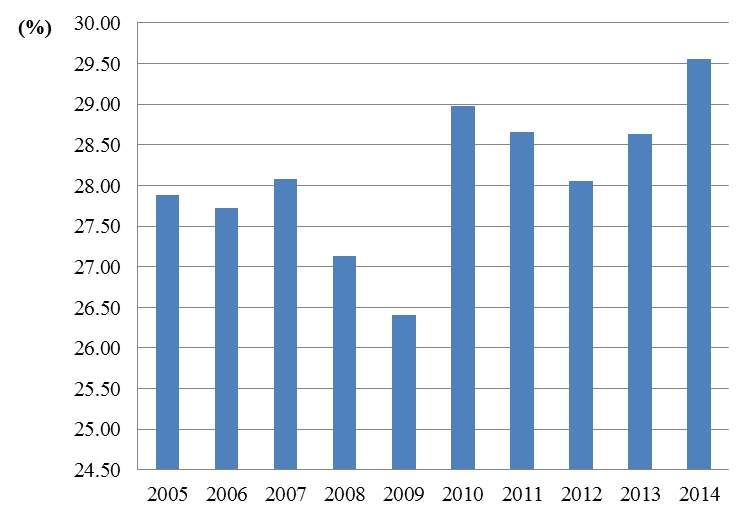
**Abstract**

The development of manufacturing and logistics industries is an important economic index and plays a significant role in developed countries. In Taiwan, both manufacturing and logistics industries have continuously developed in the past few decades, and their development has become interdependent. For instance, the transportation demand of manufacturing industries has an impact on the development of logistics industries. To effectively foster the development of these two sectors in Taiwan, it is necessary to identify the relationships between them. Grey relational analysis with an entropy calculation reveals some interesting findings. (1) The main manufacturing factor driving the logistics industry is employment compensation. (2) The main logistics factor driving the manufacturing sector is length of roads. (3) A fairly strong interaction exists between logistics and manufacturing industries.

*Keywords*: Logistics; Manufacturing; Multiple criteria decision making; Grey relational analysis; Entropy

**1. Introduction**

All the historical examples of successful economic development and catch-up since 1870 have been associated with industrialization (Szirmai, 2012). The development of manufacturing industry is an important index in measuring the overall strength of a country (Szirmai and Verspagen, 2015). The manufacturing industry in Taiwan has undergone extensive development in recent decades. At present, Taiwanese manufacturing includes metal, nuclear power, electronics, information, chemical, and livelihood sectors, with advanced technology and strong production capacity. In addition, Taiwan has tens of thousands of product categories and an efficient supply–production–sales chain that flows from upstream to downstream industries (Chiang and Hwang, 2007). In particular, Taiwan has become an important global production base for high-tech products (Chan, Chang, and Hsu, 2004). Figure 1 shows the contribution of manufacturing industry to GDP in Taiwan. The total value of manufacturing output accounted for 26.41–29.56 % of GDP during 2005–2014. Therefore, manufacturing has become a major factor in economic growth (Fagerberg and Verspagen, 2002).



Data Sources: The website of Directorate General of Budget, Accounting and Statistics, Executive Yuan of Taiwan.

Figure 1 Contribution of manufacturing industry in GDP of Taiwan

Logistics can reduce inventory, accelerate revenue turnover, and improve the competitiveness of enterprises (Sandberg and Abrahamsson, 2011). As the third profits source, logistics has been the focus of increasing attention (Marasco, 2008). As an important part of producer services, the logistics industry is highly dependent on the manufacturing sector (Chan, 2005; Voordijk, 1999). Manufacturing is the main source of logistics demand (Mortensen and Lemoine, 2008), and progress in manufacturing has greatly helped and promoted the logistics sector (Hertz and Alfredsson, 2003). Conversely, the development level of the logistics industry is directly related to the efficiency of manufacturers and the benefits they experience (Choi, Wallace, and Wang, 2016). An increasing number of manufacturers are realizing the importance of logistics, and outsource non-core business activities such as delivery and distribution to third-party logistics enterprises (3PLs) (Li et al., 2012). However, transmission of logistics information among manufacturers and 3PLs is not very smooth, which has seriously affected the efficiency of enterprises (Shi *et al*., 2016). Therefore, interactive development of logistics and manufacturing industries is essential (Hwang, Chen, and Lin, 2016) and is key to improving core competitiveness and promoting upgrading among manufacturing firms (Shang and Marlow, 2005).

Previous studies have investigated the interactive development of manufacturing and logistics industries. Wang and Chen (2012) believed that the interactive development of two industries is aimed at symbiotic development, with reciprocity and complementarity principles. Good interaction between two industries can contribute to reducing operating costs, encouraging manufacturing productivity, and improving core manufacturing competitiveness while simultaneously improving logistics service levels (Peng and Feng, 2010). Therefore, the goal of interaction is to achieve a win–win situation (Wang, 2014). Grey relational analysis (GRA) as proposed by Deng (1982) can be used to effectively measure the degree of relationships between given data sequences (Liu and Lin, 2006; Wen, 2004). Therefore, the relationships among index factors for the development of manufacturing and logistics industries can be measured using GRA. The dominant factors affecting interactive development between manufacturing and logistics industries can thus be determined. GRA has been widely applied to various fields (Wei, 2011; Li et al., 2015; Hu, 2015, 2016; Huang and Wang, 2016; Wu *et al*., 2016).

Here, we discuss whether interactive development exists between manufacturing and logistics industries in Taiwan. We also explore indicators with a significant influence on the interactive development of these two industry sectors.

**2. Methodology**

We use entropy to determine the relative importance of each evaluation factor and then apply GRA to identify dominant factors affecting interactive development between manufacturing and logistics industries.

**2.1. Entropy**

The theory of entropy was first proposed by Clausius in 1865, and is now widely used in many fields, such as economy, management, energy, and mathematics. Machado (2016) addressed the concept of negative probability and its impact on entropy. Stosic et al. (2016) used entropy to explore the foreign exchange rate during financial crises. Xu, Shang, and Huang (2016) proposed a modified method of generalized sample entropy as a new measure to assess the complexity of the stock market. Entropy is typically used to calculate weights for factors, especially when combined with GRA (Hsu and Chien, 2008; Hsu and Kuo, 2007; Kuo, Yang, and Huang, 2008; Rajesh, Rajakarunakaran, and Sudhkarapandian, 2014; Shuai and Wu, 2011; Sun, 2014; Verma, Sarangi, and Kolekar, 2014; Wu, 2012).

*2.1.1. Calculating entropy*

Decide a matrix *D* of *m* alternatives and *n* attributes (criteria):

. (1)

Then define the attribute *j*, *pij*:

, for ; (2)

The entropy of the set of attribute *j* is

, for ; (3)

where , is a constant that guarantees that 0l.

*2.1.2. Calculating the entropy weight*

The degree of diversification *dj* of the information provided by attribute *j* can be defined as

, for ; . (4)

Then the best weight set we can expect, instead of the equal weight, is

, for ; . (5)

**2.2. Grey relational analysis**

GRA can be used to determine the relationships between one major sequence and the other sequences in a given system. Unlike statistical correlation analysis, which measures the relationship between any two random variables, GRA tries to find the relationships between one reference sequence and other comparative sequences by viewing the reference sequence as the desired goal (Hu et al., 2003). In other words, to identify dominant factors that can affect interactive development between manufacturing and logistics industries, given one reference sequence with respect to an evaluation factor in one industry (e.g., manufacturing), and comparative sequences with respect to all evaluation factors in the other industry (e.g., logistics), we can easily find the most influential factor among comparative sequences, [and](javascript:void();) vice versa.

