

A study on group evaluation with body mass index

C. H. Hung *

Department of Recreation and Sports Management

National Chin-Yi Institute of Technology

No. 35, Lane 215, Section 1

Chung Shan Road Taiping

Taichung 411

Taiwan

R.O.C.

Abstract

This paper refers to the process capability indices in the field of management to set up *Body Mass Indices* (BMI), which can be used to evaluate and compare the BMI values of people at different ages as a group. A large number of improvement plans were brought up to settle obesity problems; however, there could be up to thousands or even tens of thousands of subjects involved. With BMI, the results and effects of the plans can be evaluated by sampling, a characteristic of BMI. Therefore, BMI has served as an accurate, easy and convenient measurement to evaluate group BMI.

Keywords : *Body Mass Index (BMI), BMI index, BMI reaching rate.*

I. Preface

In 1997, the World Health Organization (WHO) pointed out that obesity is not a state or a risk factor, but a disease. As the world obese population grows rapidly, obesity has become a new epidemic. A variety of evidence has shown that obesity is closely related to malignancies, heart diseases, strokes, diabetes, hyperlipidemia and hypertension; what's worse, obesity enhances the risk of suffering from gallbladder diseases, pains in bones, muscles or joints, and respiratory tract diseases. Obesity even results in mental social barrier. Nevertheless, some researches indicate that obesity can be effectively controlled and prevented by changing

*E-mail: hongjh@chinyi.ncit.edu.tw

Journal of Statistics & Management Systems

Vol. 9 (2006), No. 3, pp. 651–660

© Taru Publications

lifestyle and behavior, especially modifications in exercises and dietary habits. Weight loss contributes to the control of the risk factors of heart diseases such as blood sugar, blood pressure and lipid.

In order to solve the "Little Fatty" problem among six hundred thousand elementary and junior high school students, the Ministry of Education, R.O.C., drew up a "Promoting Students' Healthy Body Position 5-Year Project" in 2004. That is to say, in the coming five years, the government will promote "No snacks and drinks in canteens!" and "Take less elevator, walk more!" projects in every school and wish to make each school a "Health Promotion School." Referring to the normal BMI value of different age groups, published by Department of Health, Executive Yuan, the government intends to make school children restore to their normal healthy body position by controlling nutrition and lengthening exercise time. From 2005, the Department of Health, Executive Yuan, plans to conduct an "Adults' Weight-Controlling — Challenge 1824" project on a larger scale, which is expected to be completed in 2007. The project aims to reduce the obesity rate of the citizens from 11.5% to 8% and overweight rate from 21.5% to 18%. From the above, it can be seen that the authorities concerned place great emphasis on obesity problems of the citizens and have worked out response plans to contain the growing rate of obese population, cherishing a hope to improve the citizens' health.

Although obesity affects one's health, how do we tell if a person is obese or overweight? Furthermore, how do we evaluate the effects of the weight-loss and weight-controlling plans? Employing *Body Mass Index* (BMI) to measure the degree of obesity is easy and suitable for males and females alike; accordingly, BMI is widely used in medical research. BMI is an exponent to decide if a person is obese, which equals weight divided by the square of the height, say, kg/m^2 . Since February 2001, the Department of Health, Executive Yuan, has invited professionals and experts from Chinese Taipei Nutrition Association, Taiwan Medical Association for the Study of Obesity, Diabetes Association and Chinese Taipei Association for the Study of Obesity to form an obesity-defining commission and a response team, in which it is agreed that BMI 24 represents overweight to an adult while BMI 27 stands for obesity and BMI 18.5-24 is considered normal. In Aug. 2002, the obesity standard of children and adolescents is announced and the BMI value of normal and obese children, aged from 2 to 18, is defined. (See Table 1)

BMI helps individuals to figure out if she/he is obese based on his/her own height and weight. BMI is thus counted self-measurement. However, as far as "Promoting Students' Healthy Body Position 5-Year Project" and "Adults' Weight-Controlling — Challenge 1824 Project" are concerned, both engage thousands of people or tens of thousands of people and intend to assess the effects of the projects by BMI. To measure BMI of tens of thousands of people is a complicated task. If a tool to measure the proportion of population with "normal" BMI value is developed, we can learn the BMI value of the population as a whole or assess the effects of the weight-controlling plans. Thereby, it is necessary to establish BMI indices.

