APPLICATION OF MULTISTATE MODEL TO ESTIMATE AVERAGE COST OF ILLNESS

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Abstract

The main goal of the paper is an application of a multistate model to estimate cost of illness calculated per patient. Multistate models are used in the insurance domain. Costs borne by society for treatment of diseases can be considered as benefits paid by the public payer. A certain analogy to the issues dealt with in insurance is noticeable. The probability structure of a multistate model is determined in a similar way as in the case of insurance. This approach allows us to determine the expected value and variance of treatment costs calculated with regards to the probability distribution estimated on the basis of treatment process history analysis. The multistate model presented in the paper allows us to analyze cost taking into account their structure. In the paper, an example of treatment cost for cancer is considered.

Key words: *average cost of treatment, incidence-based analysis, multistate model, probabilistic structure.*

1. Introduction

Societies of the European Union countries including Poland are relatively rapidly aging groups. Such societies are faced with many challenges related to the provision of social and medical care for older people. Chronic diseases such as cardiovascular and respiratory illnesses, cancer and diabetes are particularly acute for the social system and afflict the older people. Thus, the process of the population aging will cause increased morbidity and mortality, and it results in the growth of treatment cost for these diseases. Due to limited funds ensuring effective health care financing is a key socio-economic issue. Determining the structure of expenditure (by taking into account a prevention, treatment and palliative care) can be helpful in the efficient allocation of resources.

Determining the perspective and time horizon are important issues in the economic cost analysis. The cost calculation can be conducted from social, public payer, business, government and patients perspective. Each perspective can be useful to cost estimation, but the social perspective seems to be the most general. The analysis carried out from the perspective of the society as a whole enables the broadest consideration of the costs generated by particular disease, taking into account medical and nonmedical costs connected with incidence, morbidity and mortality of disease. The time horizon chosen in the analysis is determined by the type of disease. In case of chronic diseases, several-years horizon is desired.

In the literature, two kinds of analysis are considered, the incidence and prevalence-based analysis. The incidence rate measures the index of new cases of disease incidence in some

period (compare Henry et.al., 2013). The prevalence rate denotes the index of actual number of cases, who are suffering from particular disease. The incidence-based researches evaluates the cost of illness from the point of view determined by onset taking into account the whole history of illness in the analyzed period of study, for example a year. The prevalence-based studies consider the cost connected with diseases obtained for the whole group of patients who are treated in some period of time. This approach requires less data and fewer assumptions than the incidence-based studies. Therefore, the studies based on prevalence are more common in practice. Incidence and prevalence rates have important influence on all medical and nonmedical costs and should be taken into consideration in estimating of an average and typical costs, which can be used in turn when planning the budget for a disease entity treatment.

In case of chronic diseases with the burned longer than one year cost, the incidence-based study provides more information connected with diseases prevention policy. The prevalence-based study can be performed for these illnesses but the cost analysis reflects only some snapshot of cost in a year.

Many methods of estimation of average and typical costs exist. One approach consists in the use of micro-data sets to analyse the course of diseases for individual patients. Multi-state models used in insurance are an appropriate tool to achieve this goal. They describe a process connected with the disease history of an individual patient, which at any time achieves one of a few possible states. Transition probabilities between states reflected possible events connected with the course of diseases. This class of models allows to use an extremely flexible approach to model many kinds of disease history (Christinsen, 2012; Eerola and Helske, 2016; Hougaard, 1999; Pittaco, 1999). In the paper, we present usage of the multistate models to estimate an average and typical cost of cancerous diseases. Two approaches will be used, the first one is the incidence based studies and the second is the prevalence-based studies.

The paper is organized as follows. In Section 2, a brief information about system of financing by public payer is presented. Additionally, the influence of incidence, mortality and length of survival time on treatment cost for cancer is described in Section 3. Section 4 provides the multistate model and its probabilistic structure, which is used to presenting the individual histories of patients. In Section 5, the procedure of calculating average costs is presented.

2. The Financing of Health Care for Oncological Patients

The main source of funding for the health care system in Poland is common insurance in the National Health Fund (NHF) which acts as a public payer. Citizens in Poland are burdened with an obligatory insurance premium representing 9% of personal income, of which 1.25% covers the insurer and 7.75% is deducted from the income tax. Some highly specialized services are funded directly from the state budget, not by NHF. The fund signs a contract for the provision of health care benefits financed from public funds.

In oncology, the system of resources to combat cancer consists of the following benefits: outpatient (ambulatory) specialist care, hospital treatment, palliative care and hospice care, preventive health programs and health care services contracted separately. In Table 1, the total amount of benefits financed by the National Health Fund in Poland and the average value of a single contract for a given type benefit are presented. Additionally, the percentage structure of disbursed funds for particular benefits is shown. A large part of funds spent on the fight against cancer is a result of the hospital treatment, palliative and hospice care. Resources for these areas constitute about 90% of all funds spent by the National Health Fund in relation to

treatment of cancer. Only considerable resources are earmarked for prevention. In various regions of Poland some diversity of morbidity and mortality from cancer is observable. For this reason, in Table 1, the aforementioned quantities are also shown for the region of Lower Silesia. The probability structure is quite similar to whole Poland. A little larger amounts are spent on outpatient specialist, palliative and hospice care in Lower Silesia and the lower resources are expended on hospital treatment.