GRA includes four main steps (Kuo, Yang, and Huang, 2008):

Step 1: Grey relational generating;

Step 2: Reference sequence definition;

Step 3: Grey relational coefficient calculation; and

Step 4: Grey relational grade calculation.

The details of the proposed GRA procedure are presented below.

*2.2.1. Grey relational generating*

When the units in which performance is measured differ for different attributes, the influence of some attributes may be neglected (Deng, 1982). This may also occur if some performance attributes have a very large range (Luo et al., 2016). In addition, differences in the goals and directions of these attributes will lead to incorrect results in the analysis (Huang and Liao, 2003). Therefore, it is necessary to process all performance values for every alternative into a comparability sequence in a process analogous to normalization (Kuo, Yang, and Huang, 2008).

If there are *m* alternatives and *n* attributes, the *i*th alternative can be expressed as *Yi* = (y*i1*, y*i2*, …, y*ij*, …, y*in*), where y*ij* is the performance value of attribute *j* for alternative *i*. The term *Yi* can be translated into the comparability sequence X*i* = (x*i1*, x*i2*, …, x*ij*, …, x*in*). In this paper, all selected attributes in manufacturing and logistics industries are the-larger-the-better attributes, so the following equation can be used:

for ;. (6)

*2.2.2. Reference sequence definition*

After grey relational generating, all performance values are scaled to the interval [0, 1]. For an attribute *j* for alternative *i*, if the value *xij* processed by the grey relational generating procedure is equal to 1 or nearer to 1 than the value for any other alternative, then the performance of alternative *i* is the best for attribute *j*. Therefore, an alternative will be the best choice if all of its performance values are closest to or equal to 1. However, this type of alternative does not usually exist. In this paper, the attributes of the logistics industry are defined as the sequence *X*i as (*x*i1, *x*i2, …, *x*ij, …, *x*in). Meanwhile, the attributes of the manufacturing industry are defined as the reference sequence *Y*i as (*y*i1, *y*i2, …, *y*ij, …, *x*in). Our aim is to find an alternative, whose comparability sequence is closest to the reference sequence.

*2.2.3. Grey relational coefficient calculation*

Grey relational coefficient (GRC) is used to determine how close *x*ij is to *y*ij. The larger the GRC, the closer *x*ij and *y*ij are. The GRC can be calculated as

for, (7)

where is the GRC between *y*ij and *x*ij, and

,

,

, and

is the distinguishing coefficient; .

The purpose of the distinguishing coefficient is to expand or compress the range of the grey relational coefficient. In this study, we initially set the distinguishing coefficient to 0.5.

*2.2.4. Grey relational grade calculation*

After calculating the GRC *γ*(*y*ij, *x*ij), the grey relational grade (GRG) can be calculated according to

for, (8)

where is the GRG between and . and represents the level of correlation between the reference sequence and the comparability sequence. is the weight for attribute *j* and is calculated using Eq. (5). GRG indicates the degree of similarity between the comparability sequence and the reference sequence (Wei, 2011). Therefore, if a comparability sequence for an alternative has the highest GRG with the reference sequence, then it is most similar to the reference sequence.

**3. Empirical study**

**3.1. Data collection**

According to pervious research, many indicators can be used to evaluate manufacturing development (e.g., output, provincial output, tertiary industry output, industrial added value) and logistics (e.g., freight volume, retail sales of consumer goods, turnover volume, national transportation line length, fixed assets investment, number of employees) (Fan, Lin, and Gu, 2011; Wang and Chen, 2010; Wang and Li, 2013).

Data for this study for all selected indicators were taken from the *Taiwan Statistical Yearbook* during the period 2005–2014. Table 1 and Table 2 list indicators for the manufacturing and logistics industries.

Table 1 Indicators of Logistics Industry

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Year | *X*1 | *X*2 | *X*3 | *X*4 |
| Total output of transportation and storage  (NT$ million) | Total freight volume  (1000 MTs ) | Gross Fixed Capital Formation of transportation  (NT$ million) | Year-end No. of Operating Vehicles  (Vehicle) |
| 2005 | 993370 | 842544 | 213793 | 84347 |
| 2006 | 1026304 | 873094 | 165141 | 80737 |
| 2007 | 1070800 | 904859 | 164264 | 76294 |
| 2008 | 1069997 | 883010 | 120799 | 73210 |
| 2009 | 934271 | 843801 | 127675 | 70844 |
| 2010 | 1100761 | 887414 | 173436 | 72126 |
| 2011 | 1090176 | 895760 | 178597 | 73492 |
| 2012 | 1127429 | 905146 | 184161 | 74723 |
| 2013 | 1133546 | 807640 | 186341 | 81760 |
| 2014 | 1196146 | 810654 | 217470 | 82302 |
| Year | *X*5 | *X*6 | *X*7 | *X*8 |
| No. of Vehicle Kilometers (1000 Truck-kms) | Freight Tonnage  (1000 MTs) | Length of Roads (km) | Number of employees Transportation & Storage（Thousand） |
| 2005 | 4959971 | 561831 | 37336 | 412 |
| 2006 | 4952581 | 594214 | 38297 | 417 |
| 2007 | 4863470 | 617567 | 38526 | 415 |
| 2008 | 4730607 | 604137 | 39315 | 414 |
| 2009 | 4466423 | 596742 | 39849 | 402 |
| 2010 | 4628448 | 628 167 | 40353 | 404 |
| 2011 | 4552187 | 638499 | 40995 | 411 |
| 2012 | 4599969 | 653265 | 41924 | 414 |
| 2013 | 4171623 | 551430 | 42520 | 425 |
| 2014 | 4212537 | 541939 | 41916 | 433 |

Data Sources: The website of *Directorate General of Budget, Accounting and Statistics, Executive Yuan of Taiwan*.

Table 2 Indicators of Manufacturing Industry

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Year | *Y*1 | *Y*2 | *Y*3 | *Y*4 | *Y*5 |
| Manufacturing output (NT$ million) | Industrial Production | Gross domestic manufacturing production deflator (%) | Manufacturing fixed capital consumption (NT$ million) | Manufacturing employment Compensation (NT$ million) |
| 2005 | 13133742 | 73 | 128 | 715688 | 1400107 |
| 2006 | 14515324 | 76 | 124 | 782351 | 1492499 |
| 2007 | 15866852 | 83 | 118 | 857874 | 1538873 |
| 2008 | 15981326 | 82 | 111 | 950651 | 1568294 |
| 2009 | 13559985 | 76 | 109 | 1007982 | 1376113 |
| 2010 | 17753198 | 96 | 106 | 1043332 | 1538706 |
| 2011 | 18723508 | 100 | 100 | 1101020 | 1664002 |
| 2012 | 18327450 | 100 | 97 | 1147402 | 1697072 |
| 2013 | 18380201 | 100 | 101 | 1137998 | 1719388 |
| 2014 | 19182851 | 107 | 102 | 1188895 | 1811810 |

Data Sources: The website of *Directorate General of Budget, Accounting and Statistics, Executive Yuan of Taiwan*.

