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STROKE INSURANCE UNDERWRITING

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Abstract. *Permanent disability causes a financial burden to individuals, families, and the country. One of the illnesses is stroke. Permanent disability insurance covering various causes of disability can be expensive. Illness-specific insurance is more affordable. Governments also need to analyze the cost of specific illnesses on their health social security funding to plan and allocate funding more strategically and know which illness prevention should be prioritized. Therefore, insurance models that allow underwriting on some risk factors are essential. This paper presents a stroke insurance model that includes gender, age, hypertension, diabetes, and body mass index (BMI) as the risk factors. Our model can be applied to any country, and we show an example of a case study using the Indonesian national health survey data. For each gender and age, the model consists of 33 states. Any policyholder can transition between these states during the period of insurance protection. In the complete model, there are 1089 transition probabilities. By assuming that stroke is a permanent illness, we reduce the number by half. Ideally, this model needs rigorously detailed survey data. We show a method to construct the transition probabilities for incomplete survey data. The calculated transition probabilities are further used in the actuarial model for calculating premiums and reserves. We also analyze the effects of each risk factor on the cost of illness.*

Keywords: Stroke insurance, Permanent disability insurance model, Markov model, BMI, Diabetes, Hypertension

1. **Introduction.** Stroke is a critical illness that can result in a long-term disability. In the paper by hundreds of collaborators, published in The Lancet Journal (2019), the global financial burden of stroke remains high, even increases in low and middle-income countries (LMIC) [1]. The paper also stated that stroke is one of the priority areas for WHO and the UN. Thus, every country needs adequate health and disability income insurances covering both medical and rehabilitation costs of stroke [2]. LMIC must also take better risk management on the national social and healthcare security to anticipate the financial risk of stroke. A specified permanent disability insurance model for stroke is a tool for managing the risk. In [3,4], an excellent, thorough study resulting in an actuarial model for coronary heart disease and stroke is presented, an example of the necessity of a disease-specified model for risk management. In those papers, we can also learn the survey data structure that is sufficient for the model.

Insurance that only covers stroke should be cheaper than general critical illness insurance. Selling a product that covers a specific disease is an example of microinsurance, an option for LMIC to get a broader insurance participation percentage in the country. In addition, by having citizens insured for permanent disability, a country can better provide long-term (or even whole life) healthcare for the disabled.

The risk of stroke is associated with ten risk factors: hypertension, smoking, diabetes mellitus, physical activity, diet, psychosocial factors, abdominal obesity, alcohol, cardiac

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causes, and apolipoproteins [5]. In the present paper, we show a model for permanent disability insurance that includes a whole-life rehabilitation cost as a part of insurance benefits. Our model includes age, gender, hypertension, diabetes, obesity, and body mass index (BMI) as factors for underwriting the insurance costs. The model enables us to calculate premiums, interpreted as the expected costs per individual in the population, and reserves. Analyzing reserves is essential for asset-liability/risk management. Our model can be applied to any country or population. As a case study for this paper, we choose Indonesia. A study on the Indonesian population data that calculates the transition probabilities from healthy to stroke for different risk factors and geographical locations is given in [6]. However, the paper did not develop any insurance model.

In the present paper, we generalize the Markov insurance model for stroke given in [7]. In the present model, we allow individuals to change the level of BMI during their life, which is more realistic. Age is also a significant risk factor. Therefore, we allow our model to cover six different age groups, ranging from 15-85 years. For each gender and age, there are 33 states in the present model. Each state is a combination of healthy status (healthy/stroke, hypertension, and diabetes) and four levels of BMI. The insurance model enabled us to calculate premiums and reserves for an insured with different entry ages, healthy status, and BMI. The last state, number 33, represents death.

