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Research on Index System for Disabled Elders Evaluation and Grey Clustering Model Based on End-point Mixed Possibility Functions

Sifeng Liu[1,2*], Yun Fan[1,2], Yingjie Yang[2,3], Xuerui Tan[4,5], Zhigeng Fang[1,2], Yequn Chen[5], Qin Zhang[1,2], Naiming Xie[1,2], Chaoqing Yuan[1,2], Qingyuan Xue[6], Liangyan Tao[1,2], Xiaojun Guo[2,7]

1. College of Economics and Management, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, P.R. China
2. Institute for Grey System Studies, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, P.R. China
3. Institute of Artificial Intelligence, De Montfort University, Leicester LE1 9BH, UK
4. Medical College of Shantou University, Shantou 515063, China
5. The First Affiliated Hospital of Shantou University Medical College, Shantou 515041, China
6. School of Health Management, Inner Mongolia Medical University, Hohhot 010110, China
7. Department of Mathematics, Nantong University, Nantong 226019, China

Abstract

An operational ability assessment system for older adults is of great help to address health and social challenges for ageing. In this paper, the main problems in currently available ADL and ability evaluation systems have been analyzed. The basic principles to build an index system for disability elders evaluation have been put forwarded. Then， an improved Barthel index system for ADL evaluation and a new older adults ability evaluation system consisted of 4 first-level indexes and 14 secondary indexes based on experts' opinion and the ability assessment system for older adults by Ministry of Civil Affairs of China have been built. The grey clustering model based on end-point mixed triangular possibility function has been introduced. And three living examples of adults' disability evaluation have been conducted. It is confirmed clearly that the three older adults belong to different categories of "severe disability", "mild disability", and "ability passable" respectively. The research results can be used as reference for government to formulate the elderly-care policies, to run and allocate the elderly-care resources, as well as reference for various nursing or elderly-care institutions.

Key words: Disability Elders Evaluation; Index System; Grey Cluster Model; ADL; Barthel Index; End-point Mixed Possibility Functions

[*] ***Corresponding Author:*** *Sifeng Liu, Institute for Grey System Studies of Nanjing University of Aeronautics and Astronautics, Nanjing 211106, P.R. China; E-mail: sfliu@nuaa.edu.cn*

1. Introduction

On 15th July 2019, the State Council of China issued the Opinions on Implementing the Healthy China Actions[1] (The State Council of China, 2019). At the same time, the General Office of the State Council of China issued the Programme for the Implementation and Assessment of the Healthy China Actions[2] (The General Office of the State Council of China, 2019). The Healthy China Action Promotion Committee had set up at the beginning of July, 2019 and an important document, Healthy China Action (2019-2030) was issued soon[3](The Healthy China Action Promotion Committee, 2019).

Population ageing is a trend that is both pronounced and historically unprecedented in the world. Since present to 2030, every country is likely to experience social challenges like ageing. It is estimated that in the next four decades, the share of people aged 60 years and older is expected to rise to 22% of the total population[4] (World Health Organization, 2015). In China, there were about 249 million people aged 60 and over by the end of 2018. With a share of 17.9% of the total population, more than 180 million elderly people suffer from chronic disease. About 40 million elderly people with functional limitations and disability[3] (The Healthy China Action Promotion Committee, 2019).

Populations are rapidly ageing worldwide with major implications for health systems. The number of older adults living in the world continues to increase[5] (World Health Organization, 2010), and recent research has begun to target interventions to older adults who have mobility limitations and are at risk for disability.

