

**A. SHAKENOVA¹, R. SHAKENOVA^{1*}, Z. ALIMZHANOVA¹,
G. ZIYATBEKOVA^{2,3,4}**

¹*Kazakh National Research Technical University named after K.I. Satbayev,
Almaty, Kazakhstan;*

²*Almaty Technological University, Almaty, Kazakhstan;*

³*Al-Farabi Kazakh National University, Almaty, Kazakhstan;*

⁴*Institute of Information and Computational Technologies SC MSHE RK,
Almaty, Kazakhstan.*

**E-mail: r.shakenova@satbayev.university*

BIPOLAR DISORDER STATES AND MARKOV DECISION PROCESSES

Alua Shakenova – Ph.D. candidate, Kazakh National Research Technical University named after K.I. Satbayev, Almaty, Kazakhstan;

E-mail: shakenova.a@stud.satbayev.university; <https://orcid.org/0009-0004-5027-2749>

Roza Shakenova – Candidate of physical and mathematical sciences, associate professor, Kazakh National Research Technical University named after K.I. Satbayev, Almaty, Kazakhstan;

E-mail: r.shakenova@satbayev.university; <https://orcid.org/0000-0002-8833-5029>

Zhanna Alimzhanova – Candidate of physical and mathematical sciences, associate professor, Kazakh National Research Technical University named after K.I. Satbayev, Almaty, Kazakhstan;

E-mail: z.alimzhanova@satbayev.university; <https://orcid.org/0000-0001-6282-5356>

Gulzat Ziyatbekova – PhD, Associate Professor; Almaty Technological University, Almaty, Kazakhstan; Al-Farabi Kazakh National University, Almaty, Kazakhstan; Institute of Information and Computational Technologies SC MSHE RK, Almaty, Kazakhstan.

E-mail: ziyatbekova1@gmail.com; <https://orcid.org/0000-0002-9290-6074>

Bipolar disorder has been under-researched in Kazakhstan, although many individuals are susceptible to this disorder in a latent form. In this article, we applied Markov processes to study the bipolar individual's states. Different reward results can be obtained by employing Markov decision processes for analyzing bipolar individual's mood states. After employing test scenarios, we conclude that BD individual needs social support more, than other people. The practical benefit of decision-making theory is to find different ways of making decisions in order to help bipolar individual.

Keywords: Bipolar disorder; Markov decision processes; reward; depression; testing scenarios.

**А. Н. ШАКЕНОВА¹, Р. К. ШАКЕНОВА^{1*}, Ж. М. АЛИМЖАНОВА¹,
Г. З. ЗИЯТБЕКОВА^{2,3,4}**

¹*Қ.И. Сәтбаев атындағы Қазақ Ұлттық Техникалық Зерттеу Университеті,
Алматы, Қазақстан;*

²*Алматы Технологиялық Университеті, Алматы, Қазақстан;*

³ Әл-Фараби атындағы Қазақ Ұлттық Университеті, Алматы, Қазақстан;

⁴ҚР ҒжЖБМ ҒК Ақпараттық және есептеуіш технологиялар институты, Алматы, Қазақстан.

*E-mail: r.shakenova@satbayev.university

БИПОЛЯРЛЫҚ БҰЗЫЛЫСТАҒЫ КҮЙЛЕР ЖӘНЕ МАРКОВТЫҢ ШЕШІМДЕР ҚАБЫЛДАУ ПРОЦЕСТЕРІ

Шакенова Алуа Нурбакытовна – Ph.D. кандидат, Қ.И. Сәтбаев атындағы Қазақ Ұлттық Техникалық Зерттеу Университеті, Алматы, Қазақстан;

E-mail: shakenova.a@stud.satbayev.university; <https://orcid.org/0009-0004-5027-2749>

Шакенова Роза Кожаметовна – физика-математика ғылымдарының кандидаты, қауымдастырылған профессор, Қ.И. Сәтбаев атындағы Қазақ Ұлттық Техникалық Зерттеу Университеті, Алматы, Қазақстан;

