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Original Article

Using Markov chains to forecast the proportion of noncommunicable diseases

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Abstract

The university personnel annual medical check-up reports of the years 2015-2017 are classified by the 16 categories of noncommunicable diseases (NCDs) from the combinations of the 4 criteria: high fasting blood sugar, high blood pressure, high triglycerides or high cholesterol or high low-density lipoprotein, and the abnormal signs from an electrocardiogram. This study aims to project the future proportion of NCDS in order to reflect the past and current university health policy. The Markov chains are the categorical time series prediction model that are applied to identify the probabilities of short-run and long-run events for each NCD states (category). The estimated state probability of the year 2017 that is derived from the transition matrix of the year 2015 to 2016 is close to the real state probability of the year 2017 using the Chi-squared goodness of fit test (p-value < 0.002, degrees of freedom 15). The prediction for the steps of short-run (2018-2019) and long-run (2022 and so on) show that the NCDs with many more combinations will increase about 1% each, while the NCDs with lesser combinations will decrease by 1% each.

Keywords: Markov chain, noncommunicable diseases, proportion, state, step

1. Introduction

The World Health Organization (World Health Organization [WHO], 2017a) has warned that non-communicable diseases (NCDs) kill 40 million people globally each year. The four metabolic risk factors that increase the risk of NCDs are high blood pressure, overweight/obesity, high blood glucose levels, and high levels of fat in the blood. The responses to NCDs are detection, screening and treatment as well as palliative care. A WHO survey showed that Thailand is among the top ten performers for NCDs prevention and control. The Thailand population is 68.6 million, the total number of NCDs deaths is 393,000 (WHO, 2017b).

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The 5th Thailand Health Surveys by medical check-up in 2014 reported that the prevalence of metabolic syndromes for Thai citizens of age 15 years or more was 28.9% (Ekpalakorn, 2016). Metabolic syndrome is diagnosed when a patient has at least 3 of the following 5 conditions: fasting glucose ≥100 mg/dL, blood pressure ≥130/85 mm Hg, triglycerides ≥150 mg/dL, high density lipoprotein cholesterol (HDL-C) <40 mg/dL in men or <50 mg/dL in women, waist circumference ≥ 102 cm (40 in) in men or ≥88 cm (35 in) in women; if Asian or Body Mass Index >30 kg/m^2 (Medscape, 2017).

A healthy campus for students, lecturers, and personnel is the vision for a private University in Pathumthani Province, Thailand (RSU Healthy Campus, 2017). The university personnel annual medical checkup reports of 2,469, 2,486, and 1,618 persons from the years 2015, 2016, and 2017, respectively, contained data of individual bio-graphics and medical checkup items. The signs of NCDs are from the 4 criteria: fasting blood sugar (FSB), blood pressure (BP), triglycerides (TRG), cholesterols (CHL), low-density lipo-

protein (LDL), and abnormal signs from EKG (Table 1) (Office of Health Welfare, RSU, 2017). In order to tailor the health program to match each NCDs group/category, the 16 categories (states) were derived from the combination of the 4 criteria of NCDs that have been classified (Table 2).

Table 1. Non-communicable diseases out of range criteria.

Check-up item	Out of range	Code
Fasting Blood Sugar (FBS)	> 100 mg/dL.	1
Blood pressure (BP)	>= 140|90 mmHg.	2
Triglycerides (TGR) or	>= 200 mg/dL.	
Cholesterol (CHL) or	>= 150 mg/dL.	3
Low-density lipoprotein (LDL)	>= 130 mg/dL.	
Electrocardiogram (EKG)	with abnormal signs	4

Table 2. The stages of non-communicable diseases.

Stage	Stage code	Out of range check-up item using codes from Table 1
0	0	none
1	1	1
2	12	1 and 2
3	123	1 and 2 and 3
4	1234	1 and 2 and 3 and 4
5	124	1 and 2 and 4
6	13	1 and 3
7	134	1 and 3 and 4
8	14	1 and 4
9	2	2
10	23	2 and 3
11	234	2 and 3 and 4
12	24	2 and 4
13	3	3
14	34	3 and 4
15	4	4

To create health awareness on NCDs among the university members, the management seeks the method to predict the scenario of NCDs of the personnel. In the case that the university has no new policy measures against NCDs, what will be the proportion of personnel for each stated item of NCDs (or the state of probability in statistical terms) in the future?