Table 1: Amounts of contracts with the National Health Fund for oncological benefits in 2013.

Type of benefits	The total value of the contracts (in millions of PLN) in Poland	Percentage structure of component in Poland	The average value of contract (in millions of PLN) in Poland	The total value of the contracts (in millions of PLN) in Lower Silesia	Percentage structure of component in Lower Silesia	The average value of contract (in millions of PLN) in Lower Silesia
Outpatient specialist care	202.49	4.54%	0.44	16.09	5.60%	0.32
Hospital treatment	3588.60	80.38%	14.89	214.62	74.75%	11.92
Palliative and hospice care	325.48	7.29%	0.76	28.02	9.76%	1.08
Preventive health programs	116.68	2.61%	0.24	10.03	3.49%	0.24
Health care services contracted separately	231.19	5.18%	2.31	18.36	6.40%	3.06
	4464.44			287.12		

Source: Polish Oncological Society (2014).

The most expensive procedures are associated with hospital treatment, the cheapest with conducting prevention programs.

3. Influence of Incidence, Mortality and Surviving Time on Cost of Illness

Type of benefit is determined by the health stage of a patient. The patient can be diagnosed in a mild condition which, in case of cancer, is equivalent to not identified metastasis to lymph nodes or distant organs. If the patient is in critical stage connected with diagnosed metastases, palliative and hospice care is included in the process of raising the quality of life of the patient.

The type of cancer affects the structure depending on the disease state and the progress of deterioration of the health condition of the patient. A few classes of cancer with various degrees of prognosis are distinguished on the basis of the analysis of annual and five-year survival time. In Table 2, percentage of patients surviving one and five years after diagnosis is presented for the most frequent types of cancer in Poland in men and women population. The survival analysis was conducted for patients who had diagnosed cancer in years 2003 – 2005.

Tumours with poor prognosis are characterized by comparable quantities of incidence and mortality rates in a population. Lung, esophagus, stomach, and pancreatic tumors belong to the group of cancer with poor prognosis, which results in high mortality first of all due to a high degree of malignant but also because more frequent diagnosis in a very advanced stage of the disease. The patients from this group are often the recipients of the benefits of palliative care and hospice. The tumor quickly leads to death, therefore most patients die within five years after diagnosis. Long-term therapy is rarely used in this case due to high mortality.

Table 2. The percentage of patients with annual and five-year survival time after diagnosis

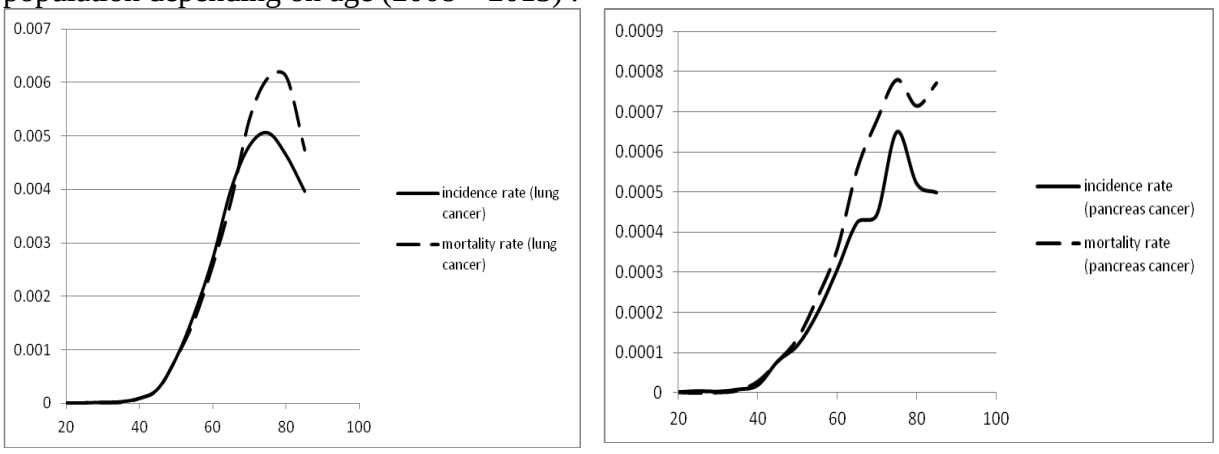
Type of cancer	Men		Women		Generally	
	1-year	5-years	1-year	5-years	1-year	5-years
Stomach cancer C16	36.8%	16.4%	39%	19.8%	37.6%	17.6%
Colon cancer C18-C21	72.4%	47.6%	70.8%	49.1%	71.7%	48.3%
Pancreas cancer C25	22.5%	8.5%	22.9%	9.1%	22.7%	8.8%
Lung cancer C33-34	34.9%	11.9%	41.7%	16.9%	36.5%	13.1%
Urinary bladder C67	78.9%	61.4%	79.2%	65.1%	79.0%	62.2%
Breast cancer C50	-	-	93.2%	77.2%	-	-
Cervix cancer C53	-	-	79.8%	54.4%	-	-
Corpus uteri C54	-	-	90.8%	78.7%	-	-
Ovary cancer C56	-	-	70.8%	42.6%	-	-
Prostate cancer C1	87.8%	76.4%	-	-	-	-

Source: Wojciechowska and Didkowska (2016).