In the field of quality management, under the condition that the process is stable, if we attempt to further understand how many nonconforming items there are among the products or to what extent the products conform to the standards, one of the convenient ways to determine is making use of process capability indices. Process capability indices are an effective tool to evaluate the process capability and performance of the product. It can be used to assess and analyze if the process capability of a product meets the requirements. On the one hand, the process quality of the product is under control to ensure the quality is above average. On the other hand, the nonconforming items can also be avoided. These years, thanks to many statisticians and quality engineers devote themselves to the study of process capability indices, process capability indices can make precise measurements of process capability and performance, and can be applied to evaluate the process capability of various industries, for example, Kane (1986); Chan *et al.* (1988); Pearn *et al.* (1992); Boyles (1994); Chen *et al.* (2002); Chen *et al.* (2004). Su *et al.* (2002) has ever applied process capability indices to evaluation of swimming teaching effectiveness. It is thought that employing the concept of process capability indices to measure the reaching capacity of BMI within normal range and assessing the effectiveness of weight-control need further discussion. In consequence, this research refers to the process capability indices in management field to establish appropriate indices to evaluate BMI as a tool to assess the effectiveness of weight-control.

II. BMI index B_j

BMI makes use of the ratio of height to weight to estimate the body composition of the individual. Higher BMI value means "obesity" while lower BMI value represents "thinness". The normal, overweight,

and obese BMI values of different age groups are within a certain range. According to the normal range of BMI in 2-18 children and adolescents, published by the Department of Health, Executive Yuan, this research establishes the BMI index B_j . Let U be the upper limit of the normal range of BMI and L be the lower limit of the normal range of BMI. Suppose X stands for BMI, X will undoubtedly be a random variable since the BMI value of each individual varies. The value of X should be within a certain range, not too high or too low. From the perspective of quality management, the quality characteristic of BMI belongs to nominal-the-best type. Consequently, this research consults the quality characteristic indices, proposed by Boyles (1994) and suitable for nominal-the-best type, to evaluate if BMI is within the reasonable range. The BMI index B_j can be defined as follows.

$$B_j = \Phi^{-1} \left\{ \frac{1}{2} \Phi \left(\frac{U - \mu}{\sigma} \right) + \frac{1}{2} \Phi \left(\frac{\mu - L}{\sigma} \right) \right\}.$$

In it, j is age, μ is the average of the random variable X and σ is the standard deviation of X . The closer μ gets to the median of (L, U) , the higher the reaching rate p_j of BMI normal range is. The smaller the standard deviation σ is, the more stable BMI is. That is, when BMI is converging and the difference among one another is not very significant, the value of BMI index B_j will become bigger. Suppose the ratio of population whose BMI index B_j reaches "normal range" is p_j , then $p_j = P(L \leq X \leq U)$. Under the normal distribution assumption, say, X obeys normal distribution where the average is μ while the standard deviation is σ , let $Z = (X - \mu)/\sigma$. Then, Z obeys the standard normal distribution and the relation between p_j and B_j can be described as follows.

$$p_j = P(L \leq X \leq U) = P \left(\frac{\mu - L}{\sigma} \leq Z \leq \frac{U - \mu}{\sigma} \right) = 2\Phi(B_j) - 1.$$

In this formula, Φ is the function of cumulative standard normal distribution. Grounded on the formula, the bigger the value of the index B_j is, the higher p_j is; the smaller the value of the index B_j is, the lower p_j is. BMI index B_j can thus fully represent the BMI reaching rate p_j .

