РОЗДІЛ 4. ЕКОНОМІКО-МАТЕМАТИЧНІ МЕТОДИ ТА МОДЕЛІ

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WEB EVOLUTIONARY DYNAMICS

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Nonlinear dynamic model has been suggested for assessing and predicting the number of social network users. It was shown that Maurer and Huberman's model describes the dynamics of users quite well in the short term. But the appearance of new services and changes in network strategy shift the parameters of system, which significantly affects to users' dynamics in the long-term. So the objective of the study was the modeling of the number of social network users in the long-term. The results have shown that the introduction of variable coefficients allows to describe the dynamics of real data more qualitative – the system can have several stable states of equilibrium; dynamics depends on the competitors' strategies; the final state of the system is sensitive to initial conditions.

Keywords: social network value, users' number evaluation, nonlinear dynamics, variable coefficients of competition.

1. Social Networks in the structure of Internet services

Nowadays the Internet has become an integral part of the cultural, economic, social and political life, deepening and extending its variety. The rapid development of information technology in the late 20th century greatly strengthened the position of the virtual space in the service of human interaction [1]. In this century the number of the Internet users reached almost 2 billion people (Table1).

Recent publications, dealt with various aspects of the Internet (development of services, self-organization of users, types of competitive dynamics of web sites, etc.), indicate a high scientific interest to this subject [3, 5, 9, 10, 11, 12]. According to the researches, the Internet is unique self-organizing system with complex forms of interaction between participants, which interests are served by diverse services (Fig.1).

On the service level (Fig.1, line 2) changes are rare — some services are pushed to the background (eg. gopher), some of them continue to develop rapidly (eg. www). The appearance of qualitatively new trends in World Wide Web started to be discussed at the end of 2005, when communication services have come to replace the information and trade services: such monsters of virtual business like E-Bay and Amazon have been pressed by Web2.0 resources — Facebook, Wikipedia and YouTube (Table 2).

As seen from Table 2, among the communication services the social networks are growing most rapidly (it evidenced by the first place of the Facebook in the ranking-2010). Gubanov [5] defines a social network (SN) as a structure consisting of agents' set and specific relations between them. In the Internet this term refers to an interactive multi-user web site based on the Web 2.0, which is used to create and maintain personal and professional relationships between people. Communication service, provided by these networks, connects users by the formal and informal criteria and provides the tools for work, self-expression, and social activity.

Nowadays there are over thousands of the SNs in the Internet; about 100 of them can be called large-scale, the most popular one is the Facebook. The SNs bring together the English-speaking users, and at the same time localized versions develop actively in many countries. Regional networks are also highly popular as well: it is, for example, wer-kennt-wen and studiVZ in Germany, QQ and Xiaonei in China, VKontakte and Odnoklassniki in Ukraine and Russia. In regional markets there is a trend of increasing competition between localized versions of world leaders and regional social networks.

2. Social Networks as a business

From a business point of view, social networks are high-risk venture projects with unclear return on investments. All the e-business risks are common to the social networks: high competition in any market segment; rapid copying of successful technologies; enormous dependence on the team. The main problems of start-ups associated with high cost of "market entry" and the need for continued funding, but most of developers even don't have a clear business model. Therefore, despite the high profitability of the largest

Table 1: World internet usage and population statistics [2]

World Regions	Internet Users, 2014	Penetration (% Population)	Growth (2000-2014)
Africa	297 885 898	25.5 %	6 498.6 %
Asia	1 386 188 112	34.7 %	1 112.7 %
Europe	582 441 059	70.5 %	454.2 %
Middle East	111 809 510	48.3 %	3 303.8 %
North America	310 322 257	87.7 %	187.1 %
Latin America	320 312 562	52.3 %	1 672.7 %
Oceania / Australia	26 789 942	72.9 %	251.6 %
World Total	3 035 749 340	42.3 %	741.0 %

Table 2: Rating of the Internet sites [4]

Rating	2005	2008	2010	2014
	yahoo.com	yahoo.com	facebook.com	google.com
	msn.com	youtube.com	youtube.com	facebook.com
	google.com	live.com	yahoo.com	youtube.com
	ebay.com	google.com	live.com	yahoo.com
	amazon.com	myspace.com	wikipedia.org	baidu.com
	microsoft.com	facebook.com	msn.com	wikipedia.org
	myspace.com	msn.com	baidu.com	twitter.com
	google.co.uk	hi5.com	qq.com	amazon.com
	aol.com	wikipedia.org	microsoft.com	qq.com
	go.com	orkut.com	sina.com.cn	linkedin.com