2. **Problem Statement and Preliminaries.** In this insurance model, we modify the permanent disability model, where there are only three possible circumstances for a policyholder, namely, healthy ($0xyz$), disabled/stroke ($1xyz$), or death (2). The hypertension status is coded by x, where $x = 1$ if hypertension and $x = 0$ if not. The diabetes status is coded by y, where $y = 1$ if diabetes and $y = 0$ if not. The BMI status is coded by z, where $z = 0$ if BMI ≤ 18.5 (thin), $z = 1$ if $18.5 <$ BMI ≤ 25 (normal), $z = 2$ if $25 <$ BMI ≤ 27 (overweight), and $z = 3$ if BMI > 27 (obese). The healthy statuses are mapped as follows: 0000→1, 0001→2, 0002→3, 0003→4, 0010→5, 0011→6, 0012→7, 0013→8, 0100→9, 0101→10, 0102→11, 0103→12, 0110→13, 0111→14, 0112→15, 0113→16. The disabled/stroke statuses are mapped as follows: 1000→17, 1001→18, 1002→19, 1003→20, 1010→21, 1011→22, 1012→23, 1013→24, 1100→25, 1101→26, 1102→27, 1103→28, 1110 →29, 1111→30, 1112→31, 1113→32. Lastly, the state of death (2) is denoted by the number 33. Thus, the state space is given by $E = \{1, 2, \ldots, 33\}$, and the occurrence $Y(x + t) = i$ for $i \in E$ means an individual whose age is x at time $t = 0$ is in state i at age $x + t$. We assume that $\{Y(x + t)\}_{t\geq 0}$ is a Markov process. Therefore, the transition probability from state i to j is well defined because its value does not depend on any information about the process before time t [8]. The transition probabilities are denoted by ${}_{t+s}p_x^{ij} = \Pr[Y(x + t + s) = j|Y(x + t) = i]$. For calculating the expected present value, we will utilize the Chapman-Kolmogorov equations for the Markov chain as given in the following equations. The first equation is the probabilities of a policyholder who is healthy at time t to stay healthy at time $t + s$, the second equation is the probabilities of a person who is healthy at time t to become ill/disabled at time $t + s$, and the third equation is the probabilities of a person who is ill/stroke at time t to remain alive (with stroke) at time $t + s$.

$${}_{t+s}p_x^{ij} = \begin{cases} \sum_{k=1}^{16} {}_tp_x^{ik}\, {}_sp_x^{kj}, & i = 1, 2, \ldots, 16,\ j = 1, 2, \ldots, 16; \\ \sum_{k=1}^{32} {}_tp_x^{ik}\, {}_sp_x^{kj}, & i = 1, 2, \ldots, 16,\ j = 17, 18, \ldots, 33; \\ \sum_{k=17}^{32} {}_tp_x^{ik}\, {}_sp_x^{kj}, & i = 17, 18, \ldots, 32,\ j = 17, 18, \ldots, 33. \end{cases}$$

Recall states 1-16 denote healthy conditions, 17-32 denote stroke conditions, and 33 denotes death. Thus, we assume that a person with a stroke cannot return to a healthy state. In other words, for all time t, ${}_tp_x^{ij} = 0$ for $i = 17, 18, \ldots, 33$ and $j = 1, 2, \ldots, 16$. From the data, we will construct a one-year transition probability matrix, denoted by $\mathbf{P}_x$, which is a 33 by 33 matrix,

$$\mathbf{P}_x = \begin{pmatrix} p_x^{1;1} & \cdots & p_x^{1;33} \\ \vdots & \ddots & \vdots \\ p_x^{33;1} & \cdots & p_x^{33;33} \end{pmatrix} = \begin{pmatrix} p_x^{1;1} & \cdots & p_x^{1;33} \\ \vdots & \ddots & \vdots \\ p_x^{33;1} & \cdots & 1 \end{pmatrix}.$$

The last element ($p_x^{33;33}$) is always one because death is an absorbing state.

In this paper, we use the exact source of data as [7]. References for data sources can be found in [7]. Ideally, in a continuous model, the one-year transition probabilities are calculated by using the Kolmogorov forward equations [8], given as follows, with μ_{x+t}^{kj} as the force of transition between state k and j.

$$\frac{d}{dt}{}_tp_x^{ij} = \sum_{k=1,k\neq j}^{33} \left({}_tp_x^{ik}\mu_{x+t}^{kj} - {}_tp_x^{ij}\mu_{x+t}^{jk} \right). \tag{1}$$

Equation (1) is a system of differential equations with 1089 unknowns. Even though we restrict to the permanent disability model, with zero probabilities for returning to any healthy states, we still have hundreds of nonzero variables. Solving this vast system requires a significant computational effort. Applying a simple discretization like the Euler method might leads to a considerably significant error or unstable. While advanced methods for a large system of equations exist, we must have sufficient data to get all the forces of transition, μ_{x+t}^{ij}. For example, to get $\mu_{x+1}^{1;18}$ we need a survey that counts the number of individuals at state-1 at age (x) and transitioned into state-18 at age ($x + 1$). In other words, Equation (1) gives guidance on an ideal survey that should be conducted to get sufficient data.