E-mail: r.shakenova@satbayev.university; <https://orcid.org/0000-0002-8833-5029>

Алимжанова Жанна Муратбековна – физика-математика ғылымдарының кандидаты, қауымдастырылған профессор, Қ.И. Сәтбаев атындағы Қазақ Ұлттық Техникалық Зерттеу Университеті, Алматы, Қазақстан;

E-mail: z.alimzhanova@satbayev.university; <https://orcid.org/0000-0001-6282-5356>

Зиятбекова Гулзат Зиятбекқызы – PhD, қауымдастырылған профессор, Алматы Технологиялық университеті, әл-Фараби атындағы Қазақ ұлттық университеті, ҚР ҒжЖБМ ҒК Ақпараттық және Есептеу Технологиялары институты, Алматы, Қазақстан.

E-mail: ziyatbekova1@gmail.com; <https://orcid.org/0000-0002-9290-6074>

Биполярлық бұзылыс Қазақстанда аз зерттелген. Дегенмен көптеген индивидтер осы бұзылыспен ауыратындарын байқамайды. Сондықтан Марков процестерін индивидтің көңіл күйлерін зерттеу үшін қолдандық. Марков процестерін индивидтің көңіл күйін анықтау үшін қолдану кезінде индивид үшін әртүрлі сыйақы нәтижелерін алуға болады. Тестілеу сценарийлерінің соңында биполярлық күйзеліске түскен индивидтер қалған индивидтермен салыстырғанда социалдық қолдауға көбірек мұқтаж екені туралы қорытындыға келеміз. Индивидке көмектесу үшін әртүрлі шешімдер қабылдау әдістерін табуға болады, шешімдер қабылдау теориясының практикалық пайдасы осыдан көрінеді.

Түйін сөздер: биполярлық күйзеліс, марков процестері, сыйақы, депрессия, сынақ сценарийлері.

**А. Н. ШАКЕНОВА¹, Р. К. ШАКЕНОВА^{1*}, Ж. М. АЛИМЖАНОВА¹,
Г. З. ЗИЯТБЕКОВА^{2,3,4}**

¹Казахский национальный исследовательский технический университет
имени К.И. Сатпаева, Алматы, Казахстан;

²Алматинский технологический университет, Алматы, Казахстан;

³Казахский национальный университет имени аль-Фараби, Алматы, Казахстан;

⁴Институт информационных и вычислительных технологий КН МНВО РК,
Алматы, Казахстан.

*E-mail: r.shakenova@satbayev.university

СОСТОЯНИЯ БИПОЛЯРНОГО РАССТРОЙСТВА И МАРКОВСКИЕ ПРОЦЕССЫ ПРИНЯТИЯ РЕШЕНИЙ

Шакенова Алуа Нурбакытовна – докторант, Казахский Национальный Исследовательский Технический Университет имени К.И. Сатпаева, Алматы, Казахстан;

E-mail: shakenova.a@stud.satbayev.university; <https://orcid.org/0009-0004-5027-2749>

Шакенова Роза Кожаметовна – кандидат физико-математических наук, ассоциированный профессор, Казахский Национальный Исследовательский Технический Университет имени К.И. Сатпаева, Алматы, Казахстан;

E-mail: r.shakenova@satbayev.university; <https://orcid.org/0000-0002-8833-5029>

Алимжанова Жанна Муратбековна – кандидат физико-математических наук, ассоциированный профессор, Казахский Национальный Исследовательский Технический Университет имени К.И. Сатпаева, Алматы, Казахстан;

E-mail: z.alimzhanova@satbayev.university; <https://orcid.org/0000-0001-6282-5356>

Зиятбекова Гулзат Зиятбеккызы – PhD, ассоциированный профессор, Алматинский технологический университет, Казахский национальный университет имени аль-Фараби, Институт информационных и вычислительных технологий КН МНВО РК, Алматы, Казахстан.