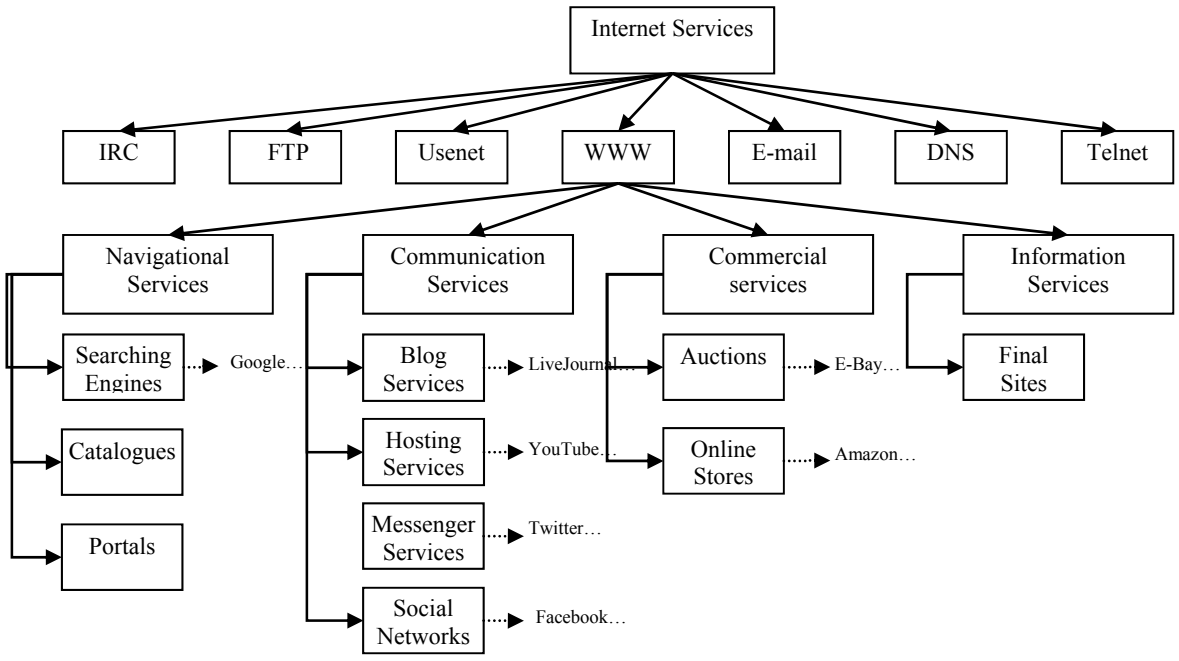


Figure 1: Block diagram of the Internet services

Table 3: Impact of exogenous factors on the success of a particular monetization model

Monetization model	Factors			Result
	The number of users	Readyness to pay	Trust	
Advertising	very strong	weak	weak	tail extension
Services	moderate	very strong	moderate	tail thickening
Transactions	strong	moderate	very strong	cut-off point shift