**3.2. GRA with entropy**

The main purpose of grey relational generating is to transfer the original data into comparability sequences (Kuo, Yang, and Huang, 2008). The attributes for the two industries are all the-larger-the-better attributes, so we normalize Table 1 and Table 2 using Eq. (6). The grey relational generating results are shown in Table 3 and Table 4.

Table 3 Normalized Data of Logistics Industry

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 | 0.2257 | 0.3580 | 0.9620 | 1.0000 | 1.0000 | 0.1787 | 0.0000 | 0.3226 |
| 2006 | 0.3514 | 0.6713 | 0.4587 | 0.7327 | 0.9906 | 0.4696 | 0.1854 | 0.4839 |
| 2007 | 0.5214 | 0.9971 | 0.4496 | 0.4036 | 0.8776 | 0.6793 | 0.2296 | 0.4194 |
| 2008 | 0.5183 | 0.7730 | 0.0000 | 0.1752 | 0.7091 | 0.5587 | 0.3818 | 0.3871 |
| 2009 | 0.0000 | 0.3709 | 0.0711 | 0.0000 | 0.3739 | 0.4923 | 0.4848 | 0.0000 |
| 2010 | 0.6358 | 0.8181 | 0.5445 | 0.0949 | 0.5795 | 0.7746 | 0.5820 | 0.0645 |
| 2011 | 0.5953 | 0.9037 | 0.5979 | 0.1961 | 0.4827 | 0.8674 | 0.7058 | 0.2903 |
| 2012 | 0.7376 | 1.0000 | 0.6554 | 0.2873 | 0.5433 | 1.0000 | 0.8850 | 0.3871 |
| 2013 | 0.7610 | 0.0000 | 0.6780 | 0.8084 | 0.0000 | 0.0853 | 1.0000 | 0.7419 |
| 2014 | 1.0000 | 0.0309 | 1.0000 | 0.8486 | 0.0519 | 0.0000 | 0.8835 | 1.0000 |

Table 4 Normalized Data of Manufacturing Industry

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Year | *Y*1 | *Y*2 | *Y*3 | *Y*4 | *Y*5 |
| 2005 | 0.0000 | 0.0000 | 1.0000 | 0.0000 | 0.0551 |
| 2006 | 0.2284 | 0.0990 | 0.8592 | 0.1409 | 0.2671 |
| 2007 | 0.4518 | 0.2863 | 0.6666 | 0.3005 | 0.3736 |
| 2008 | 0.4707 | 0.2645 | 0.4547 | 0.4965 | 0.4411 |
| 2009 | 0.0705 | 0.0763 | 0.3981 | 0.6177 | 0.0000 |
| 2010 | 0.7637 | 0.6651 | 0.3085 | 0.6924 | 0.3732 |
| 2011 | 0.9241 | 0.7971 | 0.1008 | 0.8143 | 0.6608 |
| 2012 | 0.8586 | 0.7876 | 0.0000 | 0.9123 | 0.7367 |
| 2013 | 0.8673 | 0.8041 | 0.1251 | 0.8924 | 0.7879 |
| 2014 | 1.0000 | 1.0000 | 0.1613 | 1.0000 | 1.0000 |

Taking *Y*1 as the reference sequence, results for calculated are shown in Table 5. Results for *Y*2, *Y*3, *Y*4, and *Y*5 as the reference sequences are shown in Appendix 1.

Table 5 Difference series with reference sequence *Y*1

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *Y*1 | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 |  | 0.2257 | 0.3580 | 0.9620 | 1.0000 | 1.0000 | 0.1787 | 0.0000 | 0.3226 |
| 2006 |  | 0.1230 | 0.4429 | 0.2303 | 0.5043 | 0.7622 | 0.2412 | 0.0430 | 0.2555 |
| 2007 |  | 0.0695 | 0.5452 | 0.0022 | 0.0482 | 0.4258 | 0.2275 | 0.2223 | 0.0325 |
| 2008 |  | 0.0475 | 0.3022 | 0.4707 | 0.2955 | 0.2383 | 0.0880 | 0.0890 | 0.0836 |
| 2009 |  | 0.0705 | 0.3004 | 0.0007 | 0.0705 | 0.3035 | 0.4218 | 0.4143 | 0.0705 |
| 2010 |  | 0.1279 | 0.0545 | 0.2192 | 0.6687 | 0.1842 | 0.0109 | 0.1817 | 0.6991 |
| 2011 |  | 0.3287 | 0.0203 | 0.3262 | 0.7280 | 0.4413 | 0.0567 | 0.2182 | 0.6337 |
| 2012 |  | 0.1210 | 0.1414 | 0.2032 | 0.5713 | 0.3152 | 0.1414 | 0.0264 | 0.4715 |
| 2013 |  | 0.1064 | 0.8673 | 0.1893 | 0.0589 | 0.8673 | 0.7821 | 0.1327 | 0.1254 |
| 2014 |  | 0.0000 | 0.9691 | 0.0000 | 0.1514 | 0.9481 | 1.0000 | 0.1165 | 0.0000 |

According to Table 5, =1 and =0, so all the GRCs can be calculated according to Eq. (7). With each year equally weighted, the average GRCs for reference sequence *Y*1 for 10 years are shown in Table 6. The average GRCs for *Y*2, *Y*3, *Y*4, and*Y*5 as the reference sequences are shown in Appendix 2. Aggregated GRC results are presented in Table 7.

Table 6 Grey relational coefficients with reference sequence *Y*1

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *Y*1 | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 |  | 0.6890 | 0.5828 | 0.3420 | 0.3333 | 0.3333 | 0.7367 | 1.0000 | 0.6078 |
| 2006 |  | 0.8025 | 0.5303 | 0.6847 | 0.4979 | 0.3961 | 0.6746 | 0.9208 | 0.6618 |
| 2007 |  | 0.8779 | 0.4784 | 0.9956 | 0.9121 | 0.5401 | 0.6873 | 0.6923 | 0.9390 |
| 2008 |  | 0.9132 | 0.6233 | 0.5151 | 0.6285 | 0.6772 | 0.8504 | 0.8489 | 0.8567 |
| 2009 |  | 0.8765 | 0.6247 | 0.9987 | 0.8765 | 0.6223 | 0.5424 | 0.5469 | 0.8765 |
| 2010 |  | 0.7963 | 0.9017 | 0.6953 | 0.4278 | 0.7308 | 0.9787 | 0.7335 | 0.4170 |
| 2011 |  | 0.6033 | 0.9609 | 0.6052 | 0.4072 | 0.5312 | 0.8981 | 0.6961 | 0.4410 |
| 2012 |  | 0.8052 | 0.7795 | 0.7111 | 0.4667 | 0.6133 | 0.7795 | 0.9498 | 0.5147 |
| 2013 |  | 0.8246 | 0.3657 | 0.7254 | 0.8946 | 0.3657 | 0.3900 | 0.7903 | 0.7995 |
| 2014 |  | 1.0000 | 0.3403 | 1.0000 | 0.7675 | 0.3453 | 0.3333 | 0.8110 | 1.0000 |
| AVG. |  | 0.8188 | 0.6188 | 0.7273 | 0.6212 | 0.5155 | 0.6871 | 0.7990 | 0.7114 |

In this case, the importance of all indicators was not equal. Thus, the weights for all attributes were calculated using entropy. All the weights for *W*X and *W*Y calculated according to Eqs. (1)–(5) are listed in Table 7. The detailed calculation steps are presented in Appendix 3. GRG values calculated according to Eq. (8) are shown in Table 7.