E-mail: ziyatbekoval@gmail.com ; <https://orcid.org/0000-0002-9290-6074>

Биполярное расстройство мало исследовано в Казахстане, хотя многие индивиды подвержены этому расстройству в скрытой форме. Применяя Марковские процессы в анализе состояний индивида, можно получить различные результаты в виде вознаграждения для индивида. После сценариев тестирования приходим к выводу, что индивид с биполярным расстройством нуждается в социальной поддержке больше, чем другие индивиды. Чтобы помочь индивиду, можно найти различные способы принятия решений и в этом проявляется практическая польза от теории принятия решений.

Ключевые слова: биполярное расстройство, Марковские процессы, вознаграждение, депрессия, сценарии тестирования.

This article considers the problem of Markov process with discount factor. The discount factor β determines the support level for individual from society. The individual receives a reward depending on his efforts and depending on the values of discount factor. A game with testing scenarios is proposed to determine the beneficial reward for the individual. The topic of application of Markov decision processes to bipolar disorder is not covered in Kazakhstani publications. Therefore, this article is devoted specifically to the study of this mental illness in Kazakhstan.

Methods. In literature [1-6], [9] bipolar disorder mood states are modelled by Markov chains. The main goal of these papers was to use Markov decision processes for predicting mood switches. Bipolar disorder process cannot be explored in isolation from economic and social factors. The interactions with social environment play an important role on dynamics of bipolar disorder. The cornerstone should be placed on a person as a member of society and we'll demonstrate further that social support has a significant effect on bipolar disorder.

Markov decision-making process in depression. Consider a system which state space M contains a finite number of elements. Let M to coincide with the set of integers $M = \{1,$

2, ..., N }. Each state $i \in M$ corresponds to a finite set R_i of solutions (or alternatives) with elements $r = 1, 2, 3, \dots, R_i$. We consider problem of making sequential decisions [8] which consists of choosing solutions for current states at moments $n = 0, 1, 2, \dots$

If the system is in state $i \in M$ and the decision $r \in R_i$, is made, then

1) The system receives income (or reward) d_i^r ,

2) Its state at the next moment in time is determined by the probabilistic law p_{ij}^r , $j \in M$, where p_{ij}^r is the probability that the system transitions from state i to state j , when a solution r is chosen.

It is assumed that income d_i^r is finite for all $i \in M$, $r \in R_i$. In addition, $\sum_{j \in M} p_{ij}^r = 1$, $p_{ij}^r \geq 0$ for $i, j \in M$, $r \in R_i$.

Strategy b is defined as the sequence $\{p_n, n = 1, 2, \dots\}$, i.e. $b = (p_1, p_2, \dots, p_n, \dots)$, where p_n is a vector, which i^{th} element, $p_n(i)$, is the decision taken in state $i \in M$ at time n .

Let β , $0 \leq \beta \leq 1$ to be the discount coefficient. This means that a unit of income will cost β^n units after time n (for example, n days). From a mathematical point of view, introducing this coefficient leads to a finite average income.

For any $r = p(i) = R_i$, it is possible to determine the $(N \times 1)$ - dimensional vector of total average incomes, which i^{th} element corresponds to the initial state of the process $i \in M$, and has the form

$$\begin{aligned} W_\beta(b) &= \sum_{n=0}^{\infty} \beta^n \cdot P_n(b) \cdot d(p_{n+1}). \quad \sum_{n=0}^{\infty} \beta^n \cdot P_n(b) \cdot d(p_{n+1}) = \\ &= d(p_1) + \beta \cdot P(p_1) \cdot W_\beta(E_b), \end{aligned}$$

where $E_b = (p_2, p_3, \dots)$ is the new strategy obtained by shifting one element from the initial. Here, $P_n(b) = P(p_1) \cdot P(p_2) \cdot \dots \cdot P(p_n)$. $n = 1, 2, \dots$, where $P(p_n)$ is a transition matrix of size $N \times N$, (i, j) , which element is equal to p_{ij}^r .

