Quantitative Evaluation of Medical Consultation Recommendation based on the Transition Probability Model

Shigeaki Sakurai, Rumi Hayakawa and Hideki Iwasaki
Toshiba Corporation, Japan (E-mail: shigeaki.sakurai@toshiba.co.jp)

ABSTRACT: This paper proposes a new method that quantitatively measures the effect of medical consultation recommendation for the diabetes. It uses a new transition probability model. The model is composed of 7 kinds of status related to the diabetes. The status is "no consultation", "consultation", "medication", "insulin", "dialysis", "healthy", and "secession". The method estimates the transition probability between status by analyzing both the medical examination data and the medical receipt data. It evaluates behavioral modifications of object members which are candidates participating in the program of medical consultation recommendation. The transition probability is adjusted by their behavioral modifications. This paper applies the method to the data managed by Toshiba health insurance union. Also, it verifies the effect of the method based on the simulated result.

KEYWORDS: transition probability model, disease aggravation, medical data, medical consultation recommendation, diabetes

1. INTRODUCTION

Owing to the progress of aging of population, medical expenses in industrialized countries are expanding year by year. The expansion is one of common problems in the countries. They try to reduce the expenses. The diabetes is one of chronic diseases caused by life style. It tends to be progressing without subjective symptoms. If appropriate medical treatment is not timely performed, the diabetes progresses to more serious status and its complication may happen. The progress leads to the increase of the medical expenses. In addition, the expenses related to the diabetes occupies large parts of medical expenses. Therefore, it is important for the reduction of the expenses to focus on patients or future patients with diabetes.
Practice Fusion [8] is fastest growing electronic health record community in USA. The community tackles on the reduction of the expenses by activating the records. In 2012, the community has held a competition for the diabetes classification. The competition identifies patients diagnosed with type 2 diabetes based on 10,000 de-identified medical records. Jose A. Guerrero is the winner in this competition. He identifies the diabetes by using 8 boosted regression trees and 4 random forest models [3].

On the other hand, Muhammad A. Abdul-Ghani et al. [1] propose a model for the prediction of type 2 diabetes risk. The model is based on both a multivariate logistic model and 1-h plasma glucose concentration. It is developed in a cohort of 1,562 non-diabetic subjects and is validated in 2,395 non-diabetic subjects. Also, Peter W. F. Wilson et al. [11] develop prediction rules for type 2 diabetes based on the estimation of its 7-year risk. They deal with middle-aged participants who had an oral glucose tolerance test at baseline. They show that parental diabetes, obesity, and metabolic syndrome traits can effectively predict type 2 diabetes risk in a middle-aged white population sample. In addition, Philippa J. Talmud et al. [10] develop a 65 type 2 diabetes variant-weighted gene score. They combine the score with the phenotypically derived Framingham Offspring Study for type 2 diabetes risk model. They show that the combination leads to an important improvement for the prediction of type 2 diabetes risk.

In Japan, Aoshi Okamoto et al. [7] acquire prediction models for the diabetes. They use medical examination data of employees belonging to Fujitsu corporation. They show that the model based on SVM (Support Vector Machine) can predict whether an employee gets diabetes or not in the next year with 96% or more accuracy.

In the other type of researches, Rudi Rudi and Branko G. Celler [9] discuss the use of the home telecare systems as a diabetes management tool. The system is expanded in order to manage the diabetes. They show that the data collected by the system can be used to estimate future blood glucose levels and provide recommendations on insulin doses. Also, Anun Chaikoolvatana and Peter Haddawy develop a computer based learning program in diabetes management for health care providers and academic staff. They evaluate the usability of the program by the responses for the questionnaire. The responses show that the program is useful for the diabetes management. In addition, Cindy Marling et al. [6] develop three emerging applications employing artificial intelligence. First one is the case-based decision support for diabetes management, second one is the machine learning classification of blood
glucose plots, and third one is the support vector regression for blood glucose prediction. The applications can ease the difficulty of the diabetes management task.