Table 7 GRG Matrix of Manufacturing and logistics industries in Taiwan

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 | *W*Y | *GRG*Y | Ranking(Y) |
| *Y*1 | 0.8188 | 0.6188 | 0.7273 | 0.6212 | 0.5155 | 0.6871 | 0.7990 | 0.7114 | 0.2237 | 0.7095 | 3 |
| *Y*2 | 0.8051 | 0.5602 | 0.7431 | 0.6481 | 0.5175 | 0.6189 | 0.8181 | 0.7029 | 0.2376 | 0.7139 | 2 |
| *Y*3 | 0.5432 | 0.6131 | 0.5772 | 0.6671 | 0.7427 | 0.6513 | 0.5250 | 0.5885 | 0.1104 | 0.5966 | 5 |
| *Y*4 | 0.7618 | 0.5997 | 0.6533 | 0.5647 | 0.5239 | 0.6927 | 0.8620 | 0.6465 | 0.3330 | 0.6563 | 4 |
| *Y*5 | 0.8726 | 0.5382 | 0.7666 | 0.6876 | 0.5376 | 0.6114 | 0.7845 | 0.7865 | 0.0953 | 0.7371 | 1 |
| *W*X | 0.0901 | 0.0335 | 0.6215 | 0.0727 | 0.0667 | 0.0721 | 0.0347 | 0.0088 |  |  |  |
| *GRG*X | 0.7713 | 0.5902 | 0.6936 | 0.6202 | 0.5460 | 0.6616 | 0.7929 | 0.6813 |  |  |  |
| Ranking(X) | 2 | 7 | 3 | 6 | 8 | 5 | 1 | 4 |  |  |  |

**3.3. Results**

The GRG between the logistics indicators and manufacturing indicators is as follows: 0.7095 for manufacturing output (*Y*1); 0.7139 for industrial production (*Y*2); 0.5966 for gross domestic manufacturing production deflator (*Y*3); 0.6563 for manufacturing fixed capital consumption (*Y*4); and 0.7371 for manufacturing employment compensation (*Y*5). Thus, the GRG ranking for manufacturing indicators is *Y*5 *Y*2 *Y*1 *Y*4 *Y*3. Therefore, the following conclusion can be drawn:

Result 1: The dominant manufacturing factor influencing the development of the logistics industry is employment compensation.

The GRG between the manufacturing indicators and logistics indicators is as follows: 0.7713 for total output of transportation and storage (*X*1); 0.5902 for total freight volume (*X*2); 0.6936 for gross fixed capital formation for transportation (*X*3); 0.6202 for year-end number of operating vehicles (*X*4); 0.5460 for number of vehicle kilometers (*X*5); 0.6616 for freight tonnage (*X*6); 0.7929 for length of roads (*X*7); and 0.6813 for number of employees in transportation and storage (*X*8). Thus, the GRG ranking for manufacturing indicators is *X*7 *X*1 *X*3 *X*8 *X*6 *X*4 *X*2 *X*5. Therefore, the following conclusion can be drawn:

Result 2: The dominant logistics factor influencing the development of manufacturing industry is length of roads.

According to Table 8, the GRG for the 13 indicators selected ranges from 0.5155 to 0.8726. The following conclusion can be drawn:

Result 3: A fairly strong interaction exists between logistics and manufacturing industries.

**4. Discussion and conclusions**

We used GRA with entropy to measure interaction between two industry sectors. The results in Table 7 show the following. (1) The dominant manufacturing factor influencing the development of the logistics industry is employment compensation. (2) The dominant logistics factor influencing the development of the manufacturing sector is length of roads. (3) A fairly strong interaction exists between logistics and manufacturing industries.

With higher compensation, manufacturing employees may have a higher consumption capacity, which could enhance the social demand for commodities, promoting the development of the logistics industry. Accordingly, it can be inferred that logistics development is closely related to the level of employment compensation. There is a consensus that roads are very important for social economic development. On one hand, road accessibility affects the layout of the manufacturing industry, because factories are usually built in easily accessible areas. On the other hand, the length of roads determines logistics capability in Taiwan, and thus affects manufacturing feasibility. Therefore, it can be inferred that manufacturing development is closely related to the length of roads. In summary, to promote effective interaction between manufacturing and logistics industries, the government should build more roads to extend the total road length and manufacturers should pay more attention to employment compensation.

Both manufacturing and logistics industries play very important roles in social development and economic growth. Interaction between these two sectors is attracting increasing attention and some useful research has been carried out. However, previous studies mainly focused on the importance of interaction between manufacturing and logistics industries, and differences among indicators (attributes) have largely been ignored, with all indicators set to be equally weighted. The highlights of this study are twofold: (1) we take into account that the importance of attributes to the reference sequence differs, so we obtain weights for all attributes using the entropy method; and (2) we provide a new approach for measuring interaction between two industries.

Although GRA with entropy overcomes many of the shortcomings of other methods, our study has several limitations. First, we selected just eight logistics and five manufacturing indicators; other measurable indicators could also be considered. Second, the weight for each attribute was obtained using the entropy method. It would be more reasonable to obtain the weights by combining practical knowledge, expert analysis, and intelligent systems. Third, our conclusions are only for Taiwan. Logistics development is also affected by area, topography, and other natural factors, so development patterns for the logistics industry in different regions may differ. More data from other countries could be considered.

This research can be extended in a number of ways. First, multiple-attribute decision-making methods such as analytic hierarchy process and analytic network process could be used for weight calculations. Second, a separate weight for each year should be considered. Third, GRCs can be regarded as a partial GRG, so the relationship between attributes could also be analyzed. Fourth, time differences in interactions between manufacturing and logistics industries could be investigated. In addition, the GM (1,1) model could be considered during simulation of original sequences.

**Acknowledgements**

This research is partially supported by the National Science Council of Taiwan under grant MOST 104-2410-H-033-023-MY2.

**References**

Chan, J. W. K. (2005). Competitive strategies and manufacturing logistics: An empirical study of Hong Kong manufacturers. *International Journal of Physical Distribution & Logistics Management*, 35(1), 20-43.

Chan, L.Y., Chang, M. C., & Hsu, C. C. (2004). Vertical Disintegration and Industry Agglomeration in Taiwan's Manufacturing Sector. *Taiwan Economic Review*, 32(4), 483-511.

Chiang, S. H., & Hwang, J. T. (2007). An Investigation of Urban Agglomeration Economies in Taiwanese Manufacturing. *Journal of Taiwan Land Research*, 10(2), 127-149.

Choi, T. M., Wallace, S. W., & Wang, Y. L. (2016). Risk management and coordination in service supply chains: information, logistics and outsourcing. *Journal of the Operational Research Society*, 67(2), 159-164.

Deng, J. L. (1982). Control problems of grey systems. *Systems & Control Letters*, 1(5), 288-294.

Fagerberg, J., & Verspagen, B. (2002). Technology-gaps, innovation-diffusion and transformation: an evolutionary interpretation. Research Policy, 31(8–9), 1291-1304.