In Figure 1 and Figure 2, the examples of cancer with poor prognosis (lung cancer and pancreas cancer) are presented in men and women populations of the Lower Silesia inhabitants. The values of mortality and incidence rate calculated per 100000 of population in five-year age groups are obtained from the National Cancer Registry. Morbidity and mortality fluctuate in particular years, so the values were averaged from a six-years period on the basis of datasets from 2008 to 2013.

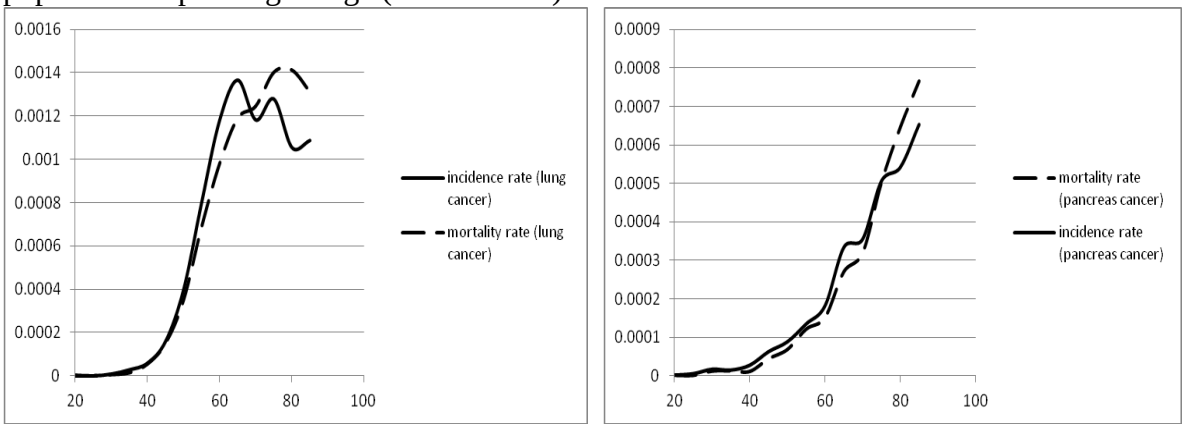
The malignant tumours with better prognosis have the lower mortality rates compared to incidence rates. Many patients, especially in older groups, die because of reasons other than cancer and tumour is revealed during autopsy and this case is recorded in the National Cancer Registry. This phenomenon is most visible for the oldest group of men in case of prostate cancer (the right part of Figure 3). The mortality rate after 85 years of age is rapidly growing because the cancer is not diagnosed during living, develops slowly and is not life-threatening. The incidence of cancer is diagnosed at autopsy.

Figure 1: The average mortality and incidence rates per 100 000 inhabitants in men population depending on age (2008 – 2013) .



Source: the author on the basis of Wojciechowska and Didkowska (2016).

Figure 2: The average mortality and incidence rates per 100 000 inhabitants in women population depending on age (2008 – 2013).

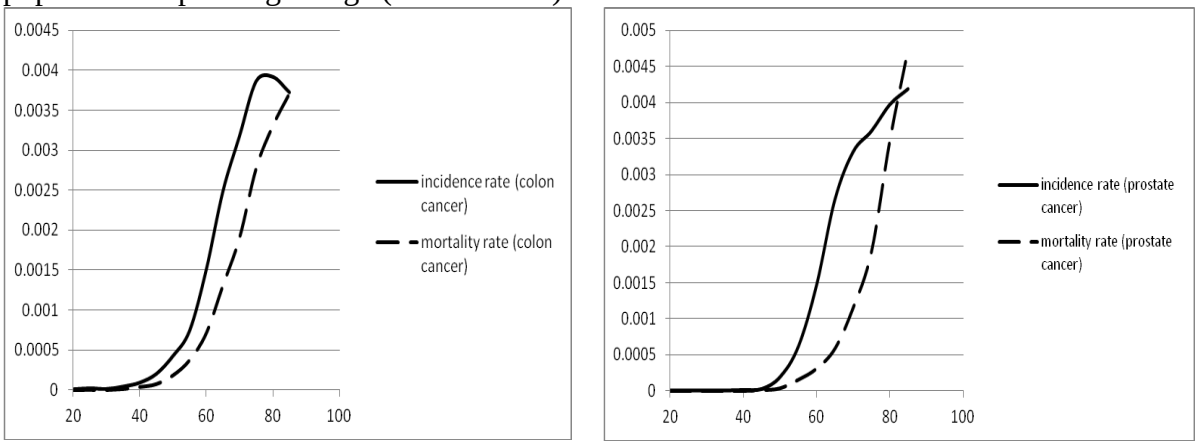


Source: the author on the basis of Wojciechowska and Didkowska (2016).