Not all country conducts a highly detailed survey that counts all transitions within the sample. Therefore, we need to adjust our methodology so that we can approximate the transition probabilities. The approximation is given in the following example. Suppose we would like to calculate the probability of a male age 35 who is at state-1 (healthy, no hypertension, no diabetes, BMI $\leq$ 18.5) for being at state-18 (healthy, no hypertension, no diabetes, 18.5 $<$ BMI $\leq$ 25) next year. The probability is $p_x^{1;18} = \Pr\left[Y(x+1) = 18 | Y(x) = 1\right]$. We approximate $p_x^{1;18}$ as the probability of a healthy male aged 35 for being stroke at age 36 multiplied by the probability of a male aged 35 with BMI $\leq$ 18.5 for having BMI between 18.5 and 25 at age 36. For Indonesia, the first probability has been calculated in [7] using the Kolmogorov forward equations for the permanent disability model with three states (healthy, stroke, and death), and the second probability has been calculated in [10] using the generalized linear model (GLM) Poisson regression. In the present paper, the calculations use results from [7] (transition probabilities from healthy to healthy, healthy to stroke, stroke to stroke, healthy to death, and stroke to death) and result from [10] (probabilities of changing the BMI category depending on age, gender, hypertension status, and diabetes status). The data were categorized into 7 age groups: 15-24, 25-34, 35-44, 45-54, 55-64, 65-74, and 75+. It is assumed that each age group follows the uniform distribution of transitions (the actuarial UDD assumptions).

After the transition probability for each condition is obtained, the premium can be calculated using the equivalence principle with the current payment approach method. As a case study, we price term insurance until 85 years old. Premiums are paid as long as the policyholder is healthy, i.e., at state-1 to 16. Premium payments will stop when entering any stroke state, i.e., state 17 to 32, or when entering a death state, i.e., state

33, or having reached the age of 85 years, where the coverage period ends. The insured who is sick and then dies will receive the death benefit after the sick benefit annuity.

Underwriting is done at time $t = 0$. Every new policyholder is healthy. Thus, they are at one of the state-i, for $i = 1, 2, \ldots, 16$. The expected present values of the premium ($EPV(P)$), the stroke benefit ($EPV(B_s)$), and the death benefit ($EPV(B_d)$) are given by

$$EPV(P) = P \sum_{j=1}^{16} \ddot{a}^{ij}_{x:\overline{85-x|}} = P \sum_{j=1}^{16} \left(\sum_{k=0}^{85-x-1} v^k {}_kp^{ij}_x \right), \tag{2}$$

$$EPV(B_s) = B_s \sum_{j=17}^{32} a^{ij}_{x:\overline{85-x|}} = B_s \sum_{j=17}^{32} \left(\sum_{k=1}^{85-x} v^k {}_kp^{ij}_x \right), \tag{3}$$

$$EPV(B_d) = B_d \sum_{j=1}^{32} \left(\sum_{k=0}^{85-x-1} v^{k+1} {}_kp^{ij}_x p^{j;33}_{x+k} \right). \tag{4}$$

Here $v = (1+i)^{-1}$ denotes the discount factor of the present value, in which i is the annual interest rate. Furthermore, using the equivalence principle, we can calculate the premium paid by the insured every year. Thus, by assigning payment amounts for both benefits B_s and B_d, the annual premium P is calculated from the following relation:

$$EPV(P) = EPV(B_s) + EPV(B_d). \tag{5}$$

Reserve calculation is done by the prospective method, as the expected present value at time t of the future cash flows. The reserve for every policyholder who is healthy at time t is given as follows, for $i = 1, 2, \ldots, 16$,

$$tV = B_s \sum_{j=17}^{32} a^{ij}_{x+t:\overline{85-x-t|}} + B_d \sum_{j=1}^{32} \sum_{k=0}^{85-x-1} v^{k+1} {}_kp^{ij}_x p^{j;33}_{x+k} - P \sum_{j=1}^{16} \ddot{a}^{ij}_{x+t:\overline{85-x-t|}}. \tag{6}$$

A policyholder will stop paying the premium when they suffer a stroke. Reserve for a policyholder who is alive but has a stroke at time $t > 0$ is given as follows, for $i = 17, 18, \ldots, 32$,

$$tV = B_s \left(\sum_{j=17}^{32} a^{ij}_{x+t:\overline{85-x-t|}} \right) + B_d \sum_{j=17}^{32} \left(\sum_{k=0}^{85-x-1} v^{k+1} {}_kp^{ij}_x p^{j;33}_{x+k} \right). \tag{7}$$

3. **Main Results.** We take as an example $B_s = 50$ million and $B_d = 100$ million. First, the premium is calculated using Equation (5), and afterward, reserves are calculated using Equations (6) and (7). The calculation of reserves is done since the insured enters ($t = 0$) until the insured is 85 years old. In this paper, we only present the reserves for healthy policyholders. The analysis used the Kruskal-Wallis test, which is non-parametric, to determine whether there were significant differences in two or more groups without meeting normality assumptions. Within a 95% confidence level, the results (presented in Table 1) indicated that there is not enough evidence to deny the statement that there are no premium differences in different healthy conditions (hypertension and diabetes) in the same BMI category, both in insurance with death benefits and without death benefits. Therefore, we need to include other lifestyle factors, such as smoking, eating and drinking habit, and regular exercise habits for future research. For example, it might be that people who got diagnosed with hypertension and diabetes take a careful lifestyle to reduce their overall risks of stroke and other diseases.