Hertz, S., & Alfredsson, M. (2003). Strategic development of third party logistics providers. *Industrial Marketing Management*, 32(2), 139-149.

Hsu, P. F., & Chien, P. C. (2008). Optimal selection of media agencies for an advertiser using the GRA and Entropy. *Journal of Grey System*, 20(1), 27-38.

Hsu, P. F., & Kuo, M. H. (2007). An application of the GRA & Entropy to select a city in China for an international business office center. *Journal of Grey System*, 19(3), 269-282.

Hu, Y. C. (2016). Tolerance rough sets for pattern classification using multiple grey single-layer perceptrons, *Neurocomputing*, 179, 144-151.

Hu, Y. C. (2013). A novel flow-based method using grey relational analysis for pattern classification. *International Journal of Information Technology and Decision Making*, 12(1), 75-93.

Hu, Y. C., Chen, R. S., Hsu, Y. T., Tzeng, G. H. (2002). Grey self-organizing feature maps. *Neurocomputing,* 48(1), 863-877.

Huang, J. T., & Liao, Y. S. (2003). Optimization of machining parameters of Wire-EDM based on Grey relational and statistical analyses. *International Journal of Production Research*, 41(8), 1707-1720.

Huang, M. Q., & Wang, B. (2016). Factors influencing CO2 emissions in China based on grey relational analysis. *Energy Sources Part a-Recovery Utilization and Environmental Effects*, 38(4), 555-561.

Hwang, B. N., Chen, T. T., & Lin, J. T. (2016). 3PL selection criteria in integrated circuit manufacturing industry in Taiwan. *Supply Chain Management-an International Journal*, 21(1), 103-124.

Fan, J., Lin, L. S., & Gu, C. M. (2011). Research on manufacturing and logistics linkage development based on the Grey correlation model - Case study of Zhejiang Province. *Paper presented at the 2nd International Conference of Electrical and Electronics Engineering, ICEEE 2011*, December 1, 2011 - December 2, 2011, Macau, China.

Kuo, Y., Yang, T., & Huang, G. W. (2008). The use of grey relational analysis in solving multiple attribute decision-making problems. *Comput. Ind. Eng.*, 55(1), 80-93.

Li, F., Li, L., Jin, C., Wang, R., Wang, H., & Yang, L. (2012). A 3PL supplier selection model based on fuzzy sets. *Computers & Operations Research*, 39(8), 1879-1884.

Li, X. M., Hipel, K. W., & Dang, Y. G. (2015). An improved grey relational analysis approach for panel data clustering. *Expert Systems with Applications*, 42(23), 9105-9116.

Liu, S., Lin, Y. Grey Information: Theory and Practical Applications, Springer-Lerlag, London, 2006.

Luo, X. L., Wang, Y. Z., Zhao, J., Chen, Y., Mo, S. P., & Gong, Y. L. (2016). Grey relational analysis of an integrated cascade utilization system of geothermal water. *International Journal of Green Energy*, 13(1), 14-27.

Machado, J. A. T. (2016). Entropy analysis of systems exhibiting negative probabilities. *Communications in Nonlinear Science and Numerical Simulation*, 36, 58-64.

Marasco, A. (2008). Third-party logistics: A literature review. *International Journal of Production Economics*, 113(1), 127-147.

Mortensen, O., & Lemoine, O. W. (2008). Integration between manufacturers and third party logistics providers? *International Journal of Operations & Production Management*, 28(4), 331-359.

Peng, B. H., & Feng, L. Q. (2010). A Study on the Symbiotic Mechanism of Modern Logistics Industry and Advanced Manufacturing. *Journal of Business Economics*, (1), 18-25.

Rajesh, S., Rajakarunakaran, S., & Sudhkarapandian, R. (2014). Optimization of the red mud-aluminum composite in the turning process by the Grey relational analysis with entropy. *Journal of Composite Materials*, 48(17), 2097-2105.

Sandberg, E., & Abrahamsson, M. (2011). Logistics capabilities for sustainable competitive advantage. *International Journal of Logistics*, 14(1), 61-75.

Shang, K. C., & Marlow, P. B. (2005). Logistics capability and performance in Taiwan's major manufacturing firms. *Transportation Research Part E: Logistics and Transportation Review*, 41(3), 217-234.

Shi, Y. Y., Zhang, A., Arthanari, T., Liu, Y. P., & Cheng, T. C. E. (2016). Third-party purchase: An empirical study of third-party logistics providers in China. *International Journal of Production Economics*, 171, 189-200.

Shuai, J. J., & Wu, W. W. (2011). Evaluating the influence of E-marketing on hotel performance by DEA and grey entropy. *Expert Systems with Applications*, 38(7), 8763-8769.

Stosic, D., Stosic, D., Ludermir, T., de Oliveira, W., & Stosic, T. (2016). Foreign exchange rate entropy evolution during financial crises. *Physica a-Statistical Mechanics and Its Applications*, 449, 233-239.

Sun, C. C. (2014). Combining grey relation analysis and entropy model for evaluating the operational performance: an empirical study. *Quality & Quantity*, 48(3), 1589-1600.

Szirmai, A. (2012). Industrialization as an engine of growth in developing countries, 1950–2005. *Structural Change and Economic Dynamics*, 23(4), 406-420.

Szirmai, A., & Verspagen, B. (2015). Manufacturing and economic growth in developing countries, 1950–2005. *Structural Change and Economic Dynamics*, 34, 46-59.

Verma, A., Sarangi, S., & Kolekar, M. H. (2014). Stator winding fault prediction of induction motors using multiscale entropy and grey fuzzy optimization methods. *Computers & Electrical Engineering*, 40(7), 2246-2258.

Voordijk, H. (1999). Obstacles and preconditions for logistics and manufacturing improvements in Africa - a case study. *International Journal of Operations & Production Management*, 19(3-4), 293-307.

Wang, Z. Z., & Chen, G. Y. (2010). Empirical Analysis of Interactive Development between Manufacturing Sub-sectors and Logistics Industry: Based on Gray Correlational Model. *Journal of Shanghai University of Finance and Economics*, 12(3), 65-74.

Wang, Z. (2014). Interactive development of Manufacturing and Logistics: A literature review. *Journal of Management*, 27(1), 41-47,57.

Wang, Z., & Chen, G. (2012). Analysis on the Evolutionary Game of Interactive Development between Manufacturing and Logistics Industry. *Economic Issues in China*, (2), 86-97.

Wei, G. W. (2011). Grey relational analysis model for dynamic hybrid multiple attribute decision making. *Knowledge-Based Systems*, 24(5), 672-679.

Wen, [K. L., Grey Systems: Modeling and Prediction, Yangs Scientific Research Institute, AZ, 2004.](http://lms.ctu.edu.tw/blog.php?user=s0204&f=portfolio&m=publication#_pf3931)

Wu, L., Zhang, Q. S., Guo, K., & Qiu, Q. R. (2016). Identification of Overlapping Community Structure with Grey Relational Analysis in Social Networks. *Journal of Grey System*, 28(1), 98-108.

Wu, W. W. (2012). An integrated solution for benchmarking using DEA, gray entropy, and Borda count. *Service Industries Journal*, 32(2), 321-335.