In Figure 3 and Figure 4, the mortality and incidence rates for cancer with better prognosis are presented. A significant difference between the incidence and mortality rates makes the cancer a chronic disease. In the initial period of the disease the patient is treated and hospitalized, then the treatment is associated with taking drugs for a long time and with regular visits to doctors.

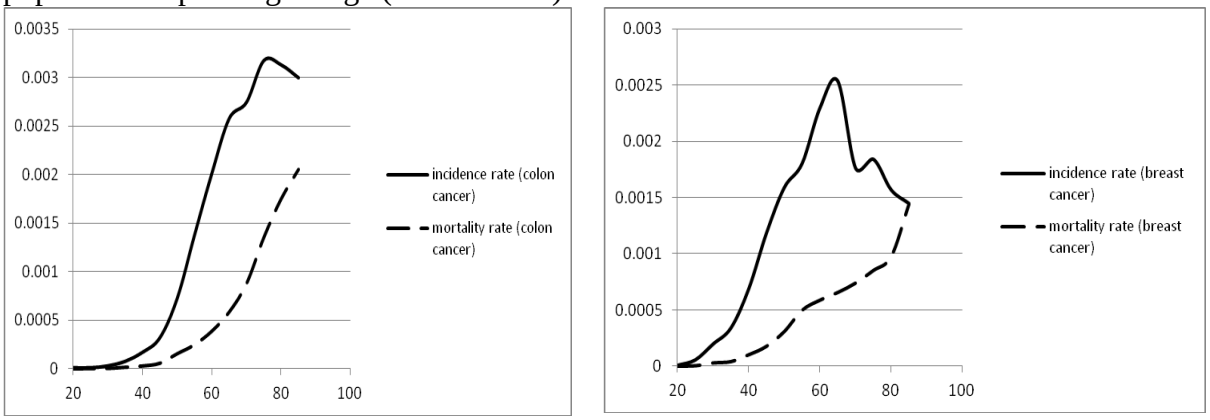
A strong dependence of morbidity and mortality on age is observed. The most kinds of cancers usually affect people in middle and old age. Therefore, the concept of cancerous age has been introduced into medical literature as a determination of the time in human life, wherein the risk of cancer morbidity increases significantly. As can be inferred on the basis of epidemiological data in Poland, cancerous age for women appears after exceeding the limit age of forty years of age and for males starts at the beginning of the fifth decade of life. The patient's age, sex and place of residence should be taken into account as important demographic predictors affecting the morbidity and mortality from cancer.

Figure 3: The average mortality and incidence rates per 100 000 inhabitants in men population depending on age (2008 – 2013).



Source: the author on the basis of Wojciechowska and Didkowska (2016).

Figure 4: The average mortality and incidence rates per 100 000 inhabitants in women population depending on age (2008 – 2013).



Source: the author on the basis of Wojciechowska and Didkowska (2016).

4. Determining the Course of Cancerous Disease Using Multistate Model

Benefits paid by the public payer as part of a general health insurance pose costs from the perspective of a society as a whole. The costs incurred by the society on the health care system arise from an occurrence of diseases. We can assume that morbidity and mortality due to cancer have a random nature. The course of the disease is determined by the patient's condition. In case of cancer, metastases (especially distant to the other organs) largely affects the condition of the patient. Therefore, depending on the diagnosis two basic conditions, mild without diagnosed metastases and critical with metastases, can be distinguished in modeling the course of cancerous disease. Obviously, more stages of the disease can be distinguished depending on assumptions. The distinction of disease stage is necessary due to the fact that the average life expectancy of a patient in a critical state is significantly shortened. In addition, disability pensions are more often granted to patients in the critical stage, and these patients have access to palliative care and hospice. The method of treatment also depends on the diagnosis, which influences the costs. During treatment course the patient's condition may improve, remain unchanged or worsen.

The history of a disease can be explored by the multistate model, wherein consecutive stages of the disease are described by states. The particular state is denoted as s_i. We assume that the the state space is finite, consists of *N* elements and is presented as $S = \{s_1, s_2, ..., s_N\}$. To simplify the notation, we assume that $s_i \equiv i$. Additional information on the course of disease is reflected by transitions between states. Denote $T = \{(i, j) : i \neq j; i, j \in S\}$ as the set of all possible direct transitions between states *i* and *j*. Thus, the course of the disease can be described by the state space and a set of transitions between states (S, T).