Markov chain is the categorical time series forecasting technique which applies market share analysis for products in the short-run and the long-run, stock management, agricultural product processing, logistics among warehouses, and college student graduation plans (Voskoglou, 2016). Markov models have been suggested in health care (Sato & Zouain, 2010), and have predicted the natural progression of diabetic retinopathy (Srikanth, 2015). A Markov chain decision model for examining which surgical interventions are more effective in treating women with stress urinary incontinence (SUI) is based on two measures: number of quality adjusted life years (QALY) and cost per QALY (Kumar, Ghildayal, & Ghildayal, 2017). A stochastic Markov chain model used to describe lung cancer growth and metastasis (Newton *et al.*, 2012) predicted psychiatric inpatient utilization (Sweillam & Tardiff, 1978). In Thailand, the Markov model was applied in an economic evaluation of the costs of effectiveness and utility of renal replacement therapy (Teerawattanayont, 2006). Descriptive statistics, Chi-square test and multiple logistic regression analysis were used in predicting the risk factors of complications of diabetic patients during the worst flood in 2011 in Phra Nakhon Si Ayutthaya Province (Chokkhanchitchai, Keiwkarnka, & Sillabutra, 2014), and also in predicting factors of health among village health volunteers (Numkham *et al.*, 2015).

The problem in identifying the market share (Voskoglou, 2016) is similar to predicting the proportion of the state of NCDs in the short-run and long-run. This study uses the Markov model to forecast the future proportion of NCDs for this private university.

2. Methods

The medical check-up data come from one private university. This university has personnel annual medical check-up reports of 2,469, 2,486, and 1,618 persons from the years 2015, 2016, and 2017, respectively. The reports are in digital format, and each medical check-up report entry is composed of the following fields: personnel identification number (Personnel_ID), age, sex, height, weight, body mass index (BMI), and the 4 criteria: fasting blood sugar (FBS), blood pressure (BP), triglycerides (TGR), cholesterol (CHL), low-density lipoprotein (LDL), and electrocardiogram (EKG). The transition from normal (in the control range of each criteria) to and from non-normal (out of the control range) of each criterion of each person can be tabulated.

The Markov chain, first utilized by Andrei Markov (1856–1922) in 1907 (Gagniuc, 2017; Ibe, 2009; Lindsey, 2004; Voskoglou, 2016), is a stochastic process that interprets and (or) describes the various phenomena of the real world that evolves over time (a process) and that also involves a random (stochastic) component. For forecasting the proportions of the state of NCDs, the discrete-state for this problem, are the 16 combinations of NCDs (Table 2); the discrete-time is the event of annual medical check-up. The matrix manipulations of the Markov chains are as follows.

A finite Markov chain with n states, where n is a non negative integer, $n \geq 2$. The transition probabilities are the entries of an n x n matrix M, where m_{ij} (the entry in the i th row and j th column) is the transition probability from state S_i to state S_j, $i, j, = 1,2,\ldots,n$. Since the transition from a state to some other state (including itself) is a certain event, M is called the transition probability matrix and for any row i, $m_{i1} + m_{i2} + \ldots + m_{in} = 1$, for i = $1,2,\ldots,n$.

The row-matrix $P_k = [p_1^{(k)}\ p_2^{(k)} \ldots p_n^{(k)}]$ is the probability vector of the chain, the probabilities $p_i^{(k)}$ for the chain to be in state i at step k, for $i = 1,2,\ldots,n$. and $k = 1,2,\ldots$ and $p_1^{(k)} + p_2^{(k)} + \ldots + p_n^{(k)} = 1$.

To make short-run forecasts for the evolution of various situations that can be represented by a finite Markov chain of k+1 steps state probability, $P_{k+1} = P_kM$ and $P_{k+1} = P_0M^k$ for all non-negative integers k.

A Markov chain is said to be an Ergodic chain, if it is possible that, as the number of its steps tends to infinity (long-run), a chain tends to an equilibrium situation, in which the steady-state probability vector P_k takes a constant price $P=[p_1\ p_2\ \ldots\ p_n]$, called the limiting probability vector of the chain. The equilibrium situation is P=PM and $p_1 + p_2 + \ldots + p_n = 1$. With the Ergodic chains, one obtains long-run forecasts for the evolution of the corresponding phenomena.

To apply the Markov chain to predict the NCDs state proportion, the data processing steps from the original medical check-up reports to the transition matrices and the state vectors are shown in Figure 1.