As early as late of 1950s, Katz et al[6] had done research on standardized measure of biological and psychosocial function of older adults and published the first activities of daily living (ADL) indexes system in 1963 (Katz, Ford and Moskowitz et al, 1963). In 1965, Mahoney and Barthel[7] proposed an ADL evaluation system named the Barthel Index (BI) (Mahoney and Barthel, 1965), which become a widely used tool for ADL evaluation. In the late 1990s, Tennant et al analyzed the advantages and disadvantages of BI[8, 9](Tennant, Geddes, and Chamberlain, 1996; Tennant,1997). In 2002, Lan et al[10] developed an objective index of mobility-related limitation to measure performance and disability (Lan, Melzer, Tom, 2002). In 2007, Groessl et al[11] found that older adults who are at risk for disability had reduced Health-related quality of life (HRQOL). And mobility was a stronger correlate of HRQOL than an index of comorbidity, suggesting that interventions addressing mobility limitations may provide significant health benefits to this population (Groessl, Kaplan, and Rejeski, et al, 2007). In 2010, Mollaoglu, Tuncay, and Fertelli[12] found that disability is a factor that has a significant effect on the life satisfaction of elderly people (Mollaoglu, Tuncay, and Fertelli, 2010). In 2018, Xia, Yu, Zhang, et al[13] used a three-round Delphi method involving 33 experts to build an appropriate ability rating system for old people (Xia, Yu, Zhang, et al, 2018). At the same time, to stratify an older adult population for subsequent interventions based on functional ability, and to estimate prevalence, characteristics and impact of mobility limitations on health outcomes. Musich, Wang, Ruiz et al[14] conducted a research based on a stratified random sample of AARP(R) Medicare Supplement insured. They found that among weighted survey respondents (N = 15,989), severe, moderate and no limitation levels were 21.4%, 18.4% and 60.3%, respectively. Peng, Song, and Mao[15] published a review article which focus on the disability assessment tools in China's long-term care service. They tried to clarify the conceptual differences between

"disability" and "care dependency", emphasized the importance of "frailty" and "resilience" in life course study of disability. To develop and promote efficient policies for ageing and providing the possible "Chinese version" solutions in this field for the rest of the world (Peng, Song, and Mao, 2018). In 2019, Chen, Ding, Wu, et al[16] conducted a research to examine the psychometric properties of the BI in the assessment of older patients admitted to internal medicine wards using Rasch analysis. A total of 190 older inpatients were included from the internal medicine wards of a general hospital in Guangzhou. All participants were evaluated using BI. They did Rasch analysis for the BI data from reliability, discrimination, unidimension, matched-degree, item difficulty, response threshold validity and item functional difference and got some valuable conclusions (Chen, Ding, Wu, et al, 2019).

In fact, in the process of ability or disability evaluation, the concepts of ability intact, mild disability, moderate disability, and severe disability are all grey concepts as people only can obtain a grey understanding from all the capability descriptions of sub-indexes such as ability or disability for eating, bathing, or going to the lavatory, etc. Therefore, grey system theory, especially the grey clustering evaluation models can be used for ability or disability evaluation.

Grey cluster evaluation models using possibility functions are being widely used for uncertain systems analysis. For the past three decades, researches on modeling techniques are very active, and new research results are constantly emerging. Deng[17] proposed the grey variable weight clustering model (Deng, 1986) and Liu[18] proposed the grey fixed weight clustering evaluation model (Liu, 1993), the grey cluster evaluation models using end-point triangular possibility functions[19-21] (Liu and Zhu, 1993; Liu, 1991; Liu and Lin, 2006), and the grey cluster evaluation models using centre-point triangular possibility functions[22, 23] (Liu and Xie, 2011; Liu, Yang and Forrest, 2017), etc. These models have wide applications. Grey variable weight clustering models are applicable to the problems with the same meanings and dimensions for each criterion. When the criteria for clustering have different meanings, dimensions, grey fixed weight clustering evaluation models and grey cluster evaluation models using possibility function are more suitable. Particularly, compared with grey variable weight clustering models and grey fixed weight clustering models, grey cluster evaluation models using possibility function are more suitable for solving the problem of poor information clustering evaluation. Grey cluster evaluation models using end-point triangular possibility functions are suitable for the situation when all grey boundaries are clear, but the most likely points belonging to each grey class are unknown; grey cluster evaluation models using centre-point triangular possibility functions are suitable for those problems where it is easy to judge the most likely points belonging to each grey class, but the grey boundary is not clear[24, 25] (Liu, et al 2015; Liu, 2017).