Changes the health condition of the population studied in time are described using function $X(x,t) \in S$, where *x* denotes the person's age at the start of cost analyses (in a particular case, that is the age at which a person became ill), and *t* is the time which has elapsed since the start. In further considerations we use a simpler notation $X(t)$. Due to the fact that the settlement between the providers and the public payer made are not continuous but at certain time intervals (usually monthly) we consider the discrete model $\{X(t) \text{ for } t = 0,1,...,n\}$. Let

$X(t)$ be a stochastic process, which takes the value of a finite state space, and which are includes changes for n moments in time. Description of changes in the disease process in time requires the determination of probability distributions of reaching by the process state i at time t

$$P\left(X(t)=i\right)=p_i(t) \text{ for } i=1,2,...,N \text{ and } t=0,1,2,...,n, \tag{1}$$

and the joined probability of reaching by the process state i at time t and state j at time $t+1$

$$P\left(X(t)=i, X(t+1)=j\right)=p_{ij}(t,t+1) \text{ for } i,j=1,2,...,N \text{ and } t=0,1,2,...,n. \tag{2}$$

Examination of probability of reaching all states in time t requires the introduction of vectors of probabilities (Dębicka, 2012)

$$\mathbf{p}(t)=\left(p_1(t), p_2(t),..., p_N(t)\right) \text{ for } t=0,1,2,...,n. \tag{3}$$

Probability of reaching all states in the consecutive periods t and $t+1$ can be expressed by the following probability matrix (Dębicka, 2012)

$$\mathbf{P}(t,t+1)=\begin{pmatrix} p_{11}(t,t+1) & p_{12}(t,t+1) & \dots & p_{1N}(t,t+1) \\ p_{21}(t,t+1) & \ddots & & p_{2N}(t,t+1) \\ \vdots & & \ddots & \vdots \\ p_{N1}(t,t+1) & \dots & & p_{NN}(t,t+1) \end{pmatrix}. \tag{4}$$

The vector (1) for $t=0$ is defined as an initial distribution.

In case of cancer, the analysis of the disease course requires introduction of a five-state model presented in Figure 5, where circles represent the states and arcs correspond to direct transitions between the states.

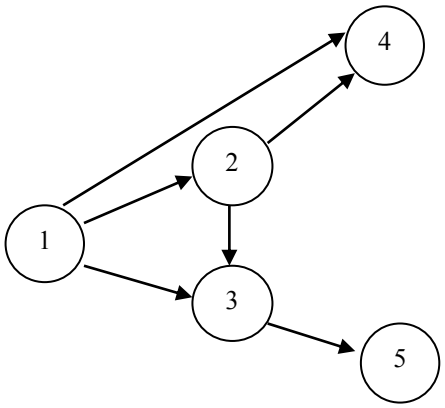
The meaning of the states is as follows:

1. a person is alive and healthy (without cancer);
2. a person is ill with cancer but in a mild stage, this is connected with not diagnosed metastases, in that state the risk of death is only slightly increased, chance of recovery in a long term is large;
3. a person is suffering from cancer a in critical stage, it means that metastases are diagnosed, the risk of death is greatly increased and the chance of recovery is minimal;
4. a person is dead for reasons other than cancer or being sick with cancer without diagnosed metastases
5. a person is dead being sick with cancer with diagnosed metastases.

Determination of the states and transitions between them is the result of the acceptance of assumptions:

1. A person can be diagnosed either in a mild stage or a critical one.
2. In a period of several years it can not be considered that the patient is cured of cancer (there is no possibility to transit from state 2 or 3 to state 1).
3. Two causes of death are considered, the first from cancer in a critical condition, the second from other reasons (the states 4 and 5 are distinguished).

Figure 5: Multi-state model describing the course of cancerous disease.



Source: the author (compare with Dębicka and Zmyślona, 2016).

The idea of model, which considers two potential health condition and two causes of death in case of health insurance, is described in detail in (Dębicka, Zmyślona, 2016). The patient's condition during the course of the disease can change (improve or worsen). Therefore, a duration of the process $X(t)$ in state 2 and 3 depends on the history of the process. Duration of stay of the process in state 2 has a significant impact on the probability of the transition to state 3, and duration of stay in state 3 has a significant impact on the probability of transition to state 5. The mentioned dependencies can be taken into account by the construction of a new model with extended state space. In the new extended model state 2 and 3 are divided into a larger number of states.

In case of other diseases, such as influenza, the patient's condition can change from hour to hour or day to day. In case of cancerous diseases, analysis of the health condition of a patient can be made with an accuracy to a month. Therefore, the state 2 and 3 are divided into 12 states in order to reflect the health condition of a patient in subsequent months. The extended model is presented in Figure 6.