In Japan, Hitachi health insurance union [5] performs a program of medical consultation recommendation for persons with diabetes in order to prevent the aggravation of diabetes. The union evaluates the effect of the program by calculating the improvement ratios for medical examination values such as HbA1c or weight, and life style such as dietary habit and exercise habit. The union compares the medical expenses for participants of the program with the one for non-participants. Also, Fukuoka Branch of Japan Health Insurance Association [2] performs a similar program. The association evaluates the effect of the program by estimating the decrease of the medical expenses based on the number of participations. Then, it is assumed that the program can delay the aggravation of the diseases by one year. These results show that the program is effective for the prevention of the aggravation to some extent. However, the union and the association evaluate the effect by referring to limited small sample data. Also, they set bold assumption in order to evaluate it. Therefore, the effect is not always estimated precisely. Thus, this paper proposes a new method measuring the effect based on medical big data and reasonable assumptions.

In the following, Section 2 proposes a new measuring method for the effect of the medical consultation recommendation. It introduces both the transition probability model and the recommendation effect matrix. Also, it proposes how to calculate them from the medical examination data and the medical receipt data. Section 3 simulates the number of object members included in each status of the model by applying the method to the data managed by Toshiba health insurance union. It shows simulated results and discusses the effect of the method. Lastly, Section 4 summarizes this paper and shows future research works.

2. MEASURING METHOD

In Japan, almost companies perform the periodical health examination for each member every year. Also, the medical receipts are monthly collected by health insurance unions. The receipts describe the contents of medical treatment. Therefore, we can understand the health status of members by referring to the data. The effect of medical consultation recommendation is highly related to the health status. This paper constructs the model
representing the effect based on both the medical examination data and the medical receipt data.

2.1 Transition probability model

This paper proposes a new transition probability model representing the status of members related to the diabetes. This model has 7 kinds of status: "no consultation", "consultation", "medication", "insulin", "dialysis", "healthy", and "secession". "medication", "insulin", and "dialysis" are three kinds of status representing the degree for aggravation of the diabetes. That is, "medication" is light status of the disease condition, "insulin" is moderate one, and "dialysis" is heavy one. Also, they represents the medical activities such as medication, insulin therapy, and artificial dialysis. Medical expenses dramatically increase according to the aggravation of the status. Fukuoka Branch of Japan Health Insurance Association estimates the expense of "medication" as 120,000 yen (about 972 dollar) per year, the one of "insulin" as 220,000 yen (about 1,782 dollar) per year, the one of "dialysis" as 5,500,000 yen (about 44,550 dollar) per year [2]. On the other hand, "no consultation" and "consultation" are status representing whether members go to the hospital for the diabetes. In the case of "consultation", the members receive only the medical examination and the consultation. The expense is estimated as 60,000 yen (about 486 dollar) per year by the association. "healthy" represents that the members do not contract the diabetes. Lastly, "secession" represents such status that the members secede from the union by reasons such as demise, change of job, moving to other health care system, and so on. In this model, each member is assigned to specific status per year. This is because each member receives periodical health examination every year. This paper assumes that each member transits the status based on given transition probability. The assumption is reasonable because the aggravation of the diabetes does not dramatically progress. We define the transition probability between status. The probability is estimated by referring to both the medical examination data and the medical receipt data. The calculation method is discussed in the following sub-sections. Figure 1 shows the transition probability model. In this figure, $p_{xy}$ represents transition probability transiting from the status $x$ to the one $y$. $n$, $c$, $m$, $i$, $d$, $h$, and $s$ represent "no consultation" ,"consultation", "medication", "insulin", "dialysis", "healthy", and "secession", respectively. We note that the status $x$ and the one $y$ can be equal to each other. That is, members can stay at the same status.
The model is represented by a transition matrix $P$ as shown in Formula (1). Then, these elements in the matrix are satisfied with the normalization conditions as shown in Formula (2).

$$P = \begin{pmatrix}
    p_{nn} & p_{nc} & p_{nm} & p_{ni} & p_{nd} & p_{nh} & p_{ns} \\
    p_{cn} & p_{cc} & p_{cm} & p_{ci} & p_{cd} & p_{ch} & p_{cs} \\
    p_{mn} & p_{mc} & p_{mm} & p_{mi} & p_{md} & p_{mh} & p_{ms} \\
    p_{in} & p_{ic} & p_{im} & p_{ii} & p_{id} & p_{ih} & p_{is} \\
    p_{dn} & p_{dc} & p_{dm} & p_{di} & p_{dd} & p_{dh} & p_{ds} \\
    p_{hn} & p_{hc} & p_{hm} & p_{hi} & p_{hd} & p_{hh} & p_{hs} \\
    p_{sn} & p_{sc} & p_{sm} & p_{si} & p_{sd} & p_{sh} & p_{ss}
\end{pmatrix} \quad (1)$$

$$\sum_{y \in \{n,c,m,i,d,h,s\}} p_{xy} = 1, \quad 0 \leq p_{xy} \leq 1 \quad (2)$$