The purpose of this study is to set up a novel ADL evaluation system based on the Barthel Index (BI), and a novel ability assessment system for older adults will be build based on the civil administration professional standard of MZ/T 039-2013[26] (Ministry of Civil Affairs of China, 2013). Then, the grey clustering model based on end-point mixed possibility functions which can be used for comprehensive evaluation of both ADL and the ability will be presented. The open access software for grey clustering evaluation modeling can be found in the grey system modeling software version 8.0 written by Professor Bo Zeng which contains applications of commonly used grey systems models, and is available at the websites of the International Association of GSUA (www.iagsua.org) and the

Institute for Grey System Studies at Nanjing University of Aeronautics and Astronautics (igss.nuaa.edu.cn).

2. Problems in currently available ADL and ability evaluation systems

2.1 Problems of Barthel Index

Table 1 Barthel Index

Index	Capability description	Score
Eating	Independent. Able to feed himself/herself. The food may be prepared and served by someone else	10
	Needs help with cutting meat or bread but is able to feed himself/herself	5
	Dependent. Must be fed by someone else	0
Getting Dressed	Independent. Able to put on and take off clothing without help	10
	Needs help. Completes at least half the tasks by himself/herself within a reasonable time	5
	Dependent	0
Grooming Personal hygiene	Independent. The items needed may be supplied by someone else	5
	Dependent. Needs some help	0
Bathing	Independent. The items needed may be supplied by someone else	5
	Dependent. Needs some help	0
Bowel control	Continent	10
	Occasional accidents. Less than once a week. Needs help with handling catheters or other devices	5
	Incontinent	0
Bladder control	Continent	10
	Occasional accidents. Maximum 1 episode of incontinence per 24 hr. Includes needing help with handling catheters or other devices	5
	Incontinent	0
Going to the lavatory	Independent. Enters and leaves by himself/herself. Does not need assistance from someone else	10
	Needs help. Able to manage with a little help. Able to wipe himself/herself	5
	Dependent. Needs a lot of help	0
Chair-bed transfer	Independent	15
	Minimal assistance. Includes verbal supervision or a little physical assistance	10
	A lot of help. Needs the assistance of a strong or trained person	5
	Dependent. Needs the lift. Unable to maintain sitting position	0
Ambulation	Independent. Able to walk 50 metres without assistance. May use instrumental aids (cane, crutches), except for a walker	15
	Needs help. Needs supervision or a little physical assistance from someone else. Requires a walker	10
	Independent (in wheelchair) at 50 m. Needs no assistance or supervision	5
	Dependent	0
Going up and down stairs	Independent	10
	Needs help	5
	Dependent	0

The Barthel Index (see Table 1) is the most used ADL evaluation system in the world. However, Tennant, Geddes and Chamberlain[8, 9] and O'Connor，Cano，and Thompson[27] found some major problems of the Barthel Index (Tennant, Geddes and Chamberlain, 1996; Tennant, 1997; O'Connor，Cano，and Thompson, 2004). In 2019, Chen, Ding, and Wu, et al[16] had pointed out the following defects of the Barthel Index (BI) based on Rasch analysis and the previous discovers (Chen, Ding, Wu, et al, 2019).

(1) The fitting errors of some indexes such as chair-bed transfer, ambulation, bathing, getting dressed and going to the lavatory are out of the acceptable range.

(2) The correlation coefficient of bowel control and bladder control > 0.7.

(3) For some indexes, the degree of difficulty don't mate to the ability of the testees.

(4) The threshold of some indexes are unreasonable.

(5) The scoring method of BI is unreasonable, and the total score of BI are significantly different to ability of the testees.