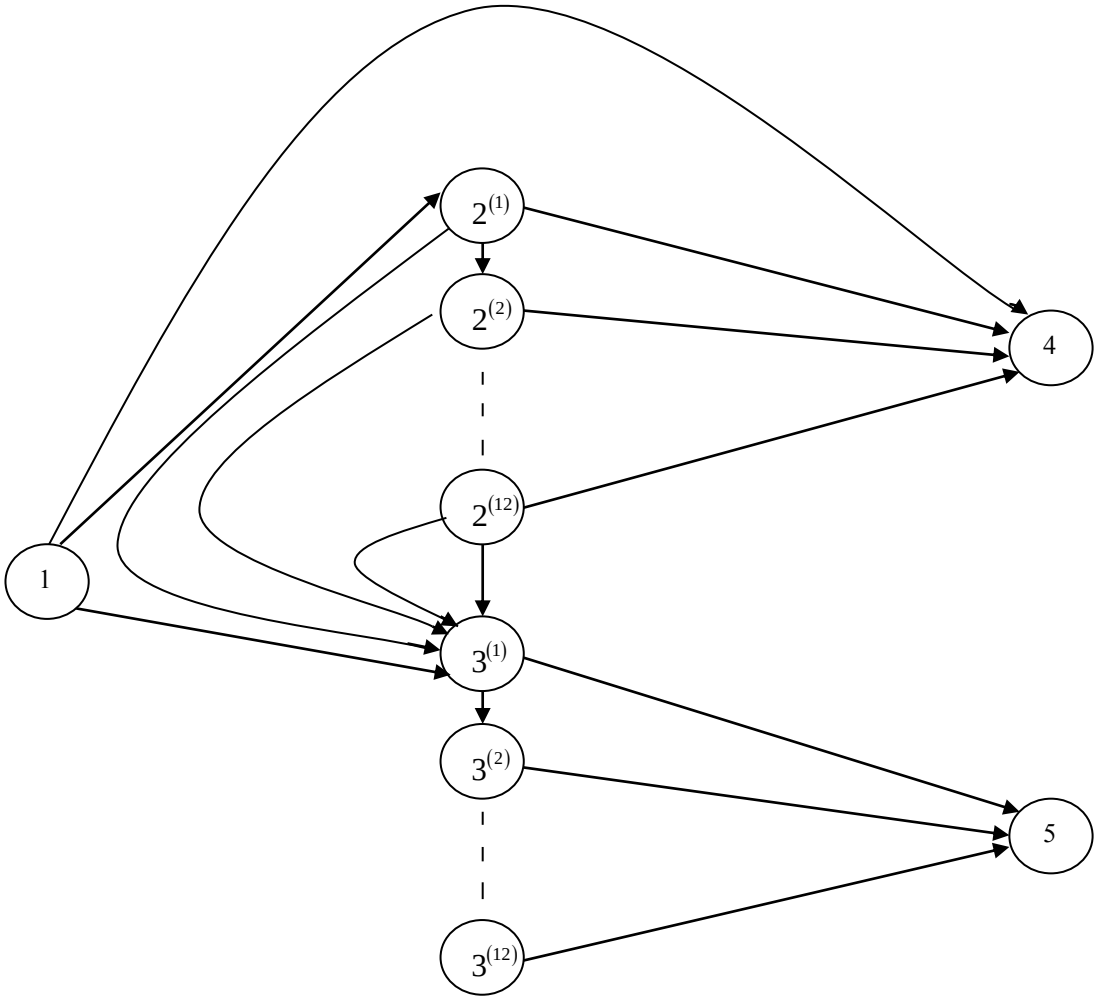
State 2 was divided into twelve states, the same was applied to state 3. State $2^{(j)}$ means that a patient is ill in mild health condition in *j*-th month, state $3^{(j)}$ that a patient is critically ill in *j*-th month. The health status of the patient in mild stage may deteriorate in *j*-th month, which means the transition from state $2^{(j)}$ to state $3^{(1)}$.

The model presented in Figure 6 describes only an annual disease history of a patient. A consideration of disease course in further time requires extension a state space of the model by introducing the states $2^{(g)}$ and $3^{(g)}$, where $g = 13,14,...,12 \cdot d$ and *d* denotes the number of considered years.

The transition matrix for the extended model presented in Figure 6 takes the following form

$$\mathbf{Q}(t) = \begin{pmatrix} q_{11}(t) & q_{12^{(1)}}(t) & \cdots & \cdots & \cdots & q_{13^{(1)}}(t) & \cdots & \cdots & q_{14}(t) & 0 \\ 0 & 0 & q_{2^{(1)}2^{(2)}}(t) & 0 & \cdots & q_{2^{(1)}3^{(1)}}(t) & 0 & \cdots & q_{2^{(1)}4}(t) & 0 \\ \vdots & \vdots & & \ddots & & \ddots & & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & q_{2^{(11)}2^{(12)}}(t) & q_{2^{(12)}3^{(1)}}(t) & \cdots & \cdots & q_{2^{(12)}4}(t) & 0 \\ 0 & 0 & 0 & \cdots & \cdots & \cdots & q_{3^{(1)}3^{(2)}}(t) & 0 & \cdots & q_{3^{(1)}5}(t) \\ 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & q_{3^{(11)}3^{(12)}}(t) & 0 & q_{3^{(11)}5}(t) \\ 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & q_{3^{(12)}5}(t) \\ 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & 0 & 1 \end{pmatrix}. \quad (5)$$

Figure 6: Multi-state model describing the course of cancerous disease with extended state space.



Source: the author.