2.2 Introduction of recommendation effect matrix

We think that the medical consultation recommendation can refrain the aggravation of the diabetes by changing the behaviors of object members in the daily life. Therefore, we can believe that the medical consultation recommendation causes to change the transition probability. Thus, we formalize the change by introducing the recommendation effect.
matrix. The recommendation effect matrix represents the effect of the medical consultation recommendation. The following relation is satisfied.

\[ QP_b = P_a \] (3)

Here, \( P_b \) is the transition probability matrix before the recommendation and \( P_a \) is the one after the recommendation. Each element in these matrixes has respective transition probabilities. \( Q \) is the recommendation effect matrix. On the other hand, we think that some object members change their behaviors due to the medical consultation recommendation but the other ones do not change them. Therefore, only the status of the former members transits from "no consultation" to "consultation". Thus, we formalize the transition by introducing the transition rate. The rate represents the rate of the object members transiting from "no consultation" to "consultation". The following relation is satisfied.

\[ QR_b = R_a \] (4)

\[ R_b^T = (r_n, r_c, r_m, r_i, r_d, r_h) \] (5)

\[ R_a^T = (r_n - \alpha, r_c + \alpha, r_m, r_i, r_d, r_h) \] (6)

Here, \( R_b \) is the member rate vector before the recommendation and \( R_a \) is the one after the recommendation. Each element in these vectors represents such a rate that the number of members included in specific status is divided by the total number of members. \( r_x \) shows the rate corresponding to the status \( x (= n, c, m, i, d, h, s) \). Also, \( \alpha \) is the transition rate. Then, the ratios are satisfied with the normalization condition as shown in Formula (7).

\[ \sum_{x \in \{n,c,m,i,d,h,s\}} r_x = 1, \quad 0 \leq r_x \leq 1 \] (7)

Even if Formula (4)–Formula (7) restrict elements in the recommendation effect matrix, we cannot decide all the elements. This is because their numbers are too many. This paper assumes that the effect of medical consultation recommendation can be represented by only both "no consultation" and "consultation". The assumption is reasonable because most of people seldom changes their behavior and the aggravation of the diabetes does not dramatically progress. Therefore, we can anticipate that the change of the member rate appears only the two kinds of status. On the other hand, it is necessary for the sum of the transition probability starting from specific status to be 1. Therefore, the sum of elements in the column vector composing the recommendation effect matrix is 1. That is, the following
relation as shown in Formula (8) is satisfied.

\[ \sum_{y \in \{n, c, m, l, d, h, s\}} q_{xy} = 1 \quad (8) \]

Here, \( q_{xy} \) is the element in the recommendation effect matrix in the case that the status \( x \) is transited to the one \( y \).

Lastly, the recommendation effect matrix is described as shown in Formula (9). In this formula, \( q_{nn} \) is the recommendation effect element in the case staying in "no consultation" and \( q_{cc} \) is the one in the case staying in "consultation".

\[
Q = \begin{pmatrix}
q_{nn} & 1 - q_{nn} & 0 & 0 & 0 & 0 \\
1 - q_{cc} & q_{cc} & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 \\
\end{pmatrix} \quad (9)
\]

The following relations as shown in Formula (10) and Formula (11) are given by Formula (4) ~ Formula (9).

\[
q_{nn}r_n + (1 - q_{nn})r_h = r_n - \alpha \quad (10)
\]

\[
(1 - q_{cc})r_n + q_{cc}r_h = r_h + \alpha \quad (11)
\]

We can get the following relation as shown in Formula (12) by solving Formula (10) and Formula (11).

\[
q_{nn} = q_{cc} = \frac{r_c - r_n + \alpha}{r_c - r_n} \quad (12)
\]

According to the given assumptions, the recommendation effect matrix is described by a value as shown in Formula (12). The value is called by the recommendation effect value \( q \), hereafter.