From Table 1, it's easy to find that there are other problems in BI system as well e.g.,

(6) Ability is a concept of continuously changing but don't jump from independent to dependent. For example, the eating capability of an older adult can be scored as 10, 9, 8, 7, 7.5 and so on, but don't 10, 5, 0 only.

(7) There are several indexes to reflect one ability. For example, bowel control, bladder control and going to the lavatory are all reflect the ability to excrete.

(8) The weights of the indexes were reflected by different scores are unreasonable. According to the results by Xia, Yu, Zhang, et al[13], the weights of different indexes without significant difference (Xia, Yu, Zhang, et al, 2018).

2.2 Problems of the ability assessment system for older adults by MZ/T 039-2013

The ability assessment system for older adults by Ministry of Civil Affairs of China is shown in table 2[26] (Ministry of Civil Affairs of China, 2013). According to the scores of four first –level-indexes, the ability of older adults was divided in four grades: ability intact, mild disability, moderate disability, and severe disability. Actually, the four grades are four grey classes. For example, for ADL evaluated by BI, the grading standards of four grades or classes as shown in Table 2.

Table 2 The grading standards of ADL of MZ/T 039-2013

Grade	Grade description	Range of score
0	ability intact	100
1	mild disability	65-95
2	moderate disability	45-60
3	severe disability	0-40

The assessment result is obtained by considering the grades of four first-level-indexes but don't an integrated score by the scores of four first –level-indexes.

From the gradation standard of ADL in Table 2 and the ability assessment system for older adults in Table 3, we can find that there are some problems have hampered the application of the assessment system.

(1) There is no an integrated score to reflect the assessment outcome.

(2) As a grade or class, the meaning of ability intact not quite right. As a

grey class, “ability passable” may be better than “ability intact” in implication.

Table 3 The ability assessment system for older adults of MZ/T 039-2013

First-level-index	Secondary Indexes	Score
ADL	10 Barthel Indexes	0-100
Mental status	3 indexes: cognition ability, attack behavior, depression	0-6
Sensory and communication	4 indexes: level of consciousness, vision, hearing, communication	0-3
Social involvement	5 indexes: ADL, capacity for work, temporal/ spatial orientation, orientation for person, social interaction	0-20

(3) There are some range of scores which no corresponding grades are defined. Such as (40-45), (60,65), and (95,100). Any scores in these sub-intervals without corresponding grades.

(4) The index ADL assessed by BI which with many other problems as mentioned in 2.1.

(5) The direction of the four first-level indexes in table 3 are inconsistency.

(6) The scores of different indexes are unreasonable.

(7) The first –level-index ADL included in Social involvement as a secondary index. It doesn’t satisfy with independence. Some secondary indexes are incident with one another. Such as cognition ability and level of consciousness are interrelated, level of consciousness and communication are interrelated, communication, social interaction and capacity for work are interrelated.

(8) It’s difficult to obtain a comprehensive evaluation outcome by this ability assessment system for older adults.

3. The novel ability assessment system for older adults

3.1 The principles to establish an index system for older adults ability evaluation

One should abide by the following principles to build index system for older adults ability evaluation:

(1) The principle of inheritance. The novel ability assessment system for older adults should absorb all the scientific and valuable results from existing evaluation systems such as BI, and the ability assessment system for older adults by Ministry of Civil Affairs of China. Including the conclusions obtained by scholars worldwide.

(2) Completeness principle. The index system for ADL or ability evaluation should include all the main factors and related variables which are the characterization of ADL or ability for older adults. It also means to avoid one sidedness as far as possible and even more no important omission.

(3) Hierarchical principle. The index system for older adults ability evaluation is composed of some secondary indexes, and each secondary index can be divided into a plurality of sub-indexes. And it finally forms a multi-level index system for older adults ability evaluation.

(4) The principle of independence. The index system for older adults ability evaluation can be as an integrated whole, requires the independence of each evaluation index of the same level.