1. Each medical check-up report entry is composed of the following fields: personnel identification number (Personnel_ID), age, sex, height, weight, body mass index (BMI), and the 4 criteria; fasting blood sugar (FBS), blood pressure (BP), triglycerides (TGR), cholesterol (CHL), low-density lipoprotein (LDL), and electrocardiogram (EKG).

2. Each field of the five criteria are coded as per the condition in Table 1.

3. The out of range coding is concatenated to get the state and code that state with the condition as shown in Table 2 (S_i, i=0,1,2,…,15).

4. Cross tabulating is used to get the frequency distribution of the states of 2015 and 2016, and the states of 2016 and 2017. Compute the real state probabilities P_{2015R}, P_{2016R}, P_{2017R} are compared (Table 3).

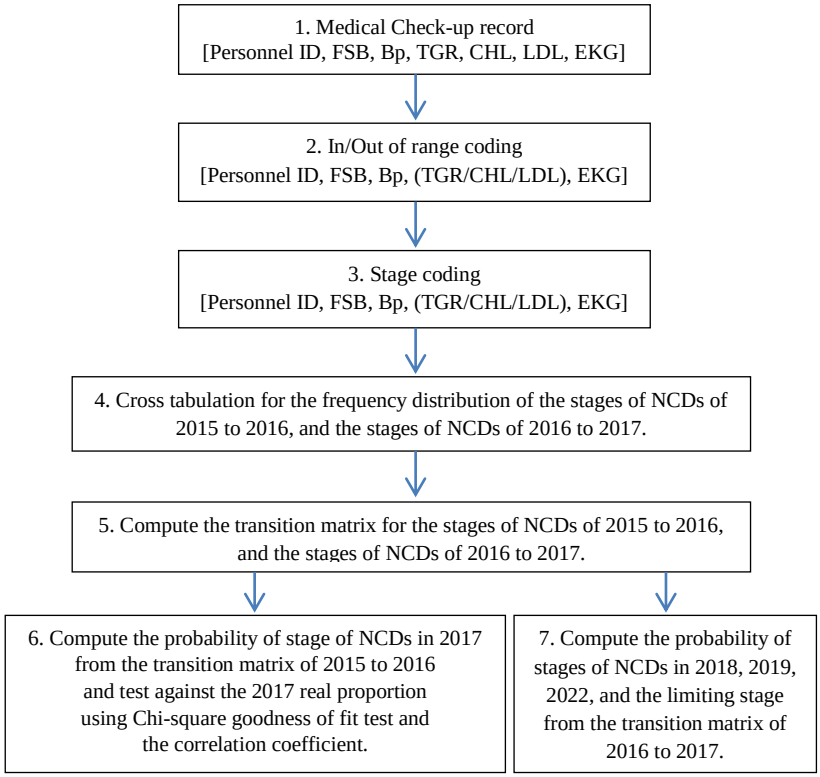

Figure 1. The processing steps

Table 3. The number of personnel and probability classified by NCDs Stage Code.

Stage code	Stage number	Year			Real stage probability		
		2015	2016	2017	P_{2015R}	P_{2016R}	P_{2017R}
0	0	189	230	215	0.16	0.19	0.18
1	1	15	10	22	0.01	0.01	0.02
12	2	5	14	16	0.00	0.01	0.01
123	3	17	17	14	0.01	0.01	0.01
1234	4	17	15	20	0.01	0.01	0.02
124	5	11	10	7	0.01	0.01	0.01
13	6	35	34	47	0.03	0.03	0.04
134	7	30	22	26	0.03	0.02	0.02
14	8	12	15	16	0.01	0.01	0.01
2	9	16	20	34	0.01	0.02	0.03
23	10	67	68	67	0.06	0.06	0.06
234	11	41	41	35	0.03	0.03	0.03
24	12	12	23	17	0.01	0.02	0.01
3	13	467	437	460	0.39	0.36	0.38
34	14	190	167	142	0.16	0.14	0.12
4	15	59	77	62	0.05	0.06	0.05
Total		1,183	1,200	1,200	1.00	1.00	1.00

5. Cross tabulating is used to get the transition matrix for the states of NCDs of 2015 to 2016 ($M_{2015\rightarrow2016}$), and the transition matrix for the states of NCDs of 2016 to 2017 ($M_{2016\rightarrow2017}$) (Tables 4 and 5).