2.3 Calculation of transition probability

The transition probability is calculated by evaluating the status of each member for two continuous fiscal years of medical receipt. The status is decided by referring to both the medical examination data and the medical receipt data. That is, the calculation method checks
HbA1c value included in the medical examination data. Here, the HbA1c value is an representative indicator in order to identify whether a member has diabetes or not. Next, the method checks the frequency of hospital visiting and the medical treatment regimen for each month by referring to the medical receipt. It judges the degree of disease aggravation based on the frequency and the regimen. Also, it does whether a member goes to the hospital in order to receive medical treatment for the diabetes. Additionally, it identifies whether a member secedes from the health insurance union by confirming the member information. The results are summarized as the summary table for each fiscal year. Table 1 shows an example of the summary table.

Table 1 Example of summary table

<table>
<thead>
<tr>
<th>ID</th>
<th>201X</th>
<th>201X+1</th>
<th>H</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>01</td>
<td>02</td>
<td>03</td>
<td>04</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

In this table, ID shows an identification number for each member. 3~12 of 201X and 1~2 of 201X+1 show months, respectively. We note that the table is generated from March of a year to February of next year due to the Japanese fiscal year of medical receipt. In each month, each member is assigned its medical treatment regimen. If some regimens are extracted from the receipt of a month, the worst regimen is assigned to the member for the month. "-" shows that there is not a receipt in the month. "0" shows that there are receipts with the regimen unrelated to the diabetes. "1", "2", "3", and "4" do that there are receipts with the regimen related to the diabetes. They correspond to medical examination, medication, insulin therapy, and artificial dialysis. Also, H is the HbA1c value for the fiscal year. The value ranges from 3.0 to 20.0. The value except the range is regarded as abnormal value [4]. S is the secession flag representing the secession for the fiscal year. "0" corresponds to the case the member exists over the fiscal year and "1" does to the case the member secedes in the fiscal year.

Lastly, the method applies the summary table into the decision flow as shown in Figure 2. It decides the status for each member. That is, the decision flow firstly evaluates whether a member secedes in the fiscal year by referring to the secession flag. Next, it evaluates the
number of months including receipts. If the number is larger than or equal to the minimum receipt given by analysts, the flow assigns the worst regimen. Otherwise, it evaluates the HbA1c value (at the step st1 in Figure 2). If the value is larger than or equal to the maximum HbA1c value given by the analysts, "no consultation" is assigned. Otherwise, "healthy" is assigned. On the other hand, if there is not a receipt related to the diabetes, the flow evaluates the HbA1c (at the step st2 in Figure 2). In the case that the value is larger than or equal to the maximum HbA1c value, "no consultation" is assigned. In other case, "consultation" is assigned.

If the status in two continuous fiscal years for each member is decided, the calculation method calculates the number of members transiting from the status of a year to the one of next year. The method estimates the transition probability by Formula (13).

![Figure 2 Decision flow of the status](image)

\[ p_{xy} = \frac{n_{xy}}{\sum_{z \in \{n,c,m,i,d,h,s\}} n_{xz}} \]  (13)
Here, \( n_{xy} \) is the number of members transiting from the status \( x \) to the one \( y \).

### 2.4 Calculation of recommendation effect value

The recommendation effect value can be calculated from the member rate of "no consultation", the one of "consultation", and the transition rate. We can calculate the member rates by dividing the number of members assigned to the status into the total number of members. That is, they are calculated as shown in Formula (14).

\[
    r_x = \frac{n_x}{\sum_{z \in \{n, c, m, i, d, h, s\}} n_z}
\]  

(14)

Here, \( n_x \) is the number of members belonging to the status \( x (= n, c, m, i, d, h, s) \) in a fiscal year. The number is calculated by the method as shown in subsection 2.3.

On the other hand, we can calculate the transition rate by referring to such results that we performed the program of medical consultation recommendation to object members. That is, the rate is calculated as shown in Formula (15).

\[
    \alpha = \frac{n_g}{\sum_{z \in \{n, c, m, i, d, h, s\}} n_z}
\]  

(15)

Here, \( n_g \) is the number of members that continuously go to the hospital after the program. We note that the number includes members that refuse to participate in the program. This is because some members may go to the hospital even if they refuse to do it.