(5) The principle of comparability. The essence of evaluation is comparison.

Only comparable indicators can provide relatively accurate information. Each index of the index system for older adults ability evaluation requires have comparability. So in addition to having the coherent caliber and scope, it is best for us to use comparable indicators such as relative numbers, proportional numbers, and average numbers to evaluate.

(6) The principle of operability. To establish the index system for older adults ability evaluation, we should fully consider its operability. Firstly, it should be concise and to use as little as possible indicators to reflect the overall ability state. Secondly, the data can be obtained easily, such as no complex special checks are required. The third is easy to measure and calculation method is easy to master. The fourth is that the indicators which with clear meanings and have strong representative should be selected at first. So that the evaluation result can be easy understood.

In addition, we should also pay attention to the dialectical unity of quantitative index and qualitative index, static indicators and dynamic indicators, absolute index and relative index.

3.2 The new evaluation index systems

The results were discussed repeatedly by team members who were interested in disability elders evaluation and thought deeply. We finally got the ADL of the improved BI consisted of 6 sub-indexes and the older adults ability evaluation system which consisted of 4 first-level-indexes and 14 secondary indexes. The scores of all the indexes are set as 0 to100 for convenience. On this basis, 36 experts independently reviewed the indexes and gave the advice of the first-level and secondary indexes and the weights. In the improved BI (see Table 4), bathing has included in Grooming and Personal hygiene, Bowel control, Bladder control and Going to the lavatory are combined to one index of excretion, Going up and down stairs has included in ambulation. The comprehensive ADL is the weighted sum of the 6 first-level-indexes.

Table 4 The improved Barthel Index

Index	Capability description	weight
Eating	Capability of self feed	0.20
Getting Dressed	Capability to put on and take off clothing	0.14
Grooming Personal hygiene	Capability of Grooming, Personal hygiene and bathing	0.13
Excretion	Capability of going to toilet without accidents	0.20
Chair-bed transfer	Degree of independence	0.13
Ambulation	Degree of independence, including going up and down stairs	0.20

The new older adults ability evaluation system can be seen in Table 5. There the ADL evaluated by the improved Barthel Indexes. The comprehensive adults ability can be evaluated by grey clustering model based on end-point mixed possibility functions.

All the indexes in Table 5 are positive change indexes i.e., the larger the value of an index, the stronger the ability is. The weights of the four first-level indexes of ADL, Mental status, Sensory and communication and Social involvement are 60, 12, 13 and 15, respectively. Due to limited space, the secondary Indexes of Mental status, Sensory and communication and Social involvement are not further elaborated.

Table 5 The adults ability evaluation system

First-level index	Secondary Indexes	weight
ADL (0.60, The improved Barthel Indexes)	Eating	0.12
	Getting Dressed	0.08
	Grooming Personal hygiene	0.08
	Excretion	0.12
	Chair-bed transfer	0.08
	Ambulation	0.12
Mental status (0.12)	attack behavior	0.06
	depression	0.06
Sensory and communication (0.13)	vision	0.06
	hearing	0.04
	communication	0.03
Social involvement (0.15)	capacity for work	0.06
	temporal/spatial orientation	0.05
	orientation for person	0.04

4. The grey cluster evaluation model based on end-point mixed possibility function

The grey cluster evaluation model based on end-point mixed possibility function is suitable for situations where all grey boundaries are clear, but the most likely points belonging to each grey class are unknown. The modeling steps are explained as follows.

Assume that there are *n* older adults to be classified into *s* different grey classes according to the values of *m* criteria.

Step1: Divide the value range of each index into s classes. For example, the value range $[a_1, a_{s+1}]$ of index j can be divided into s small intervals:

$$[a_1, a_2], \cdots, [a_{k-1}, a_k], \cdots, [a_{s-1}, a_s], [a_s, a_{s+1}]$$

The value of a_k $(k = 2, \cdots, s)$ can be determined by the actual assessment requirements or the qualitative research results.