The extended model enables to consider the process $\{X(t) \text{ for } t = 0,1,...,n\}$ as a nonhomogenous Markov chain. In this case, the probability distribution of the process can be

expressed by the initial distribution $\mathbf{p}(0)$ and the sequence of transition matrix $\mathbf{Q}(t)$ for t=0,1,...,n . The probability of the process expressed by (3) and (4) can be written as (Dębicka, 2012, 2013):

$$\mathbf{p}^T(t) = \mathbf{p}^T(0)\prod_{k=0}^{t-1}\mathbf{Q}(k), \tag{6}$$

and the joint probability as

$$\mathbf{P}(t_1,t_2) = \begin{cases} diag\left(\mathbf{p}^T(0)\right)\prod_{k=0}^{t_2-1}\mathbf{Q}(k), & 0 = t_1 < t_2, \\ diag\left(\mathbf{p}^T(0)\prod_{k=0}^{t_1-1}\mathbf{Q}(k)\right)\prod_{k=0}^{t_2-1}\mathbf{Q}(k), & 0 < t_1 < t_2, \\ diag\left(\mathbf{p}^T(0)\prod_{k=0}^{t-1}\mathbf{Q}(k)\right), & t_1 = t_2 = t \neq 0. \end{cases} \tag{7}$$

5. Estimation of Cost of Illness

The model presented in Figure 6 enables the analysis of various costs, which are generated by the process of a diseases. These costs can be considered as cash flows. We assume that the cost are born when the process $\{X(t)\}$ changes the states. We consider medical and nonmedical costs. The following medical costs are distinguished:

1. Cost of diagnosis (with a change state from 1 to $2^{(1)}$ or $3^{(1)}$ and also from $2^{(j)}$ to $3^{(1)}$).
2. Cost of treatment in hospital or cost of outpatient specialist care (a part of costs connected with a change state from $2^{(t)}$ to $2^{(t+1)}$ and from $3^{(t)}$ to $3^{(t+1)}$).
3. Cost connected with palliative and hospice care (a part of costs connected with a change state from $3^{(t)}$ to $3^{(t+1)}$).

The following nonmedical cost can be taken into account:

1. Mortality cost (with a state change from $2^{(t)}$ to 4 and from $3^{(t)}$ to 5).
2. Cost of lost productivity, costs associated with the payment of pensions (connected with transition of process in states $2^{(i)}$ and $3^{(i)}$) and other.

In the paper, we consider only the medical cost. All medical costs associated with the treatment process of patients born by the public payer are listed in Table 1. From the standpoint of the public payer, the flows related to medical costs are benefits (subsidies) paid to providers for the performance of services. These benefits are paid always after the settling period which usually takes one month. Medical expenses consist of: costs of the population prevention programs for early detection of cancer, the cost of hospital treatment and outpatient services including oncological surgery, chemotherapy, radiation therapy, medication and the use of other treatments, the costs of palliative care and hospice stay. In the paper, we consider the cost born by the public payer.

We assume that when the process $\{X(t)\}$ stays in state 1 a benefit is equal to zero. We do not consider the mortality costs, so benefits connected with a change state from $2^{(i)}$ to 4 and from $3^{(i)}$ to 5 are also zero.

Let us consider the sets of benefits $\mathsf{B} \in \{b_1, b_2, ..., b_M\}$ which are paid by the public payer in connection with the treatment process. The average amount of benefit depends not only on

disease state, but also on the age of a patient. Elderly patients often require longer hospitalization and have complications after treatment more frequently than younger ones. The incidence rates are also much higher for the elderly. Therefore, in procedure of estimation the age of patient should be taken into account. The incidence rates are differential depending on the sex of a patient.

We calculate the cost of illness using the incidence-based analysis. This means that the histories of people who have fallen ill in a given year are considered. The transition matrix for the extended model presented in Figure 6 is estimated for a patient at age x years separately in men and women populations. We obtain the sequence of matrixes $\hat{\mathbf{Q}}^{[x]}(t)$ for x = 20, 21,..., 100 and for t=0,1,...,12. A realistic assumption is made that the character of the matrix $\hat{\mathbf{Q}}^{[x]}(t)$ does not change in particular months of the year. The following rates and estimators of probabilities are used in estimation of the transition probabilities of matrix: the mortality rate, the incidence rate, the percentage of patients who are diagnosed with metastases during the first diagnosis, the probability of metastases detection during the first, the second etc. month after diagnosis, the probability of death, the fatality rate in the first, the second etc. month after diagnosis with metastases. Each of these factors is the estimate for a person aged x. The incidence, mortality rates and probability of death should be calculated for the population of inhabitants of an analysed region. The probability connected with health conditions and fatality rates should be obtained on the basis of the analysis of histories of disease treatment. Costs are not discounted, because the analysis concerns a single year. We define the matrix