6. The Markov chain forecasting for 2017 is evaluated against the real probability states of NCDs in 2017 by computing the probability of state in 2017 (P_{2017}) from the transition matrix of 2015 and 2016 and tested against the 2017 real states of NCDs proportion using Chi-square goodness of fit test and their linear correlation (Table 6).

7. The probability of states of NCDs in 2018, 2019, 2022, and the limiting state ($P_{2017}, P_{2018}, P_{2022}$, and $\mathbf{P}$) are computed from the transition matrix of 2016 and 2017 ($M_{2016\rightarrow2017}$) (Table 7).

3. Ethical Approval

Prior to the study, ethical approval to conduct this study was obtained from Ethics Committee of the Research Institute of Rangsit University, Project number RSPE 03/2560 dated Oct, 31 2017. The researchers also had the letter of permission to use the personnel medical check-up records from the Office of Health Welfare, Rangsit University as well.

4. Results

The university personnel annual medical check-up reports of 2,469, 2,486, and 1,618 persons from the years 2015, 2016, and 2017, respectively were used in this study. The descriptive biographical statistics from 1,200 records of medical check-up data from 2017 are; 489, 711 male and female. The average age, height, and weight were 43.83 years, 161.95 cm, and 65.06 kgs, respectively. The average of the 4 criteria were; fasting blood sugar (FBS) 92.10 mg/dL, blood pressure (BP) 117.25/77.92 mmHg, triglycerides (TGR) 128.50 mg/dL, cholesterol (CHL) 216.06 mg/dL, low-density lipoprotein (LDL) 133.68 mg/dL, and electrocardiogram (EKG) 37% with abnormal signs. The detailed biographical statistics and the statistics of the 4 criteria are shown Tables 8 and 9, respectively.

Table 4. The transition probability matrix, $M_{2015\rightarrow2016}$.

Stage code	Code no.	0	1	12	123	1234	124	13	134	14	2	23	234	24	3	34	4	Total
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
0	0	0.68	0.02				0.01	0.03		0.01	0.01	0.01			0.16	0.02	0.07	1.00
1	1	0.13	0.13	0.13			0.07	0.13	0.07	0.20				0.07	0.07			1.00
12	2		0.20	0.40		0.20					0.20							1.00
123	3			0.06	0.24	0.18	0.06	0.18	0.06			0.18			0.06			1.00
1234	4			0.06		0.35		0.24	0.12	0.06			0.12			0.06		1.00
124	5			0.27		0.18	0.27	0.09		0.09				0.09				1.00
13	6		0.09	0.06	0.06	0.06		0.26	0.11	0.03	0.03			0.03	0.29			1.00
134	7	0.03	0.03	0.03	0.03	0.13		0.23	0.27	0.07		0.03	0.07	0.03		0.03		1.00
14	8	0.08	0.08	0.08			0.08		0.08	0.08				0.08	0.08	0.17	0.17	1.00
2	9	0.13				0.06				0.06	0.56	0.06		0.06			0.06	1.00
23	10	0.03	0.01		0.09			0.03				0.33	0.09		0.31	0.10		1.00
234	11	0.12			0.02	0.02	0.05				0.02	0.22	0.32	0.05	0.07	0.07	0.02	1.00
24	12	0.25								0.17			0.08	0.42			0.08	1.00
3	13	0.10	0.00		0.00	0.00		0.02	0.01		0.00	0.04	0.02	0.00	0.65	0.13	0.01	1.00
34	14	0.04					0.01	0.01	0.03		0.01	0.05	0.06	0.01	0.24	0.51	0.05	1.00
4	15	0.17		0.02			0.02			0.02	0.02		0.05	0.05	0.03	0.08	0.54	1.00

Table 5. The transition probability Matrix, $M_{2016\rightarrow2017}$.