Step 2: Determine the turning point λ_j^1 and λ_j^s of $[a_1, a_2]$ and $[a_s, a_{s+1}]$ that correspond to grey classes 1 and s. At the same time, calculate the midpoint $\lambda_k = (a_k + a_{k+1})/2$ for each small interval $[a_k, a_{k+1}]$, $k = 2, \cdots, s-1$.

Step 3: For grey class 1 and grey class s, construct the corresponding possibility function of lower measure $f_j^1[-,-,\lambda_j^1,\lambda_j^2]$ and the possibility function of upper measure $f_j^s[\lambda_j^{s-1},\lambda_j^s,-,-]$ (shown in Fig.1).

Step 4: For grey class $k(k \in \{2,3,\cdots,s-1\})$, connecting point $(\lambda_j^k,1)$ with both midpoint $(\lambda_j^{k-1},0)$ of grey class $k-1$ (or turning point $(\lambda_j^1,0)$ of grey class 1) and midpoint $(\lambda_j^{k+1},0)$ of grey class $k+1$ (or turning point $(\lambda_j^s,0)$ of grey class s), we can get the triangular possibility function $f_j^k[\lambda_j^{k-1},\lambda_j^k,-,\lambda_j^{k+1}]$, $j = 1,2,\cdots;m;k = 2,3,\cdots,s-1$ of index j regarding grey class k (shown in Figure 1).

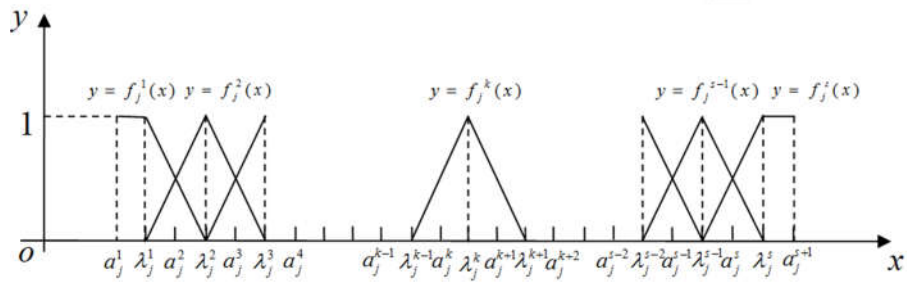

Figure 1 The end-point mixed possibility functions

Step 5: Determine the weight $w_j, j = 1,2,\cdots,m$ of each index.

Step 6: Calculate the clustering coefficient σ_i^k of object $i(i = 1,2,\cdots,n)$ regarding grey class $k(k = 1,2,\cdots,s)$

$$\sigma_i^k = \sum_{j=1}^{m} f_j^k(x_{ij}) \cdot w_j \tag{1}$$

where $f_j^k(x_{ij})$ is the possibility function of index j in concern of subclass k, w_j is the weight of index j among comprehensive clustering.

Step 7: By $\max_{1\le k\le s}\{\sigma_i^k\} = \sigma_i^{k^*}$, we can confirm that object i belongs to grey class k^*.

5. Examples – Adults ability evaluation

The evaluation score of ADL is the weighted sum of the 6 indexes shown in table 4, Therefore, the evaluation scores of the 4 first-level-indexes in table 5 are laid in the interval of [0, 100]. The evaluation results are divided into four grey classes or grades including "ability passable", "mild disability", "moderate disability" and "severe disability" according to the ability assessment system for older adults of MZ/T 039-2013. The value range of [0,100] was divided into four sub-intervals of [0,50), [50, 70), [70, 90), [90, 100] correspondingly. The turning points of "ability passable" and "severe disability" were set up as $\lambda_j^4 = 95$ and $\lambda_j^1 = 30$ respectively. The midpoints of sub-intervals [50, 70) and [70, 90) are $\lambda_j^2 = 60$, $\lambda_j^3 = 80$ respectively.