III. BMI reaching rate p_j

Actually, BMI reaching rate is the function of BMI index B_j ; moreover, they are one-to-one correspondent. Thereby, the relation between BMI index B_j and BMI reaching rate p_j can be expressed as the following.

$$p_j = 2\Phi(B_j) - 1, \quad j = 2, 3, 4, 5, \dots, 18.$$

Table 1
Obesity definition of children and adolescents

Age	Male			Female		
	Normal (BMI between)	Overweight (BMI \geq)	Obese (BMI \leq)	Normal (BMI between)	Overweight (BMI \geq)	Obese (BMI \leq)
2	15.2-17.7	17.7	19.0	14.9-17.3	17.3	18.3
3	14.8-17.7	17.7	19.1	14.5-17.2	17.2	18.5
4	14.4-17.7	17.7	19.3	14.2-17.1	17.1	18.6
5	14.0-17.7	17.7	19.4	13.9-17.1	17.1	18.9
6	13.9-17.9	17.9	19.7	13.6-17.2	17.2	19.1
7	14.7-18.6	18.6	21.2	14.4-18.0	18.0	20.3
8	15.0-19.3	19.3	22.0	14.6-18.8	18.8	21.0
9	15.2-19.7	19.7	22.5	14.9-19.3	19.3	21.6
10	15.4-20.3	20.3	22.9	15.2-20.1	20.1	22.3
11	15.8-21.0	21.0	23.5	15.8-20.9	20.9	23.1
12	16.4-21.5	21.5	24.2	16.4-21.6	21.6	23.9
13	17.0-22.2	22.2	24.8	17.0-22.2	22.2	24.6
14	17.6-22.7	22.7	25.2	17.6-22.7	22.7	25.1
15	18.2-23.1	23.1	25.5	18.0-22.7	22.7	25.3
16	18.6-23.4	23.4	25.6	18.2-22.7	22.7	25.3
17	19.0-23.6	23.6	25.6	18.3-22.7	22.7	25.3
18	19.2-23.7	23.7	25.6	18.3-22.7	22.7	25.3

DATA SOURCE: Department of Health, Executive Yuan, Taiwan, R.O.C., 2005

After the BMI index B_j is figured out, the BMI reaching rate p_j can be referred to in the appendix. Under the condition that BMI reaching rate is the function of BMI index and the two are one-to-one correspondent, p_j will be higher when B_j is bigger; p_j will be lower when B_j is smaller. Once the value of B_j is calculated, we can work out the BMI reaching rate p_j within normal range on the basis of the value of B_j . For instance, if $B_{18} = 2.0$, then $p_{18} = 95.44$ based on Appendix. The figure means 95.44 percent of 18-year-old people have their BMI within "normal range."

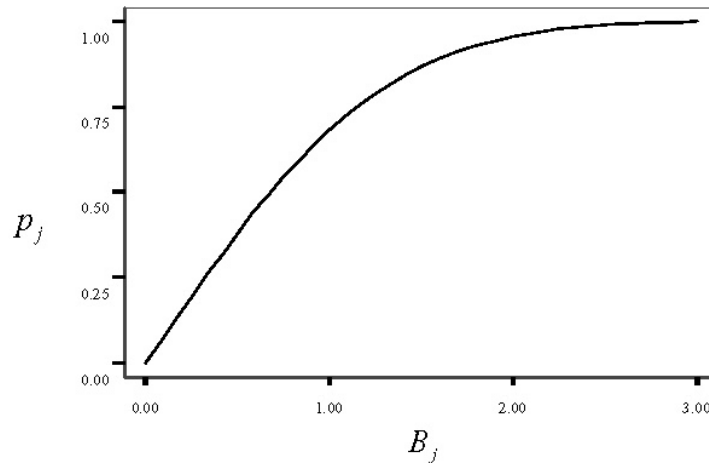


Figure 1
The functional relation between p_j and B_j

IV. BMI General index B^T

BMI index corresponds to the BMI reaching rate of different age groups. This section intends to establish BMI general index and from it infer BMI general reaching rate to facilitate the evaluation of group BMI. Based on the analysis of BMI reaching rate and BMI index in the previous section, let $W_j = N_j/N$ represent the weight of the age group j , say, the number of people at the age of $j(N_j)$ divided by the total number of people $N = N_2 + N_3 + \dots + N_{18}$. Thereby, a general index B^T reflecting the BMI general reaching rate is set as follows.

$$B^T = \Phi^{-1} \left[\sum_{j=2}^{18} W_j \Phi(B_j) \right].$$

It is obvious that if the BMI index B_j of each age group reaches ν , BMI general index B^T will be ν , that is, $B^T = \Phi^{-1} [\sum W_j \Phi(\nu)]$. Besides, seeing that

$$\begin{aligned} \sum_{j=2}^{18} W_j \Phi(B_j) &= \Phi(B^T), \text{ say, } 2\Phi(B^T) - 1 = \sum W_j [2\Phi(B_j) - 1] \\ &= \sum W_j P_j = P^T, \end{aligned}$$

the general BMI reaching rate $p^T = 2\Phi(B^T) - 1$.