For any $(N \times 1)$ - dimensional vector, we define the operator $T(p)$ which maps x into a vector $T(p)x = d(p) + \beta \cdot P(p) \cdot x$. We solve the following equations by choosing an arbitrary policy $p \in P$ [7]:

$$w_i = d_i^r + \beta \cdot \sum_{j \in M} p_{ij}^r \cdot w_j \quad (1)$$

The individual detected that he is depressed. We denote this depressive state as $s = s_1$ with probability p_d . He can stay in this state with probability p_{11} , where p_{11} is the probability of remaining in a state of depression. If the individual decides to resolve this situation, for example, to undergo treatment, he will go to another state $s = s_2$ with probability $1 - p_{11}$. We can construct the matrix of transitional probabilities:

$\begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix}$, p_{12} is the transitional probability from state s_1 to state s_2 . Accordingly, p_{21} is the transitional probability from state s_2 to state s_1 and p_{22} is the probability of staying in state s_2 .

Initial reward vector $d(p_1) = \begin{pmatrix} c_1 \\ c_2 \end{pmatrix}$. Coefficient $\beta \in [0; 1]$, means an obstacle or leadership style at work. Let's create the following system of equations to determine reward values:

$$\begin{cases} w_1 = c_1 + \beta \cdot (p_{11} \cdot w_1 + p_{12} \cdot w_2), \\ w_2 = c_2 + \beta \cdot (p_{21} \cdot w_1 + p_{22} \cdot w_2). \end{cases} \quad (2)$$

Two policies p_1, p_2 (two solutions) are presented which correspond to two states. p_1 corresponds to the policy for remaining depressed, p_2 - to be treated from depression.

We introduce the following function for managing the individual's states $f = f(p_i, p_{ij}, d(p_i), A)$, where p_i is the chosen decision or policy, p_{ij} are transitional probabilities, $d(p_i)$ is initial reward or income, A is an action.

We solve system (2) and obtain the following values:

$$\omega_1 = \frac{c_1 + \beta \cdot (c_2 \cdot p_{12} - c_1 \cdot p_{22})}{1 - \beta \cdot (p_{22} + p_{11}) + \beta^2 \cdot (p_{11} \cdot p_{22} - p_{21} \cdot p_{12})},$$

$$\omega_2 = \frac{c_2 + \beta \cdot (c_1 \cdot p_{21} - c_2 \cdot p_{11})}{1 - \beta \cdot (p_{22} + p_{11}) + \beta^2 \cdot (p_{11} \cdot p_{22} - p_{21} \cdot p_{12})}.$$

If an individual experiences three states: depression, normal and mania, we can write the system of equations in the following form:

$$\begin{cases} w_1 = c_1 + \beta \cdot (p_{11} \cdot w_1 + p_{12} \cdot w_2 + p_{13} \cdot w_3), \\ w_2 = c_2 + \beta \cdot (p_{21} \cdot w_1 + p_{22} \cdot w_2 + p_{23} \cdot w_3), \\ w_3 = c_3 + \beta \cdot (p_{31} \cdot w_1 + p_{32} \cdot w_2 + p_{33} \cdot w_3). \end{cases} \quad (3)$$

In this case, the transitional probability matrix has the form:

$$\begin{pmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{pmatrix}, d(p_1) = \begin{pmatrix} c_1 \\ c_2 \\ c_3 \end{pmatrix}.$$

Three policies (three decisions), p_1, p_2, p_3 , correspond to three states. p_1 corresponds to the policy of remaining in depressive state, p_2 – to move from depressive state to normal state, p_3 – to move from a normal state to manic state.

Results.