$$\bar{\mathbf{B}}^{[x]} = \begin{pmatrix}
0 & \bar{b}^{[x]}_{12^{(1)}} & \cdots & \cdots & \cdots & \bar{b}^{[x]}_{13^{(1)}} & \cdots & \cdots & 0 & 0 \\
0 & 0 & \bar{b}^{[x]}_{2^{(1)}2^{(2)}} & 0 & \cdots & \bar{b}^{[x]}_{2^{(1)}3^{(1)}} & 0 & \cdots & 0 & 0 \\
\vdots & \vdots & & \ddots & & \ddots & & \vdots & \vdots & \vdots \\
0 & 0 & 0 & \cdots & \bar{b}^{[x]}_{2^{(11)}2^{(12)}} & \bar{b}^{[x]}_{2^{(12)}3^{(1)}} & \cdots & \cdots & 0 & 0 \\
0 & 0 & 0 & \cdots & \cdots & \cdots & \bar{b}^{[x]}_{3^{(1)}3^{(2)}} & 0 & \cdots & 0 \\
0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \ddots & 0 \\
0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \bar{b}^{[x]}_{3^{(11)}3^{(12)}} & 0 & 0 \\
0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\
0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & 0 & 0
\end{pmatrix}. \qquad (8)$$

An element of matrix (8) is the value of an average cost (benefits from the point of view of health care providers) connected with the transition of the disease process $X(t)$ from one to another state for a patient at age x years. In case when an element is equal to zero, it is equivalent with a lack of medical cost at that phase of disease process. The average costs are calculated on the basis of micro-data connected with the disease history for particular patient. The costs for a particular patient are accounted within the framework of the so-called settlement products. Each medical service is measured by means of one or more of such products. Valuation is given in PLN by the public payer (the National Health Fund). On the basis of an average medical cost of treating patients in age of x depending on the disease process, an average cost of illness can be specified using the multistate model. We use the following formula

$$\hat{b}^{[x]} = \sum_{i,j \in S} \sum_{t=0}^{n-1} \bar{b}_{ij}^{[x]} p_{ij}^{[x]}(t, t+1), \tag{9}$$

where $S = \{1, 2, ..., N\}$ is a state space, $\bar{b}_{ij}^{[x]}$ is an element of matrix (8), and $p_{ij}^{[x]}(t, t+1)$ is an element of matrix (4) calculated using formula (7).

6. Conclusion

The usage of the multistate model for cost estimation allows to make a consideration about economic burden due to disease from the incidence-based analysis point of view. Costs are estimated for a patient at the age of *x*, therefore, cost comparisons for age are possible. Cost analysis of individual stages of a disease process makes it possible to consider the cost structure. Non-medical costs associated with mortality, morbidity and loss of productivity may also be considered using this model. However, medical costs can not be added together with the non-medical costs, so such a study should be carried out separately. In addition, the estimation of a probabilistic structure of the model allows to calculate premiums for an additional, private insurance, which can be complementary to the one financed by the public payer (Christiansen, 2012, Škřivánková and Šoltés, 2009).

References

[1] CHRISTIANSEN, M. C. 2012. Multistate models in health insurance. In Asta-Advances in Statistical Analysis, 2012, vol. 96, iss. 2, pp. 155-186.

[2] DĘBICKA, J. 2012. Modelowanie strumieni finansowych w ubezpieczeniach wielostanowych. Wrocław : Wydawnictwo Uniwersytetu Ekonomicznego, 2012.

[3] DĘBICKA, J. 2013. An approach to the study of multistate insurance contracts. In Applied Stochastic Models Business and Industry, 2013, vol. 29, iss. 3, pp. 224-240.

[4] DĘBICKA, J., ZMYŚLONA, B. 2016. Modelling of lung cancer survival data. Manuscript I, http://arxiv.org/abs/1602.08696.

[5] EEROLA, M., HELSKE, S. 2016. Statistical analysis of life history calendar data. In Statistical Methods in Medical Research, 2016, vol. 25, iss. 2, pp. 571-597.

[6] HENRY, K. A. et. al. 2013. Breast cancer stage at diagnosis : Is travel time important? In Journal of Community Health, 2013, vol. 36, iss. 6, pp. 933-942.

[7] HOUGAARD, P. 1999. Multistate models : A review. Washington : World Bank Institute. 2004.

[8] PITACCO, E. 1999. Multistate models for long-term insurance and related indexing problem. In Applied Stochastic Models in Business and Industry, 1999, vol. 15, iss. 4, pp. 429-441.

[9] ŠKŘIVÁNKOVÁ, L., ŠOLTÉS, M. 2009. The actuarial models for critical illness insurance. In Ekonomie a Management, 2009, vol. 12, iss. 3, pp. 69-76.

[10] WOJCIECHOWSKA, U., DIDKOWSKA, J. 2016. Zachorowania i zgony na nowotwory złośliwe w Polsce. Krajowy Rejestr Nowotworów. Centrum Onkologii, Instytut im. Marii Skłodowskiej-Curie. [cit. 2016-02-10] http://www.onkologia.org.pl/raporty.

[11] POLISH ONCOLOGICAL SOCIETY 2014. Obecny stan zwalczania nowotworów w Polsce załącznik do strategii walki z rakiem w Polsce 2015-2024, Raport Polskiego Towarzystwa Onkologicznego. [cit. 2016-02-16] https://pto.med.pl.