Evidently, the general BMI index B^T and the general BMI reaching rate p^T are one-to-one correspondent. When the value of B^T is big enough, the value of p^T is relatively high. For example, when $B^T = 1.0$, the general BMI reaching rate within normal range $p^T = 68.26\%$; similarly, when $B^T = 2.0$, the general BMI reaching rate within normal range $p^T = 95.44\%$.

Despite the fact that the general BMI reaching rate p^T can be obtained by calculating the ratio of the number of people whose BMI reaches "normal range" among all subjects, Montgomery (1991) pointed out that the sample size ought to be large enough to produce an accurate result. On the other hand, a large sample size is not needed in the calculation of BMI index. BMI index and BMI reaching rate are one-to-one correspondent, so the BMI reaching rate can be precisely estimated. The appendix is the correspondence of BMI index to BMI reaching rate. If the value of BMI is not found in the appendix, the BMI reaching rate can be referred to cumulative standard normal distribution in the appendix of statistics books.

V. Conclusion

This research consults the process capability indices in management field to establish BMI indices to evaluate BMI reaching rate within "normal range". The higher the value of BMI index is, the higher the BMI reaching rate is. In other words, more people conform to the standard body position. The BMI index can be used to track the variation of BMI and can serve as a reference to assess the effectiveness of weight-control projects. One of the merits of the BMI index is that BMI reaching rate can be easily secured through the BMI index. Moreover, the researcher is able to evaluate the BMI value on a regional scale as well as a national scale simply by sampling. Therefore, BMI index is a simple, accurate and convenient measure tool to evaluate BMI.

Appendix

BMI reaching rate commensurate with the BMI index

B_j	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0080	0.0160	0.0240	0.0320	0.0398	0.0478	0.0558	0.0638	0.0718
0.1	0.0796	0.0876	0.0956	0.1034	0.1114	0.1192	0.1272	0.1350	0.1428	0.1506
0.2	0.1586	0.1664	0.1742	0.1820	0.1896	0.1974	0.2052	0.2128	0.2206	0.2282
0.3	0.2358	0.2434	0.2510	0.2586	0.2662	0.2736	0.2812	0.2886	0.2960	0.3034
0.4	0.3108	0.3182	0.3256	0.3328	0.3400	0.3472	0.3544	0.3616	0.3688	0.3758
0.5	0.3830	0.390	0.3970	0.4038	0.4108	0.4176	0.4246	0.4314	0.4380	0.4448
0.6	0.4514	0.4582	0.4648	0.4714	0.4778	0.4844	0.4908	0.4972	0.5036	0.5098
0.7	0.5165	0.5224	0.5284	0.5346	0.5408	0.5468	0.5528	0.5588	0.5646	0.5704
0.8	0.5762	0.5820	0.5878	0.5934	0.5990	0.6046	0.6102	0.6156	0.6212	0.6266
0.9	0.6318	0.6372	0.6424	0.6476	0.6528	0.6578	0.6630	0.6680	0.6730	0.6778
1.0	0.6826	0.6876	0.6922	0.6970	0.7016	0.7062	0.7108	0.7154	0.7198	0.7242
1.1	0.7286	0.7330	0.7372	0.7416	0.7458	0.7498	0.7540	0.7580	0.7620	0.7660
1.2	0.7698	0.7738	0.7776	0.7814	0.7850	0.7888	0.7924	0.7960	0.7994	0.8030
1.3	0.8064	0.8098	0.8132	0.8164	0.8198	0.8230	0.8262	0.8294	0.8324	0.8354
1.4	0.8384	0.8414	0.8444	0.8472	0.8502	0.8530	0.8558	0.8584	0.8612	0.8638

(Contd.)