Wang, X., & Li, Wei. (2013). Analysis on the grey correlation between manufacturing and logistics industry in dongguan. *Paper presented at the 9th International Conference on Computational Intelligence and Security, CIS 2013*, December 14, 2013 - December 15, 2013, Emeishan, China.

Xu, M. J., Shang, P. J., & Huang, J. J. (2016). Modified generalized sample entropy and surrogate data analysis for stock markets. *Communications in Nonlinear Science and Numerical Simulation*, 35, 17-24.

**Appendix 1**

Table 8 Difference series with reference sequence *Y*2

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *Y*2 | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 |  | 0.2257 | 0.3580 | 0.9620 | 1.0000 | 1.0000 | 0.1787 | 0.0000 | 0.3226 |
| 2006 |  | 0.2525 | 0.5723 | 0.3597 | 0.6337 | 0.8917 | 0.3706 | 0.0864 | 0.3849 |
| 2007 |  | 0.2350 | 0.7108 | 0.1633 | 0.1173 | 0.5913 | 0.3930 | 0.0568 | 0.1331 |
| 2008 |  | 0.2538 | 0.5085 | 0.2645 | 0.0893 | 0.4446 | 0.2942 | 0.1172 | 0.1226 |
| 2009 |  | 0.0763 | 0.2946 | 0.0052 | 0.0763 | 0.2977 | 0.4160 | 0.4085 | 0.0763 |
| 2010 |  | 0.0293 | 0.1531 | 0.1206 | 0.5702 | 0.0856 | 0.1095 | 0.0831 | 0.6006 |
| 2011 |  | 0.2017 | 0.1067 | 0.1992 | 0.6009 | 0.3143 | 0.0703 | 0.0912 | 0.5067 |
| 2012 |  | 0.0500 | 0.2124 | 0.1322 | 0.5004 | 0.2443 | 0.2124 | 0.0974 | 0.4005 |
| 2013 |  | 0.0432 | 0.8041 | 0.1261 | 0.0043 | 0.8041 | 0.7189 | 0.1959 | 0.0622 |
| 2014 |  | 0.0000 | 0.9691 | 0.0000 | 0.1514 | 0.9481 | 1.0000 | 0.1165 | 0.0000 |

Table 9 Difference series with reference sequence *Y*3

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *Y*3 | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 |  | 0.7743 | 0.6420 | 0.0380 | 0.0000 | 0.0000 | 0.8213 | 1.0000 | 0.6774 |
| 2006 |  | 0.5078 | 0.1879 | 0.4005 | 0.1265 | 0.1314 | 0.3896 | 0.6738 | 0.3753 |
| 2007 |  | 0.1452 | 0.3305 | 0.2169 | 0.2629 | 0.2110 | 0.0128 | 0.4370 | 0.2472 |
| 2008 |  | 0.0636 | 0.3183 | 0.4547 | 0.2795 | 0.2543 | 0.1040 | 0.0730 | 0.0676 |
| 2009 |  | 0.3981 | 0.0272 | 0.3270 | 0.3981 | 0.0241 | 0.0942 | 0.0867 | 0.3981 |
| 2010 |  | 0.3273 | 0.5097 | 0.2360 | 0.2135 | 0.2710 | 0.4661 | 0.2735 | 0.2440 |
| 2011 |  | 0.4945 | 0.8029 | 0.4971 | 0.0953 | 0.3819 | 0.7666 | 0.6050 | 0.1895 |
| 2012 |  | 0.7376 | 1.0000 | 0.6554 | 0.2873 | 0.5433 | 1.0000 | 0.8850 | 0.3871 |
| 2013 |  | 0.6358 | 0.1251 | 0.5529 | 0.6833 | 0.1251 | 0.0399 | 0.8749 | 0.6168 |
| 2014 |  | 0.8387 | 0.1304 | 0.8387 | 0.6873 | 0.1094 | 0.1613 | 0.7222 | 0.8387 |

Table 10 Difference series with reference sequence *Y*4

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *Y*4 | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 |  | 0.2257 | 0.3580 | 0.9620 | 1.0000 | 1.0000 | 0.1787 | 0.0000 | 0.3226 |
| 2006 |  | 0.2106 | 0.5304 | 0.3178 | 0.5918 | 0.8498 | 0.3287 | 0.0445 | 0.3430 |
| 2007 |  | 0.2209 | 0.6966 | 0.1491 | 0.1031 | 0.5771 | 0.3789 | 0.0709 | 0.1189 |
| 2008 |  | 0.0218 | 0.2764 | 0.4965 | 0.3213 | 0.2125 | 0.0622 | 0.1148 | 0.1094 |
| 2009 |  | 0.6177 | 0.2468 | 0.5466 | 0.6177 | 0.2437 | 0.1254 | 0.1329 | 0.6177 |
| 2010 |  | 0.0566 | 0.1258 | 0.1479 | 0.5974 | 0.1129 | 0.0822 | 0.1104 | 0.6279 |
| 2011 |  | 0.2190 | 0.0894 | 0.2164 | 0.6182 | 0.3316 | 0.0531 | 0.1085 | 0.5240 |
| 2012 |  | 0.1747 | 0.0877 | 0.2569 | 0.6250 | 0.3690 | 0.0877 | 0.0273 | 0.5252 |
| 2013 |  | 0.1315 | 0.8924 | 0.2145 | 0.0840 | 0.8924 | 0.8072 | 0.1076 | 0.1505 |
| 2014 |  | 0.0000 | 0.9691 | 0.0000 | 0.1514 | 0.9481 | 1.0000 | 0.1165 | 0.0000 |

Table 11 Difference series with reference sequence *Y*5

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *Y*5 | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 |  | 0.1706 | 0.3029 | 0.9069 | 0.9449 | 0.9449 | 0.1236 | 0.0551 | 0.2675 |
| 2006 |  | 0.0843 | 0.4042 | 0.1916 | 0.4655 | 0.7235 | 0.2024 | 0.0817 | 0.2167 |
| 2007 |  | 0.1478 | 0.6235 | 0.0761 | 0.0301 | 0.5040 | 0.3058 | 0.1440 | 0.0458 |
| 2008 |  | 0.0772 | 0.3319 | 0.4411 | 0.2659 | 0.2680 | 0.1176 | 0.0593 | 0.0540 |
| 2009 |  | 0.0000 | 0.3709 | 0.0711 | 0.0000 | 0.3739 | 0.4923 | 0.4848 | 0.0000 |
| 2010 |  | 0.2626 | 0.4450 | 0.1713 | 0.2782 | 0.2063 | 0.4014 | 0.2088 | 0.3087 |
| 2011 |  | 0.0654 | 0.2430 | 0.0629 | 0.4647 | 0.1780 | 0.2066 | 0.0451 | 0.3704 |
| 2012 |  | 0.0009 | 0.2633 | 0.0812 | 0.4494 | 0.1933 | 0.2633 | 0.1484 | 0.3496 |
| 2013 |  | 0.0269 | 0.7879 | 0.1099 | 0.0205 | 0.7879 | 0.7026 | 0.2121 | 0.0459 |
| 2014 |  | 0.0000 | 0.9691 | 0.0000 | 0.1514 | 0.9481 | 1.0000 | 0.1165 | 0.0000 |