The transition rate is composed of two factors: the consultation rate \( (\beta) \) and the object member rate \( (\gamma) \). That is, it is described as shown in the Formula (16).

\[
    \alpha = \beta \gamma
\]  

(16)

Then, the consultation rate and the object member rate are defined by Formula (17) and Formula (18), respectively.

\[
    \beta = \frac{n_g}{n_r}
\]  

(17)

\[
    \alpha = \frac{n_r}{\sum_{z \in \{n, c, m, i, d, h, s\}} n_z}
\]  

(18)

Here, \( n_r \) is the number of members that are asked to participate in the program of medical consultation recommendation. The consultation rate shows such a rate that the object members continuously going to the hospital due to the program are occupied in the object members. It can evaluate the quality of the program. The high rate represents its high quality.
Also, the object member rate shows such a rate that the object members are occupied in all members. It can evaluate the quantity of the members dealing with the program. The high rate represents a large-scale program. We can interpret the transition rate as the comprehensive evaluation indicator based on the quality and the quantity.

3. NUMERICAL SIMULATION

This section explains numerical experiments based on the proposed method. Firstly, it introduces the simulation method. Next, the simulation results are explained. Lastly, this section discusses the effect of the proposed method.

3.1 Simulation method

This simulation uses the medical examination data and the medical receipt data managed by Toshiba health insurance union from 2011 fiscal year to 2013 fiscal year. They are the data for employees belonging to Toshiba group, their family, and retired persons. The summary table is generated from the data. In each fiscal year, the number of members included in the summary table is shown in Table 2. In this table, "All" shows the number of all members in each fiscal year. "Normal" shows the number of members whose HbA1c values are in normal range ([3.0, 20.0]). The latter numbers are about one-third as small as the former ones. This is because family members and retired persons do not always receive periodical medical examination and their lacking HbA1c values are not included in the normal range.

<table>
<thead>
<tr>
<th>Year</th>
<th>All</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>322,539</td>
<td>111,085</td>
</tr>
<tr>
<td>2012</td>
<td>315,617</td>
<td>111,689</td>
</tr>
<tr>
<td>2013</td>
<td>319,938</td>
<td>117,351</td>
</tr>
</tbody>
</table>

This simulation calculates two transition probability matrixes from "Normal" data. One is based on 2011 fiscal year and 2012 fiscal year. The other is based on 2012 fiscal year and
2013 fiscal year. In the simulation, we use members with "Normal" data for continuous two fiscal years. The number of members in the case of 2011 fiscal year and 2012 fiscal year is 92,654. The one in the case of 2012 fiscal year and 2013 fiscal year is 92,685. These numbers are similar to each other. We can get two tables representing number of members transiting from the status x to the one y. In these table, the decision flow in Figure 2 uses 4 and 7.0 as the minimum receipt and the maximum HbA1c value, respectively. We can get the transition probability matrix for each fiscal year by dividing each element into corresponding total number.

On the other hand, this simulation uses results based on the program of medical consultation recommendation. The program has been performed from September, 2013. The program extracts members whose HbA1c values arrive at the level of diabetes but which do not go to the hospital. It squeezes the members by referring to other conditions such as work location. 41 members are selected as object members for the program. The program recommends that the object members go to the hospital by counseling. We checked medical receipt data of the object members from September, 2013 to May, 2014 in order to confirm whether they practically go to the hospital. We identified whether the object members continuously go to the hospital by evaluating the number of months including the medical receipt data. That is, if the number is larger than or equal to 4, the object member is identified as a continuous member which continuously goes to the hospital. Otherwise, the object member is identified as a non-continuous member. In the program, the number of continuous members is 30 and the one of non-continuous member is 11. The recommendation effect matrix is calculated based on the results and "All" data for each fiscal year.

In order to verify the validity of the proposed method, this simulation focuses on the number of members in the status when the year passes by. It compares the number in the case of the transition probability after the medical consultation recommendation with the one in the case of the transition probability before it. That is, the difference calculated by Formula (19) is evaluated.

\[ N^T(P_a)^z - N^T(P_b)^z \]  

(19)

Here, \( N^T = (n_n, n_c, n_m, n_i, n_d, n_h, n_s) \) is the member vector. Each element \( (n_x, x = n, c, m, i, d, h, s) \) represents the number of members in the status for a fiscal year. Also, \( z \) is the passing of year. In this simulation, \( z \) is from 1 to 20. The comparison for 20 years is performed.