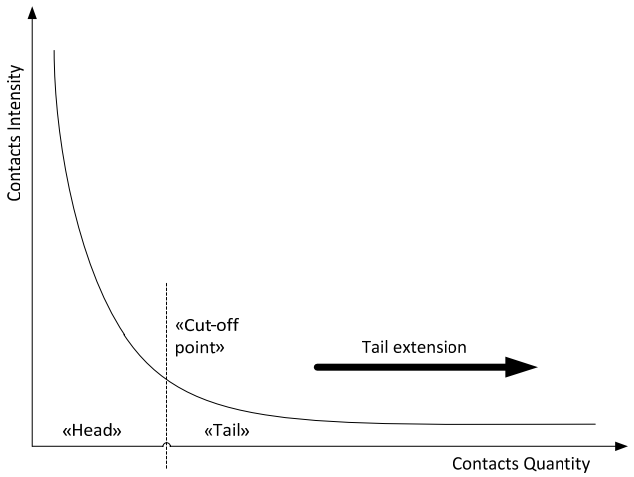


Figure 2: Tail extension of Anderson's curve

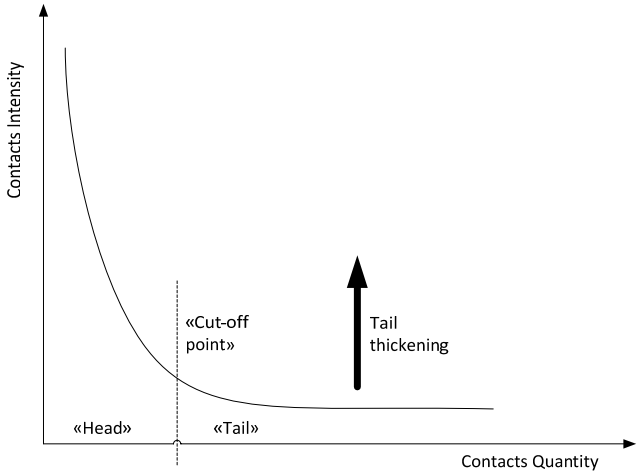


Figure 3: Tail thickening of Anderson's curve

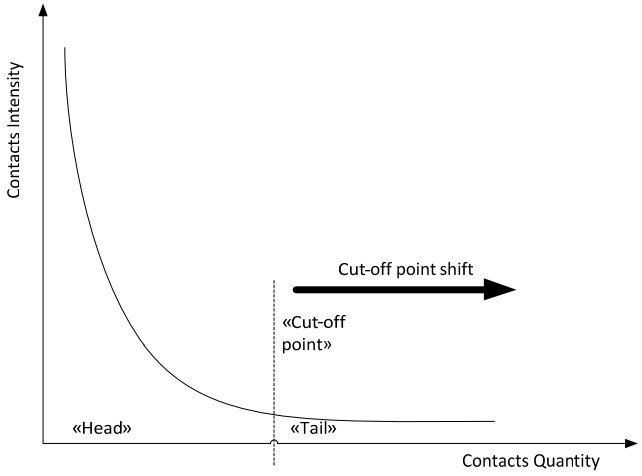


Figure 4: Cut-off point shift of Anderson's curve

social networks (eg. the Facebook), many Web 2.0 pro jects are still at a loss.

A. Enders [16], considering the basic social networks monetization models (revenue from advertising, paid services, transactions through the network), highlighted the main factors affecting the success of a particular model, and described their effects on the parameters of Anderson's curve (Table 3).

2.1. Advertising

Advertising is the most common social network monetization model. Since its success is most heavily influenced by the number of network users, the main efforts are aimed at:

1) optimization of recommendations system to the invitation the maximum number of users;

2) development of incentives system for new users;

3) hubs attracting [17].

These efforts lead to a tail extension of Anderson's curve by attracting new users (Fig. 2).

The success of the advertising as the monetization model of social networks is provided by access to two major data sources:

1) user's profile,

2) user's behavior.

Analysis of user's profiles and behavior allows to display likely to be of user's interest advertising, and provide effectively targeted by gender, age, income, occupation, etc. advertising.

2.2. Paid services

Paid services are sufficiently profitable way of social networks monetization. Most networks offer a variety of paid services — from low-cost ways of users' selection to help in achieving some purposes. The most important factor determining the readyness to pay for the service is an unique customer value that is provided by quality of a content. Users' access to the various expert groups leads to an increase of the contacts intensity and to a thickening of the "tail" of Anderson's curve (Fig. 3).

The main efforts are aimed at:

1) encouraging the creation of an unique content;

2) expansion of user accounts;

3) offering packages with different pricing schemes. [17]

2.3. Transactions

Transactions can be of two types: internal and external. When users buy goods or services using the network (such as virtual gifts on Facebook) it is internal transactions. External transactions take place if the owners sell the content created by social network users, or provide transactions opportunities between users.

The most important factor in this model is the high level of consumer trust — users must trust both the platform and the potential partners. As a result, encouraging users to interact and establish business relations, the intensity of contacts is increasing, and 'cut-off point' is shifted to the right (Fig. 4).

The shift in demand to the 'tail' can be achieved by:

1) increasing of consumers' trust to the platform, as well to other users,

2) improving the search engines in order to achieve compliance with demand and supply [17].

2.4. Sale of the network

As the social networks are costly venture project, the sale is the one of the most popular ways of their monetization. To do this, start-ups are created, accumulate the users and are sold to large companies that

have sufficient resources for the project development and promotion.

The most important pricing factor in all of these schemes is the total number of the SN participants.

3. Quantity estimation of social networks

One of the first who has proposed to evaluate value of social networks was D. Sarnoff. Sarnoff's Law says that network value grows in proportion to the participant's number *n*. R. Metcalfe (Metcalfe's Law) [6] has detailed this estimate and determined that the value of social networks grows asymptotically as n^2. D. Reed (Reed's Law) [7], assuming the correctness of the previous two laws, added components related to the users' group — 2^n-*n*-1. Dot-com massive destruction at the end of the 90s made scientists to estimate the SN value more carefully. Metcalfe's and Reed's laws were criticized [8] and there was offered to evaluate the network value as *nln(n)* (Zipf's Law). Despite the fact that today all these laws have been criticized, the relationship between the number of the SN users and its value is unquestionable; the estimating and forecast the SN users' number is still an urgent task.