Stage code	Code no.	0	1	12	123	1234	124	13	134	14	2	23	234	24	3	34	4	Total
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
0	0	0.61	0.02		0.00				0.00	0.00	0.03	0.01	0.00		0.23	0.03	0.05	1.00
1	1	0.10	0.30			0.10		0.10		0.10		0.10			0.10		0.10	1.00
12	2	0.07	0.07	0.57			0.14			0.07	0.07							1.00
123	3				0.18		0.06	0.29	0.18	0.06	0.12	0.06			0.06			1.00
1234	4		0.20	0.13		0.40	0.07		0.07		0.07					0.07		1.00
124	5		0.10	0.20		0.10	0.20			0.10	0.10			0.20				1.00
13	6	0.06	0.06		0.06	0.06		0.53	0.09			0.03			0.09	0.03		1.00
134	7		0.05	0.09	0.05	0.14		0.09	0.27	0.05		0.05			0.14	0.09		1.00
14	8		0.20			0.07		0.20		0.27			0.07			0.07	0.13	1.00
2	9	0.10	0.05			0.05					0.40	0.05		0.15			0.20	1.00
23	10	0.01			0.06	0.01		0.03	0.01		0.09	0.38	0.13		0.22	0.04		1.00
234	11	0.02			0.07	0.05	0.02		0.05			0.17	0.24	0.05	0.15	0.15	0.02	1.00
24	12	0.04		0.04					0.09	0.09	0.09		0.09	0.13	0.09	0.22	0.13	1.00
3	13	0.10	0.00	0.00				0.04	0.00	0.00	0.00	0.04	0.02	0.00	0.67	0.11	0.01	1.00
34	14	0.03				0.01			0.03	0.01		0.05	0.02	0.01	0.46	0.33	0.05	1.00
4	15	0.23	0.01							0.01	0.04	0.01	0.01	0.05	0.09	0.18	0.35	1.00

Table 6. Chi-squared goodness of fit test.

Stage code	Stage number	$P_{2015R}M^2_{2015->2016}$	Expected count 2017	Observed count 2017	Chi-square calculated
0	0	0.19	224	215	0.38
1	1	0.01	16	22	2.50
12	2	0.02	18	16	0.32
123	3	0.01	16	14	0.28
1234	4	0.02	24	20	0.79
124	5	0.01	12	7	1.88
13	6	0.04	45	47	0.13
134	7	0.02	25	26	0.05
14	8	0.01	17	16	0.05
2	9	0.02	23	34	5.02
23	10	0.05	65	67	0.04
234	11	0.04	49	35	4.04
24	12	0.02	23	17	1.59
3	13	0.33	397	460	9.98
34	14	0.14	173	142	5.50
4	15	0.06	72	62	1.50
Total		1.00	1,200	1,200	34.06

Chi-squared value for $\alpha = 0.05$, degrees of freedom = 15 is 25.00.
Chi-squared value for $\alpha = 0.002$, degrees of freedom = 15 is 35.63.
The correlation coefficient between expected and observed values is 0.99.

Table 7. The probabilities of stages of NCDs for 2018, 2019, 2022, and 2037.

Stage code	Stage number	Estimated		P	
		P_{2018}	P_{2019}	P_{2022}	P_{2037}
0	0	0.17	0.17	0.16	0.16
1	1	0.02	0.03	0.03	0.03
12	2	0.01	0.02	0.02	0.02
123	3	0.01	0.01	0.01	0.01
1234	4	0.02	0.02	0.03	0.03
124	5	0.01	0.01	0.01	0.01
13	6	0.05	0.05	0.06	0.06
134	7	0.02	0.02	0.02	0.02
14	8	0.01	0.01	0.02	0.02
2	9	0.03	0.03	0.03	0.03
23	10	0.06	0.06	0.06	0.06
234	11	0.03	0.03	0.03	0.03
24	12	0.01	0.01	0.01	0.01
3	13	0.38	0.38	0.37	0.36
34	14	0.11	0.11	0.10	0.10
4	15	0.05	0.05	0.05	0.05
Total		1.00	1.00	1.00	1.00

Note: The probability value can be converted to percent by multiplied with 100.

The real state probabilities were tabulated from 1,183 medical check-up reports for 2015, while 2016 and 2017 both used 1,200 reports.

The transition matrix of 2015->2016 ($M_{2016\rightarrow2017}$) is tabulated from 1,183 persons who had the 4 criteria data for both years of 2015 and 2016. The frequencies of change from state *i* to state *j* (or the probability m_{ij}) is counted from each person that was in one state in the 2015 and was in another state in 2016. The transition matrix of 2015->2016 ($M_{2016\rightarrow2017}$) is shown in Table 4. The transition matrix for the states of NCDs of 2016 to 2017 ($M_{2016\rightarrow2017}$) is tabulated from 1,200 persons who had the 4 criteria data of both years of 2016 and 2017 Table 5.