**Appendix 2**

Table 12 Grey relational coefficients with reference sequence *Y*2

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *Y*2 | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 |  | 0.6890 | 0.5828 | 0.3420 | 0.3333 | 0.3333 | 0.7367 | 1.0000 | 0.6078 |
| 2006 |  | 0.6645 | 0.4663 | 0.5816 | 0.4410 | 0.3593 | 0.5743 | 0.8526 | 0.5650 |
| 2007 |  | 0.6802 | 0.4130 | 0.7538 | 0.8100 | 0.4582 | 0.5599 | 0.8981 | 0.7898 |
| 2008 |  | 0.6633 | 0.4958 | 0.6540 | 0.8485 | 0.5294 | 0.6296 | 0.8101 | 0.8031 |
| 2009 |  | 0.8676 | 0.6293 | 0.9898 | 0.8676 | 0.6268 | 0.5459 | 0.5504 | 0.8676 |
| 2010 |  | 0.9446 | 0.7656 | 0.8057 | 0.4672 | 0.8538 | 0.8204 | 0.8575 | 0.4543 |
| 2011 |  | 0.7125 | 0.8242 | 0.7151 | 0.4542 | 0.6140 | 0.8767 | 0.8457 | 0.4967 |
| 2012 |  | 0.9090 | 0.7019 | 0.7909 | 0.4998 | 0.6718 | 0.7019 | 0.8370 | 0.5552 |
| 2013 |  | 0.9205 | 0.3834 | 0.7986 | 0.9915 | 0.3834 | 0.4102 | 0.7185 | 0.8894 |
| 2014 |  | 1.0000 | 0.3403 | 1.0000 | 0.7675 | 0.3453 | 0.3333 | 0.8110 | 1.0000 |
| AVG. |  | 0.8051 | 0.5602 | 0.7431 | 0.6481 | 0.5175 | 0.6189 | 0.8181 | 0.7029 |

Table 13 Grey relational coefficients with reference sequence *Y*3

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *Y*3 | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 |  | 0.3924 | 0.4378 | 0.9293 | 1.0000 | 1.0000 | 0.3784 | 0.3333 | 0.4247 |
| 2006 |  | 0.4961 | 0.7268 | 0.5552 | 0.7980 | 0.7919 | 0.5620 | 0.4260 | 0.5712 |
| 2007 |  | 0.7749 | 0.6020 | 0.6974 | 0.6554 | 0.7032 | 0.9751 | 0.5336 | 0.6692 |
| 2008 |  | 0.8872 | 0.6111 | 0.5237 | 0.6414 | 0.6628 | 0.8278 | 0.8726 | 0.8809 |
| 2009 |  | 0.5567 | 0.9484 | 0.6046 | 0.5567 | 0.9540 | 0.8415 | 0.8523 | 0.5567 |
| 2010 |  | 0.6044 | 0.4952 | 0.6793 | 0.7007 | 0.6485 | 0.5176 | 0.6464 | 0.6721 |
| 2011 |  | 0.5027 | 0.3837 | 0.5015 | 0.8399 | 0.5669 | 0.3948 | 0.4525 | 0.7251 |
| 2012 |  | 0.4040 | 0.3333 | 0.4327 | 0.6351 | 0.4792 | 0.3333 | 0.3610 | 0.5636 |
| 2013 |  | 0.4402 | 0.7998 | 0.4749 | 0.4225 | 0.7998 | 0.9262 | 0.3637 | 0.4477 |
| 2014 |  | 0.3735 | 0.7932 | 0.3735 | 0.4211 | 0.8205 | 0.7561 | 0.4091 | 0.3735 |
| AVG. |  | 0.5432 | 0.6131 | 0.5772 | 0.6671 | 0.7427 | 0.6513 | 0.5250 | 0.5885 |

Table 14 Grey relational coefficients with reference sequence *Y*4

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *Y*4 | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 |  | 0.6890 | 0.5828 | 0.3420 | 0.3333 | 0.3333 | 0.7367 | 1.0000 | 0.6078 |
| 2006 |  | 0.7037 | 0.4852 | 0.6114 | 0.4580 | 0.3704 | 0.6034 | 0.9183 | 0.5931 |
| 2007 |  | 0.6936 | 0.4179 | 0.7702 | 0.8290 | 0.4642 | 0.5689 | 0.8758 | 0.8079 |
| 2008 |  | 0.9583 | 0.6440 | 0.5017 | 0.6088 | 0.7017 | 0.8894 | 0.8133 | 0.8204 |
| 2009 |  | 0.4474 | 0.6695 | 0.4778 | 0.4474 | 0.6723 | 0.7995 | 0.7900 | 0.4474 |
| 2010 |  | 0.8983 | 0.7990 | 0.7717 | 0.4556 | 0.8158 | 0.8589 | 0.8191 | 0.4433 |
| 2011 |  | 0.6955 | 0.8483 | 0.6979 | 0.4471 | 0.6013 | 0.9041 | 0.8217 | 0.4883 |
| 2012 |  | 0.7410 | 0.8508 | 0.6606 | 0.4444 | 0.5754 | 0.8508 | 0.9483 | 0.4877 |
| 2013 |  | 0.7918 | 0.3591 | 0.6998 | 0.8561 | 0.3591 | 0.3825 | 0.8230 | 0.7686 |
| 2014 |  | 1.0000 | 0.3403 | 1.0000 | 0.7675 | 0.3453 | 0.3333 | 0.8110 | 1.0000 |
| AVG. |  | 0.7618 | 0.5997 | 0.6533 | 0.5647 | 0.5239 | 0.6927 | 0.8620 | 0.6465 |

Table 15 Grey relational coefficients with reference sequence *Y*5

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *Y*5 | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 |  | 0.7456 | 0.6227 | 0.3554 | 0.3460 | 0.3460 | 0.8018 | 0.9008 | 0.6515 |
| 2006 |  | 0.8557 | 0.5530 | 0.7230 | 0.5179 | 0.4087 | 0.7118 | 0.8595 | 0.6976 |
| 2007 |  | 0.7719 | 0.4450 | 0.8680 | 0.9433 | 0.4980 | 0.6205 | 0.7764 | 0.9161 |
| 2008 |  | 0.8663 | 0.6010 | 0.5313 | 0.6529 | 0.6511 | 0.8096 | 0.8939 | 0.9025 |
| 2009 |  | 1.0000 | 0.5741 | 0.8755 | 1.0000 | 0.5721 | 0.5039 | 0.5077 | 1.0000 |
| 2010 |  | 0.6557 | 0.5291 | 0.7448 | 0.6425 | 0.7079 | 0.5547 | 0.7054 | 0.6183 |
| 2011 |  | 0.8843 | 0.6730 | 0.8883 | 0.5183 | 0.7374 | 0.7076 | 0.9173 | 0.5744 |
| 2012 |  | 0.9981 | 0.6550 | 0.8603 | 0.5267 | 0.7212 | 0.6550 | 0.7712 | 0.5885 |
| 2013 |  | 0.9489 | 0.3882 | 0.8198 | 0.9605 | 0.3882 | 0.4158 | 0.7021 | 0.9159 |
| 2014 |  | 1.0000 | 0.3403 | 1.0000 | 0.7675 | 0.3453 | 0.3333 | 0.8110 | 1.0000 |
| AVG. |  | 0.8726 | 0.5382 | 0.7666 | 0.6876 | 0.5376 | 0.6114 | 0.7845 | 0.7865 |

**Appendix 3**

The detailed calculation steps of using Entropy to obtain weights.