Insurance premiums for different sex and healthy status are presented in Table 2. Recall that healthy states are coded by $0xyz$, where x, y, and z refer to hypertension, diabetes, and BMI level, respectively. Thus, we see that all risk factors influence the

Table 1. The Kruskal-Wallis test for hypertension and diabetes within the same BMI level

No	Hypothesis	p-value			
		With death benefits		Without death benefits	
		Male	Female	Male	Female
1.1	H_0: There is no difference in premiums at BMI 0 H_1: There is a difference in premiums at BMI 0	0.997	0.997	0.997	0.997
1.2	H_0: There is no difference in premiums at BMI 1 H_1: There is a difference in premiums at BMI 1	0.997	0.997	0.997	0.997
1.3	H_0: There is no difference in premiums at BMI 2 H_1: There is a difference in premiums at BMI 2	0.999	1	0.998	0.997
1.4	H_0: There is no difference in premiums at BMI 3 H_1: There is a difference in premiums at BMI 3	0.997	1	1	0.999

Table 2. Annual premiums for males and females at different healthy statuses at enrollment

State	Annual premiums for males age 45		Annual premiums for females age 45	
	With death benefit	Without death benefit	With death benefit	Without death benefit
0000	15,304,188.65	340,032.09	12,999,116.63	385,242.72
0003	15,330,558.76	320,309.75	13,030,591.86	357,111.94
0010	15,304,192.72	340,031.01	12,999,121.96	385,241.61
0100	15,304,198.73	340,029.42	12,999,129.11	385,239.83
0013	15,330,558.90	320,309.83	13,030,591.99	357,112.09
0103	15,330,559.10	320,309.96	13,030,592.19	357,112.31
0110	15,304,202.81	340,028.35	12,999,134.04	385,238.64
0113	15,330,559.24	329,712.71	13,030,592.32	357,112.47

annual premium. From most minor to most significant, diabetes, hypertension, and BMI level are influenced. From the columns for insurance premium without death benefit, we see that the higher the BMI level, the lower the premium. An explanation is that the death probability from stroke is higher for people with higher BMI levels. Thus, the period of disability income payment is shorter.

In Table 3, we present the calculated annual premium at different enrollment ages. Notice that the premium increases with age. For insurance with death benefits, the premium is higher for males than females because the probability of stroke and the death probability is higher for males than females. Thus, the expected present value of the death benefit is higher for males than females. On the other hand, for insurance without death benefits, female premiums are higher than males because the probability of females living longer with stroke is higher than males. Thus, it is suggested that long-term care when suffering from stroke is more needed for females than males.

Table 3. Annual premium for males and females at different enrollment age

Age	Males at state 0000		Females at state 0000	
	With death benefit	Without death benefit	With death benefit	Without death benefit
35	9,610,570.48	210,323.85	8,388,956.93	240,816.47
55	23,153,614.97	440,636.33	19,196,698.25	466,621.40
70	31,448,958.87	512,155.55	27,687,697.79	527,749.20
75	38,804,207.76	626,078.82	35,280,614.47	638,978.67

Reserves are calculated by using Equations (6) and (7). In both types of insurance, the younger the age of entry of the insured, the greater the reserves needed. This is due to a more extended coverage period. So, the risk borne by the insurer is greater.

Insurance with a death benefit covers both death and healthcare benefits for staying alive. Our calculation with Indonesia data shows that if the insured enters the insurance at age 15 to 45, the maximum reserve occurs when the insured is 65 years old and stays healthy. If the entry age is over 45, the maximum reserve occurs if they stay healthy at age 75. At the age of 15 to 35 years, the probability of staying alive from a stroke exceeds 80%. Thus, a policyholder at age 15 to 35 will receive healthcare benefits B_s for an extended time. After age 45, the probability of getting a stroke increases more than fourfold, but the probability of staying alive from a stroke decrease. Furthermore, after age 55 for males and after age 65 for females, the probability of death from a stroke is higher than staying alive from a stroke. Thus, an old age policyholder will only receive healthcare benefits for a short period.