The program of medical consultation recommendation comparatively deals with small
data set. Therefore, the recommendation effect value may be imprecisely estimated. We evaluate the influence by introducing two weights. One is a weight for the consultation rate c and the other is a weight for the object member rate t. We define the adjusted recommendation effect value q’ as shown in Formula (20).

\[
q' = \frac{r_c - r_n + (c\beta)(t\gamma)}{r_c - r_n} \quad (20)
\]

Also, we can get Formula (21) by transforming Formula (20).

\[
q' = 1 + ct \frac{\beta\gamma}{r_c - r_n} = 1 + ct(q - 1) = ctq + (1 - ct) \quad (21)
\]

The formula shows that the adjusted recommendation effect value is composed of the recommendation effect values and two weights. We can evaluate the influence of an imprecise recommendation effect value by changing two weights.

### 3.2 Simulation result

This section shows results of simulation. Table 3 shows simulation values for each fiscal year. The consultation rate (β) is calculated based on only the results for the program of medical consultation recommendation. The rate does not depend on the fiscal year. On the other hand, the other values refer to the summary table for each fiscal year. They depend on the fiscal year.

<table>
<thead>
<tr>
<th>Year</th>
<th>α</th>
<th>β</th>
<th>γ</th>
<th>q</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>2.70E-04</td>
<td>0.731707</td>
<td>3.69E-04</td>
<td>1.00056</td>
</tr>
<tr>
<td>2012</td>
<td>2.69E-04</td>
<td>0.731707</td>
<td>3.67E-04</td>
<td>1.00054</td>
</tr>
<tr>
<td>2013</td>
<td>2.56E-04</td>
<td>0.731707</td>
<td>3.49E-04</td>
<td>1.00052</td>
</tr>
</tbody>
</table>

Figure 3 shows the difference of members for each continuous fiscal years. Two graphs in Figure 3 have 7 lines, respectively. Each line in the graphs corresponds to the number of members in each status. In each graph, the horizontal axis shows passing of year and the vertical axis does the difference of numbers between the case after the recommendation and the one before it. Figure 3 (a) is a result in the case based on 2011 fiscal year and 2012 fiscal
year. Figure 3 (b) is a result in the case based on 2012 fiscal year and 2013 fiscal year.

![Graphs showing simulation results](image)

Figure 3 Simulation result: difference of members in the status

Figure 4 shows the transition of fluctuation rate by a value multiplying two weights (ct) in the case based on 2011 fiscal year and 2012 fiscal year. The fluctuation rate \( f_{x,y,z} \) is defined by Formula (22), where \( x \) is status, \( y \) is a value of the weight for the consultation rate, and \( z \) is a value of the weight for the object member rate.

\[
\begin{align*}
  f_{x,y,z} &= \frac{\text{the difference of members for the status } x \text{ in the case } c = y \text{ and } t = z}{\text{the difference of members for the status } x \text{ in the case } c = 1.0 \text{ and } t = 1.0} \\
  &= \frac{\text{the difference of members for the status } x \text{ in the case } c = y \text{ and } t = z}{\text{the difference of members for the status } x \text{ in the case } c = 1.0 \text{ and } t = 1.0} \\
\end{align*}
\] (22)

Four graphs have 7 lines corresponding to the status. However, the lines in the graphs look like a line because their values are almost equal to each other. Four graphs correspond to the transition per five years. That is "after 5 years", "after 10 years", "after 15 years", and "after 20 years". In each graph, the horizontal axis shows a value multiplying \( y \) and \( z \) together. The vertical axis shows the fluctuation rate.

Lastly, Figure 5 shows the transition of fluctuation rate by year in the case based on 2011 fiscal year and 2012 fiscal year. Five graphs correspond to the transition in the five cases \((c = 0.9, t = 0.9), (c = 1.0, t = 0.9), (c = 1.1, t = 0.9), (c = 1.0, t = 1.1), \) and \((c = 1.1, t = 1.1)\), respectively. The transition in the cases \((c = 0.9, t = 1.0), (c = 0.9, t = 1.1), \) and \((c = 1.1, t = 1.0)\) is omitted because it is equal to the transition in the cases \((c = 1.0, t = 0.9), (c = 1.1, t = 0.9), \) and \((c = 1.0, t = 1.1)\), respectively. They have 7 lines corresponding to the status. In each graph, the
horizontal axis shows passing of year. The vertical axis shows the fluctuation rate.