3.1. Maurer and Huberman's Model

To estimate the number of the SN users we have used the tools of nonlinear dynamics; as the base of research Maurer and Huberman's Model [9] has been chosen. They proposed to measure the number of website users basing not only on website parameters, but with the influence of other websites, offering similar services (that is very important, taking into account the high competition among start-ups). The model is the following system of differential equations:

$$dx_i / dt = a_i x_i (b_i - x_i) - \sum_{j \neq i, j=1}^{n-1} c_{ij} x_i x_j \qquad (1)$$

where x_i — fraction of the *i*-website users' number ($i=1,n$), a_i ($a_i \geq 0$) — growth rate of *i*-website, b_i ($0 \leq b_i \leq 1$) — website capacity, c_{ji} ($c_{ij} \geq 0$) — level of competition between websites.

Analysis of the e-statistics, taken by L. Adamik and B. Huberman [10], has shown that small number of websites owned a disproportionate share of traffic and links. An analytical study of (1) for *n* sites has confirmed their results and showed that there is a strong competition market where the 'winner takes all'. A. Ogus [11] has conducted experiments with agent-oriented model of web-competition, he also has concluded that the network effects often lead to the market monopolization, but in the situation of strong competition among the market leaders, small projects, aimed at a specialized audience, are able to develop successfully.

3.2. Experiments with the Model

We have used model (1) to analyze the dynamics and characteristics of the SNs competition on the example of the two largest networks — facebook.com and myspace.com — Fig. 5.

Identification of unknown model parameters was being carried out according to the number of unique users since May 2007 to Jan. 2009. As a result, we have got the following system of equations:

$$\begin{cases} \text{myspace}: dx_1 / dt = -0.0002 x_1^2 + 0.0002 x_1 - 0.0223 x_1 x_2 \\ \text{facebook}: dx_2 / dt = -0.0466 x_2^2 + 0.0466 x_2 \end{cases} \qquad (2)$$

Analysis of the system (2) has showed that MySpace was characterized by a slight growth rate ($a_1 = 0.0002$) and it was heavily influenced by Facebook ($a_1 < c_{12}$), while the number of FaceBook users was growing with the rate $a_2 = 0.0466$. It leads to ousting of MySpace from the marketplace (Fig. 6).

Fig.6 shows that the system with constant coefficients has described the users' dynamics quite well in the short term, but the appearance of new services, changes in network strategy and its competitors significantly affect on the long-term dynamics. The longer modeling interval has significant differences in the actual and calculated data.

3.3. Modification of the base Model

Dynamical systems are characterized by the drift of the parameters with the lapse of time, leading not only to change the position of equilibrium, but the nature of sustainability. Therefore, based on the works of M. Eskobido and M. Gernandes [15], we have proposed to model the level of competition between the networks as a function of the market share as follows:

$$c_{ij} = \frac{k_1 x_j - k_2 x_j^2 + k_3}{1 + x_i x_j},$$

where k_1-k_3 — measured parameters.

After the parameterization the system has taken the following form:

$$\begin{cases} \text{facebook}: dx_1 / dt = -0.1752 x_1^2 + 0.1752 x_1 - \left(\frac{-15.4131 x_2 + 18.1424 x_2^2 + 3.3011}{1 + x_1 x_2}\right) x_1 x_2 \\ \text{myspace}: dx_2 / dt = -0.2773 x_2^2 + 0.2773 x_2 - \left(\frac{-15.1372 x_1 + 19.528 x_1^2 + 3.3145}{1 + x_1 x_2}\right) x_1 x_2 \end{cases} \qquad (3)$$

Figure 8 presents the actual and estimated data for the system with variable coefficients (3) (May 2007 — Dec. 2010).

Equilibrium points of system (3) are presented in Table 4.

Compared with the system (2) it should be noted the appearance of an equilibrium point, which describes the oscillatory dynamics. It corresponds to a situation of coexistence of the two networks — FaceBook and Myspace, which was not observed in a system with constant coefficients. Stable points have their own domain of attraction, and the system falls into one of them depending on initial conditions (Fig. 8).