According to Eq. (2), the value of *p*ij could be calculated, as shown in Table 16 and Table 17.

Table 16 *p*ij value of logistics indicators

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 | 0.0925 | 0.0974 | 0.1235 | 0.1096 | 0.1075 | 0.0938 | 0.0931 | 0.0993 |
| 2006 | 0.0955 | 0.1009 | 0.0954 | 0.1049 | 0.1073 | 0.0992 | 0.0955 | 0.1006 |
| 2007 | 0.0997 | 0.1046 | 0.0949 | 0.0991 | 0.1054 | 0.1031 | 0.0961 | 0.1001 |
| 2008 | 0.0996 | 0.1020 | 0.0698 | 0.0951 | 0.1025 | 0.1009 | 0.0980 | 0.0998 |
| 2009 | 0.0870 | 0.0975 | 0.0737 | 0.0920 | 0.0968 | 0.0997 | 0.0994 | 0.0969 |
| 2010 | 0.1025 | 0.1025 | 0.1002 | 0.0937 | 0.1003 | 0.1049 | 0.1006 | 0.0974 |
| 2011 | 0.1015 | 0.1035 | 0.1031 | 0.0955 | 0.0987 | 0.1066 | 0.1022 | 0.0991 |
| 2012 | 0.1049 | 0.1046 | 0.1063 | 0.0971 | 0.0997 | 0.1091 | 0.1045 | 0.0998 |
| 2013 | 0.1055 | 0.0933 | 0.1076 | 0.1062 | 0.0904 | 0.0921 | 0.1060 | 0.1025 |
| 2014 | 0.1113 | 0.0937 | 0.1256 | 0.1069 | 0.0913 | 0.0905 | 0.1045 | 0.1044 |

Table 17 *p*ij value of manufacturing indicators

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Year | *Y*1 | *Y*2 | *Y*3 | *Y*4 | *Y*5 |
| 2005 | 0.0794 | 0.0818 | 0.1169 | 0.0721 | 0.0886 |
| 2006 | 0.0877 | 0.0856 | 0.1129 | 0.0788 | 0.0944 |
| 2007 | 0.0959 | 0.0927 | 0.1074 | 0.0864 | 0.0974 |
| 2008 | 0.0966 | 0.0919 | 0.1013 | 0.0957 | 0.0992 |
| 2009 | 0.0820 | 0.0847 | 0.0997 | 0.1015 | 0.0871 |
| 2010 | 0.1073 | 0.1071 | 0.0972 | 0.1050 | 0.0973 |
| 2011 | 0.1132 | 0.1121 | 0.0913 | 0.1108 | 0.1053 |
| 2012 | 0.1108 | 0.1118 | 0.0884 | 0.1155 | 0.1074 |
| 2013 | 0.1111 | 0.1124 | 0.0919 | 0.1146 | 0.1088 |
| 2014 | 0.1160 | 0.1199 | 0.0930 | 0.1197 | 0.1146 |

According to Eqs. (3) - (5), the Entropy *E*j, *d*j, *w*j could be calculated, as shown in Table 18 and Table 19.

Table 18 *E*j, *d*j, *w*j values of logistics indicators

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | *X*1 | *X*2 | *X*3 | *X*4 | *X*5 | *X*6 | *X*7 | *X*8 |
| 2005 | -0.2202 | -0.2268 | -0.2583 | -0.2423 | -0.2398 | -0.2220 | -0.2210 | -0.2294 |
| 2006 | -0.2243 | -0.2314 | -0.2241 | -0.2365 | -0.2396 | -0.2293 | -0.2243 | -0.2310 |
| 2007 | -0.2298 | -0.2361 | -0.2234 | -0.2291 | -0.2372 | -0.2343 | -0.2251 | -0.2304 |
| 2008 | -0.2297 | -0.2329 | -0.1857 | -0.2238 | -0.2335 | -0.2314 | -0.2277 | -0.2300 |
| 2009 | -0.2124 | -0.2270 | -0.1922 | -0.2195 | -0.2260 | -0.2298 | -0.2294 | -0.2262 |
| 2010 | -0.2334 | -0.2335 | -0.2305 | -0.2218 | -0.2307 | -0.2365 | -0.2311 | -0.2269 |
| 2011 | -0.2322 | -0.2348 | -0.2343 | -0.2242 | -0.2285 | -0.2387 | -0.2331 | -0.2291 |
| 2012 | -0.2366 | -0.2361 | -0.2383 | -0.2264 | -0.2299 | -0.2417 | -0.2361 | -0.2300 |
| 2013 | -0.2373 | -0.2213 | -0.2399 | -0.2382 | -0.2173 | -0.2196 | -0.2379 | -0.2335 |
| 2014 | -0.2444 | -0.2218 | -0.2606 | -0.2390 | -0.2185 | -0.2174 | -0.2360 | -0.2359 |
| SUM | -2.3004 | -2.3018 | -2.2873 | -2.3008 | -2.3009 | -2.3008 | -2.3017 | -2.3024 |
| *E*j | 0.9990 | 0.9996 | 0.9934 | 0.9992 | 0.9993 | 0.9992 | 0.9996 | 0.9999 |
| *d*j | 0.0010 | 0.0004 | 0.0066 | 0.0008 | 0.0007 | 0.0008 | 0.0004 | 0.0001 |
| *w*j | 0.0901 | 0.0335 | 0.6215 | 0.0727 | 0.0667 | 0.0721 | 0.0347 | 0.0088 |

Table 19 *E*j, *d*j, *w*j values of manufacturing indicators

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Year | *Y*1 | *Y*2 | *Y*3 | *Y*4 | *Y*5 |
| 2005 | -0.2011 | -0.2048 | -0.2509 | -0.1895 | -0.2147 |
| 2006 | -0.2135 | -0.2104 | -0.2462 | -0.2002 | -0.2228 |
| 2007 | -0.2249 | -0.2205 | -0.2396 | -0.2115 | -0.2268 |
| 2008 | -0.2258 | -0.2193 | -0.2320 | -0.2246 | -0.2292 |
| 2009 | -0.2050 | -0.2091 | -0.2299 | -0.2322 | -0.2125 |
| 2010 | -0.2395 | -0.2393 | -0.2265 | -0.2367 | -0.2268 |
| 2011 | -0.2466 | -0.2454 | -0.2185 | -0.2438 | -0.2370 |
| 2012 | -0.2438 | -0.2449 | -0.2144 | -0.2493 | -0.2396 |
| 2013 | -0.2441 | -0.2457 | -0.2194 | -0.2482 | -0.2413 |
| 2014 | -0.2498 | -0.2543 | -0.2209 | -0.2541 | -0.2483 |
| SUM | -2.2942 | -2.2937 | -2.2984 | -2.2901 | -2.2990 |
| *E*j | 0.9963 | 0.9961 | 0.9982 | 0.9946 | 0.9984 |
| *d*j | 0.0037 | 0.0039 | 0.0018 | 0.0054 | 0.0016 |
| *w*j | 0.2237 | 0.2376 | 0.1104 | 0.3330 | 0.0953 |

1. \* Corresponding author. E -mail address: jiangpeng1006@hotmail.com (P. Jiang) [↑](#footnote-ref-1)
2. [↑](#footnote-ref-2)