Table 1 – Scenarios used in testing decision rules.

scenarios	β	p_{ij}	$d(p_i)$	w_i
1	2	3	4	5
1	0.5	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(11.37; 10.32)
2	0.6	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(14.04; 12.98)
3	0.7	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(18.49; 17.42)
4	0.8	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(27.39; 26.30)

1	2	3	4	5
5	0.9	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(54.07; 52.96)
6	0.4	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(9.58; 8.54)
7	0.3	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(8.31; 7.28)
8	0.2	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(7.35; 6.33)
9	0.1	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(6.60; 5.59)
10	0.5	$\begin{pmatrix} 0,2 & 0,8 \\ 0,4 & 0,6 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(11.64; 10.36)
11	0.5	$\begin{pmatrix} 0,1 & 0,9 \\ 0,8 & 0,2 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(11.33; 10.59)
12	0.5	$\begin{pmatrix} 0,7 & 0,3 \\ 0,5 & 0,5 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(11.67; 10.56)
13	0.5	$\begin{pmatrix} 0,2 & 0,8 \\ 0,4 & 0,6 \end{pmatrix}$	$\begin{pmatrix} 8 \\ 4 \end{pmatrix}$	(13.09; 9.45)
14	0.5	$\begin{pmatrix} 0,2 & 0,8 \\ 0,4 & 0,6 \end{pmatrix}$	$\begin{pmatrix} 7 \\ 3 \end{pmatrix}$	(9.45; 7.45)
15	0.5	$\begin{pmatrix} 0,2 & 0,8 \\ 0,4 & 0,6 \end{pmatrix}$	$\begin{pmatrix} 9 \\ 2 \end{pmatrix}$	(12.91; 6.55)
16	0.9	$\begin{pmatrix} 0,1 & 0,9 \\ 0,8 & 0,2 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(55.03; 54.42)
17	0.1	$\begin{pmatrix} 0,7 & 0,3 \\ 0,5 & 0,5 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(6.63; 5.61)
18	0.3	$\begin{pmatrix} 0,3 & 0,7 \\ 0,2 & 0,8 \end{pmatrix}$	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(8.26; 7.23)

1	2	3	4	5
19	0.2	$\begin{pmatrix} 0,3 & 0,7 \\ 0,2 & 0,8 \end{pmatrix}$	$\begin{pmatrix} 8 \\ 4 \end{pmatrix}$	(9.29; 5.20)
20	0.1	$\begin{pmatrix} 0,3 & 0,7 \\ 0,2 & 0,8 \end{pmatrix}$	$\begin{pmatrix} 5 \\ 5 \end{pmatrix}$	(5.56; 5.56)

The coefficient $\beta \in [0;1]$ represents the obstacle or leadership style at work. Table 1 shows that the coefficient β is very important for income growth. Therefore, social support in life is very significant for an individual.

Table 2 – Scenarios used in testing decision rules.

№ scenarios	Input parameter (question)	Output parameter (state) and β	Decision, policy p_i	Initial reward $d(p_i)$	Income w_i	Action	Transition probabilities p_{ij}
1	2	3	4	5	6	7	8
1	You're feeling depressed today. What will you do?	Depressed, $\beta = 0,5$	1	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(11.37; 10.32)	Stay in bed all day and avoid socializing	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$
2	You're feeling depressed today. What will you do?	Depressed, $\beta = 0,6$	1	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(14.04; 12.98)	Try doing light exercise or yoga	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$
3	You're feeling depressed today. What will you do?	Depressed, $\beta = 0,7$	1	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(18.49; 17.42)	Listen to a favourite music	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$
4	You're feeling depressed today. What will you do?	Depressed, $\beta = 0,8$	1	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(27.39; 26.30)	Call a counselor or a friend	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$