The evaluation accuracy was determined by computing the expected number of personnel for each state of NCDs in the year 2017 using the real state probabilities ($\mathbf{P}_{2015R}$) and the transition matrix of 2015->2016 ($M_{2016\rightarrow2017}$) against the real values in 2017, the calculated Chi-squared is 34.06 which was less than the Chi-squared value of 35.63 with p-value < 0.002 at degrees of freedom = 15 (MedCalc, 2017) which leads to the conclusion that there are no differences between the expected and observed values. The correlation coefficient between expected and observed values is 0.99.

The future possibility for the proportion of NCD states in the next 1, 2, 5 and 20 years are the probabilities of NCDs states for 2018, 2019, 2022, and 2037 (Table 7).

Table 8. Biographic profile from medical check-up reports in the year 2017.

	Male	Female	Total
Number of Personnel	489	711	1,200
Age (years)			
- Minimum	22	23	22
- Maximum	76	79	79
- Average	44.33	43.49	43.83
- Standard Deviation	11.14	10.38	10.71
Height (cm)			
- Minimum	149	141	141
- Maximum	191	175	191
- Average	169.33	156.80	161.95
- Standard Deviation	6.05	5.67	8.48
Weight (kg)			
- Minimum	45	36	36
- Maximum	154	107	154
- Average	73.25	59.35	65.06
- Standard Deviation	12.65	12.03	14.06
BMI (kg/m^2)			
- Minimum	16.38	15.13	15.13
- Maximum	47.65	47.73	47.73
- Average	25.49	24.14	24.69
- Standard Deviation	3.77	4.72	4.41

Table 9. Statistics of the 5 criteria from medical checked-up reports in the year 2017.

	Male	Female	Total
Number of Personnel	489	711	1,200
Fasting Blood Sugar (mg/dL)			
- Minimum	70	70	70
- Maximum	358	325	358
- Average	95.27	89.90	92.10
- Standard Deviation	25.71	23.11	24.35
Systolic Pressure (mmHg)			
- Minimum	90	90	90
- Maximum	170	170	170
- Average	121.89	114.01	117.25
- Standard Deviation	11.67	12.62	12.84
Diastolic pressure (mmHg)			
- Minimum	60	56	56
- Maximum	120	100	120
- Average	81.12	75.68	77.92
- Standard Deviation	8.01	8.26	8.59
Triglycerides (mg/dL)			
- Minimum	30	34	30
- Maximum	577	600	600
- Average	149.03	113.76	128.50
- Standard Deviation	74.30	59.16	68.17
Cholesterol (mg/dL)			
- Minimum	104	69	69
- Maximum	342	356	356
- Average	214.85	216.89	216.06
- Standard Deviation	37.80	36.64	37.13
Low-density lipoprotein (mg/dL)			
- Minimum	39	51	39
- Maximum	250	252	252
- Average	132.83	134.29	133.68
- Standard Deviation	35.74	32.28	33.77
Electrocardiogram (EKG)			
- with abnormal signs	39%	37%	37%
- normal	61%	63%	63%

5. Conclusions and Recommendations

If there are no policy measures implemented and the personnel still have the same lifestyles, then the number of normal health condition personnel (State 0) will decrease from 17 percent to 16 percent (from Table 7).

From Table 7, the probabilities of State 4 [code 1234], State 6 [code 13], and State 8 [code 14] of $\mathbf{P}_{2022}$ and $\mathbf{P}$ are increased from $\mathbf{P}_{2018}$ and $\mathbf{P}_{2019}$ by about 0.01 from 0.02, 0.05, 0.01 to 0.03, 0.06, 0.02, respectively; which means that the percent of NCDs of State 4, State 6, and State 8 will increase about 1 percent each, while the probabilities of State 0 [Code 0], State 13 [Code 3], and State 14 [Code 34] will decrease by 1 percent each. The State code is the combination of [1] Fasting Blood Sugar (FBS) and [2] Blood pressure (BP) and [3] Triglycerides (TGR) or Cholesterol (CHL) or Low-density lipoprotein (LDL), and [4] Electrocardiogram (EKG) signal.

The 3 groups that were out of range on all criteria, FBS together with TGR, and FBS together with EKG; will increase by 1 percent. The 3 groups of normal, out of range of TGR only, TGR together with EKG, will decrease by 1 percent.

The campaign that is suitable for each group of NCDs should be organized to bring back the university personnel to State 0 (all medical check-up signals are within control limits).

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