For entry age 15 to 35, females' insurance reserves with death benefits are always smaller than males due to the lower risk of stroke or death. Faster death benefit payments result in a higher expected present value of benefits. Therefore, the male reserves are higher than the females. For policyholders with entry age 45 who stay healthy at age 71-76, females' reserves are higher than males due to the fact that the number of females staying alive after 70 is higher than males in Indonesia. For policyholders with entry age 55 and beyond, female's insurance reserves are always higher than males any age while they stay healthy. An explanation is that women have a higher global life expectancy than men, so women are more likely to reach old age, where the risk of stroke is highest [9].

For insurance without death benefit, if the ages of entry of both males and females are 15 to 35 years, then the maximum value of reserves occurs when the insured is 55 years old. Whereas if the insured enters insurance after age 35, the maximum value of reserves occurs when the insured is 75 years old. For insurance without death benefits, reserves are negative near the end of the coverage period. The reason is that the calculated probability of death from a stroke exceeds 99% for a person aged 75 or more. Thus, the older the policyholders' entry age, the less likely they will receive disability income benefits for an extended time (should they suffer a stroke). A negative reserve value means the insurer receives a surplus from the insurance policy.

To see differences in reserves in different BMI categories for insurance without death benefit, we carry out the Kruskal-Wallis test with a 95% confidence interval. The test results are shown in Table 4. Tests were conducted for various insurance enrollment ages of the policyholder. The null hypothesis is that there were no differences in reserves in the different BMI categories at this age.

For enrollment ages 45 and 75 (males) and 45 and 55 (females), the p-value is less than 0.05. So, there is sufficient evidence to reject the statement that there is no difference in reserves in the different BMI categories at those ages. Then a Mann-Whitney U test will be carried out to see in which BMI category the difference in reserves occurs. The results are shown in Table 5.

Table 4. The p-values of the Kruskal-Wallis test for various insurance enrollment ages

	p-value						
	Age 15	Age 25	Age 35	Age 45	Age 55	Age 65	Age 75
Male	0.919	0.991	0.484	0.005	0.118	0.887	0.043
Female	0.677	0.956	0.311	0.003	0.004	0.874	0.129

Table 5. The p-values of the Mann-Whitney U test on the reserves (males: column 1-2; females: column 3-4)

	p-value			
BMI category	Age 45	Age 75	Age 45	Age 55
0-1	0.118	0.590	0.068	0.067
0-2	0.042	0.715	0.002	0.003
0-3	0.042	0.143	0.001	0.022
1-2	0.466	0.326	0.115	0.099
1-3	0.488	0.002	0.091	0.093
2-3	0.941	0.073	0.595	0.870

For males with entry age 45, p-value < 0.05 in the BMI category 0-2 and 0-3, while for entry age 75 in the BMI category 1-3. For females with entry ages 45 and 55 years, p-value < 0.05 in BMI categories 0-2 and 0-3. So, at $\alpha = 0.05$, on these classes, there is sufficient evidence to reject the statement that there is no difference in reserves between the BMI categories.

4. **Conclusions.** Healthy statuses influence the calculated transition probabilities. The probability of increasing BMI category increases when healthy conditions worsen, resulting in an increased probability of illness and death. When the BMI category increases, premiums on insurance with death benefits get higher, the opposite happens to insurance without death benefits. Male premiums are higher than female premiums on insurance with death benefits, and the opposite happens to insurers without death benefits. In both types of insurance, the value of premiums is higher as the age of entry of the insured gets older. The highest premium occurs when the insured is 75 years old, then decreases. In both types of insurance, the reserve value is higher when the age of entry of the insured is getting younger. If policyholders enroll in insurance with death benefits at a young age, the highest reserves occur if they remain healthy at age. If policyholders enroll at age 45 or more, the highest reserves occur if they stay healthy at age 75. The highest reserve value for insurance without death benefit occurs when the insured is 55 years old for policyholders enrolling at a young age. If policyholders enroll at age 45 and beyond, the highest reserve occurs if they remain healthy at age 75. For both types of insurance, the reserve value is always negative (thus, it is a profit for the insurer) if an individual enrolls in the insurance at age 75.

We have presented a model for stroke insurance underwriting. To support the model, we need a detailed national survey that records the number of individuals transitioning between states within a particular time (at least this information can be extracted from the data). The results are beneficial for private insurance, as well as the government. Private insurance can create more affordable insurance products, and government can analyze the burden of stroke on the national health social security fund. Our research opens ideas for further research: on data collection and further models. We advise that for future research, should data be available, we consider other healthy conditions that are risk factors for stroke such as cholesterol, sedentary lifestyle such as smoking and drinking habit, and heredity that circumstances may the insurance model increases.

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