1	2	3	4	5	6	7	8
5	You're feeling depressed today. What will you do?	Depressed, $\beta = 0,9$	1	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(54.07; 52.96)	Call a counselor or a friend	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$
6	You're feeling stable today. What will you do?	Stable, $\beta = 0,4$	2	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(9.58; 8.54)	Schedule a therapy session	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$
7	You're feeling stable today. What will you do?	Stable, $\beta = 0,3$	2	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(8.31; 7.28)	Take a walk and get some fresh air.	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$
8	You're feeling stable today. What will you do?	Stable, $\beta = 0,2$	2	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(7.35; 6.33)	Work on a hobby you enjoy	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$
9	You're feeling stable today. What will you do?	Stable, $\beta = 0,1$	2	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(6.60; 5.59)	Talk to a friend	$\begin{pmatrix} 0,4 & 0,6 \\ 0,3 & 0,7 \end{pmatrix}$
10	You're feeling stable today. What will you do?	Stable, $\beta = 0,5$	2	$\begin{pmatrix} 6 \\ 5 \end{pmatrix}$	(11.64; 10.36)	Talk to a friend	$\begin{pmatrix} 0,2 & 0,8 \\ 0,4 & 0,6 \end{pmatrix}$
11	You're feeling manic today. What will you do?	Manic, $\beta = 0,5$	3	$\begin{pmatrix} 5 \\ 3 \\ 2 \end{pmatrix}$	(8.81; 6.37; 5.13)	Take a nap	$\begin{pmatrix} 0,6 & 0,2 & 0,2 \\ 0,3 & 0,4 & 0,3 \\ 0,2 & 0,3 & 0,5 \end{pmatrix}$
12	You're feeling manic today. What will you do?	Manic, $\beta = 0,6$	3	$\begin{pmatrix} 5 \\ 3 \\ 2 \end{pmatrix}$	(11.14; 8.05; 6.74)	Try to calm down and meditate	$\begin{pmatrix} 0,6 & 0,2 & 0,2 \\ 0,3 & 0,4 & 0,3 \\ 0,2 & 0,3 & 0,5 \end{pmatrix}$

1	2	3	4	5	6	7	8
13	You're feeling manic to-day. What will you do?	Manic, $\beta = 0,7$	3	$\begin{pmatrix} 5 \\ 3 \\ 2 \end{pmatrix}$	(12.46;10.02;8.75)	Talk to friends about your exciting plans	$\begin{pmatrix} 0,6 & 0,2 & 0,2 \\ 0,3 & 0,4 & 0,3 \\ 0,2 & 0,3 & 0,5 \end{pmatrix}$
14	You're feeling manic to-day. What will you do?	Manic, $\beta = 0,8$	3	$\begin{pmatrix} 5 \\ 3 \\ 2 \end{pmatrix}$	(19.38;16.59;15.14)	Take on a big project and work late into the night	$\begin{pmatrix} 0,6 & 0,2 & 0,2 \\ 0,3 & 0,4 & 0,3 \\ 0,2 & 0,3 & 0,5 \end{pmatrix}$
15	You're feeling manic to-day. What will you do?	Manic, $\beta = 0,9$	3	$\begin{pmatrix} 5 \\ 3 \\ 2 \end{pmatrix}$	(36.68;33.75;32.21)	Talk to friends about your exciting plans	$\begin{pmatrix} 0,6 & 0,2 & 0,2 \\ 0,3 & 0,4 & 0,3 \\ 0,2 & 0,3 & 0,5 \end{pmatrix}$

In Table 2 we observe that individual's income is higher when individual gets social support from others, i.e. employers, administration, relatives, friends, β coefficient increases. If individual answers the questions, he will receive a recommendation for improving his condition. These actions are indicated as individual actions in Table 2 and are included in the individual's state function $f = f(p_i, p_{ij}, d(p_i), A)$ as parameter A.

Conclusion. This article introduces β coefficient as an indicator of social support for individual from the environment. Consequently, this paper opens a new topic “bipolar disorder” in science for research in Kazakhstan. In the next paper, we will present the game which will assist bipolar patient to make optimal decisions.

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