1.5	0.8664	0.8690	0.8714	0.8745	0.8764	0.8788	0.8812	0.8836	0.8858	0.8882
1.6	0.8904	0.8926	0.8948	0.8968	0.8990	0.9010	0.9030	0.905	0.9070	0.9090
1.7	0.9108	0.9128	0.9146	0.9164	0.9182	0.9198	0.9216	0.9232	0.9250	0.9266
1.8	0.9282	0.9298	0.9312	0.9328	0.9342	0.9356	0.9372	0.9386	0.9398	0.9412
1.9	0.9426	0.9438	0.9452	0.9464	0.9476	0.9488	0.9500	0.9512	0.9522	0.9534
2.0	0.9544	0.9556	0.9566	0.9576	0.9586	0.9596	0.9606	0.9616	0.9624	0.9634
2.1	0.9642	0.9652	0.9660	0.9668	0.9676	0.9684	0.9692	0.9700	0.9708	0.9714
2.2	0.9722	0.9728	0.9736	0.9742	0.9750	0.9756	0.9762	0.9768	0.9774	0.9780
2.3	0.9786	0.9792	0.9796	0.9802	0.9808	0.9812	0.9818	0.9822	0.9826	0.9832
2.4	0.9836	0.9840	0.9844	0.9850	0.9854	0.9858	0.9862	0.9864	0.9868	0.9872
2.5	0.9876	0.9880	0.9882	0.9886	0.9890	0.9892	0.9896	0.9898	0.9902	0.9904
2.6	0.9906	0.9910	0.9912	0.9914	0.9918	0.9920	0.9922	0.9924	0.9926	0.9928
2.7	0.9930	0.9932	0.9934	0.9936	0.9938	0.9940	0.9942	0.9944	0.9946	0.9948
2.8	0.9948	0.9950	0.9952	0.9954	0.9954	0.9956	0.9958	0.9958	0.9960	0.9962
2.9	0.9962	0.9964	0.9964	0.9966	0.9968	0.9968	0.9970	0.9970	0.9972	0.9972
3.0	0.9972	0.9974	0.9974	0.9976	0.9976	0.9978	0.9978	0.9978	0.9980	0.9980

References

- [1] Department of Health, Executive Yuan, Taiwan, R.O.C. (2005), *Adults' Weight-Controlling — Challenge 1824 Project*,
URL: http://food.doh.gov.tw/healthbite/eat_health/control_weight03.htm
- [2] Department of Health, Executive Yuan, Taiwan, R.O.C. (2005), *The definition of obesity and managing principle*,
URL: http://food.doh.gov.tw/healthbite/eat_health/control_weight01.htm
- [3] R. A. Boyles (1994), Process capability with asymmetric tolerances, *Communications in Statistics – Simulation and Computation*, Vol. 23, pp. 615–643.
- [4] L. K. Chan, S. W. Cheng and F. A. Spiring (1988), A new measure of process capability: C_{pm} , *Journal of Quality Technology*, Vol. 20 (3), pp. 162–175.
- [5] K. S. Chen, W. P. Sung and M. H. Shih (2002), Study on the evaluative method for the quality of compressive strength of concrete, *Journal of Technology*, Vol. 17 (2), pp. 203–209.
- [6] K. S. Chen, R. K. Li and S. J. Liao (2004), Capability evaluation of a product family for processes of the larger-the-better type, *Journal of Information & Optimization Sciences*, Vol. 25 (1), pp. 93–104.
- [7] V. E. Kane (1986), Process capability indices, *Journal of Quality Technology*, Vol. 18 (1), pp. 41–52.
- [8] D. C. Montgomery (1991), *Introduction to Statistical Quality Control*, John Wiley & Sons, New York.
- [9] W. L. Pearn, S. Kotz and N. L. Johnson (1992), Distributional and inferential properties of process capability indices, *Journal of Quality Technology*, Vol. 24, pp. 216–231.
- [10] J. C. Su, K. S. Chen and S. L. Lai (2002), An application of process capability indices on swimming teaching, *Journal of Physical Education & Recreation*, Vol. 8 (1), pp. 53–58.

Received September, 2005