The possibility function of all 4 indicators about four grey classes of "ability passable", "mild disability", "moderate disability" and "severe disability" is the same:

$$f_j^1(x) = \begin{cases} 0 & x \notin [0,60] \\ 1 & x \in [0,30] \\ \dfrac{60-x}{60-30} & x \in [30,60] \end{cases} \tag{2}$$

$$f_j^2(x)=\begin{cases}0 & x\notin[30,80]\\ \dfrac{x-30}{60-30} & x\in[30,60]\\ \dfrac{80-x}{80-60} & x\in[60,80]\end{cases} \tag{3}$$

$$f_j^3(x)=\begin{cases}0 & x\notin[60,95]\\ \dfrac{x-60}{80-60} & x\in[60,80]\\ \dfrac{95-x}{95-80} & x\in[80,95]\end{cases} \tag{4}$$

$$f_j^4(x)=\begin{cases}0 & x\notin[80,100]\\ \dfrac{x-80}{95-80} & x\in[80,95]\\ 1 & x\in[95,100]\end{cases} \tag{5}$$

Where the possibility function of each indicator for grey class of "severe disability" is a possibility function of lower measure, for grey class of "ability passable" is a possibility function of upper measure, and for grey classes of "mild disability" and "moderate disability" are triangular possibility functions respectively.

The values of the 4 first-level-indexes for three older adults at LCY living quarter in Nanjing are shown in table 6.

Table 6 The scores of 4 first-level-indexes of the three older adults

Index	ADL	Mental status	Sensory and communication	Social involvement
Scores of A	25	75	86	10
Scores of B	76	85	90	45
Scores of C	98	95	91	90

The values of possibility functions for the different grey classes of each indicator can be calculated by formula (2)-formula(5).

The grey clustering coefficient δ_i (i=A,B,C) can be calculated by using formula (1). The outcomes are shown in table 7.

Table 7 Grey clustering coefficients of regarding to each grey class

Cluster object	Clustering coefficient			
	σ_i^1	σ_i^2	σ_i^3	σ_i^4
A	0.75	0.03	0.168	0.052
B	0.075	0.099	0.603	0.127
C	0	0	0.085	0.915

From $\max\limits_{1\le k\le 4}\left\{\sigma_A^k\right\}=0.75=\sigma_A^1$, $\max\limits_{1\le k\le 4}\left\{\sigma_B^k\right\}=0.603=\sigma_B^3$, and $\max\limits_{1\le k\le 4}\left\{\sigma_C^k\right\}=0.915=\sigma_C^4$, one can know that A belongs to the grey class of "severe disability", B belongs to the grey class of "mild disability", and C belongs to the grey class of "ability passable". It is consistent with the doctor's diagnosis.

The calculation process can be completed by the software of grey cluster evaluation model based on end-point mixed possibility function in the aforementioned grey system modeling software.

6. Concluding remarks

It is of great significance to construct a social old-age security system for assist in decision-making on resource allocation of aged service with view to build a scientific and functional older adults ability evaluation system and synthetic evaluation model for accurate assessment of health status and health needs of the elderly population. An improved Barthel Index system for ADL evaluation and a new older adults ability evaluation system based on the ability assessment system for older adults by Ministry of Civil Affairs of China have been built and the grey clustering model based on end-point mixed triangular possibility function has been introduced in this paper. And three living examples of adults ability evaluation have been conducted.

The deterioration of physical function in the elderly is a dynamic process. The mental and physical functions of the elderly gradually declining growing with age, ultimately leading to disability. Therefore, the adults ability evaluation is a continuing task. The government departments and aged service institutions should to arrange specialized personnel, set reasonable time interval for adults ability evaluation, evaluating periodically and monitoring dynamically. Enable to keep abreast of the health status and health needs of the elderly adults.

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