![Graphs showing fluctuation rate](image)

**Figure 4:** Simulation result: transition of fluctuation rate by a value multiplying two weights (2011→2012)

### 3.3 Discussion

#### 3.3.1 Validity of the proposed method

Figure 3 shows that the difference in the cases of "consultation" and "health" gradually expands to the positive direction as the year passes by. Also, the difference in the cases of "medication", "insulin", and "no consultation" expands to the negative direction. In addition, even if the expansion to the negative direction is small and it is difficult to visually confirm it, the difference in the case of "dialysis" expands to the negative direction. These expansions represent such effect that the object members go to the hospital by the recommendation. Also, they correspond to such our intuition that the aggravation of the diseases is prevented by going to the hospital. Therefore, we can believe that the proposed method can validly

This work is licensed under a [Creative Commons Attribution 4.0 International License](http://creativecommons.org/licenses/by/4.0/).
simulate the effect of the recommendation to some extent. We can qualitatively confirm the effect of the recommendation by checking these expansions.

(a) (c =0.9, t =0.9)  
(b) (c =1.0, t =0.9)  
(c) (c =1.1, t =0.9)  
(d) (c =1.0, t =1.1)
3.3.2 Robustness of the proposed method

Firstly, we note the shapes of lines in two graphs of Figure 3. The figure shows that they are similar to each other. We can believe that the trend for the difference of members is robust for different continuous fiscal years.

Next, we note Table 3. It shows that the recommendation effect value for each fiscal year is similar to each other. The relative difference between the minimum value and the maximum value is about 0.00354%. We can believe that the recommendation effect matrix is highly robust for different fiscal years if a similar program of medical consultation recommendation is performed.

Lastly, we note the transition rate. It may include big estimated error because it is estimated by referring to only the small-scale program of medical consultation recommendation. Thus, we tried to verify the influence of the error by introducing two weights. The results of Figure 4 show that the difference of members linearly changes as a value multiplying two weights increases. We can believe that the expansion of the error does not give a big impact to the difference. On the other hand, the results of Figure 5 show that the difference slowly expands as the year passes by. However, the expansion is about 0.04% in the case that the passing of year is 20 and each value of weights is 1.1. The expansion is very small. Also, the expansion gradually decreases as the year passes by. In addition, we can confirm that the results in the case of 2012→2013 are similar to the ones in the case of 2011→2012, even if the latter results are omitted. We can believe that the passing of year does not give a big impact to the difference.

3.3.3 Precision of the proposed method

Figure 3 shows that the difference of members in the case of 2011→2012 is more or less larger than the one in the case of 2012→2013. The maximum difference is about 25%. It is caused by the difference of two transition probability matrixes. Firstly, we anticipated that they are similar to each other because they are calculated by referring to large amount of data. However, the anticipation is not always true. It may be necessary to expand the data and to improve the calculation method of the transition probability matrix in order to more precisely simulate the difference of members. Even if we will tackle on this subject in the future work,
the proposed method more precisely estimates than previous methods do. This is because the difference of the members is calculated based on large amount of data and reasonable assumptions.

4. SUMMARY AND FUTURE WORKS

This paper proposed a new method that quantitatively evaluates the effect of the medical consultation recommendation by referring to the change of transition probability. The method introduced the transition probability model and the recommendation effect matrix. Also, this paper verified the effect of the method based on real medical examination data and medical receipt data managed by Toshiba health insurance union. The method can simulate the transition of status for members.

In the future work, we are planning to extend the method in order to more precisely simulate the transition of status. For example, we can anticipate that the data interpolation and the data expansion lead to the estimation of more precise transition probability. This is because we have a lot of data including abnormal values and ill-defined values. Also, we are planning to apply the method into the data managed by the other union in order to verify the effect of the method in detail. In addition, the results of the simulation will be evaluated by comparing the results with real transition of members.

REFERENCES


This work is licensed under a Creative Commons Attribution 4.0 International License.