The analysis of system (3) has showed that the introduction of variable competition coefficients allow to describe the dynamics of real data more qualitative:

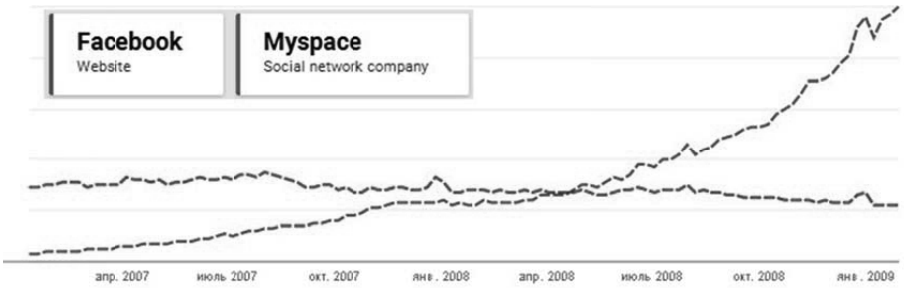


Figure 5: The dynamics of the SNs' users (Facebook, Myspace) [13]

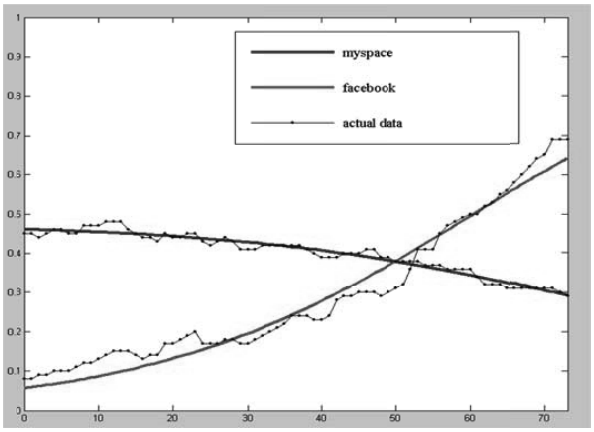


Figure 6: The actual and model data of the SNs' users (Facebook, Myspace)

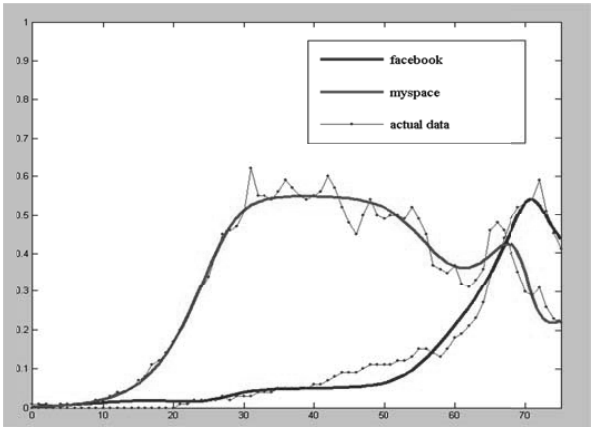
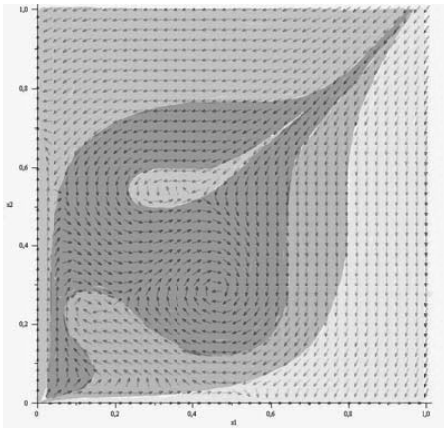
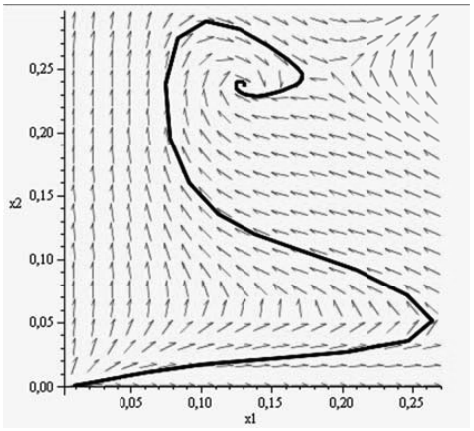


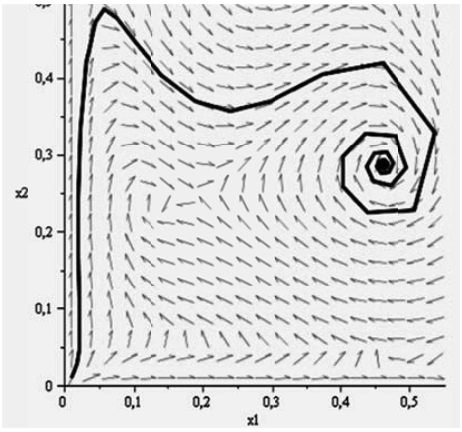
Figure 7: Actual and estimated data for the system with variable coefficients



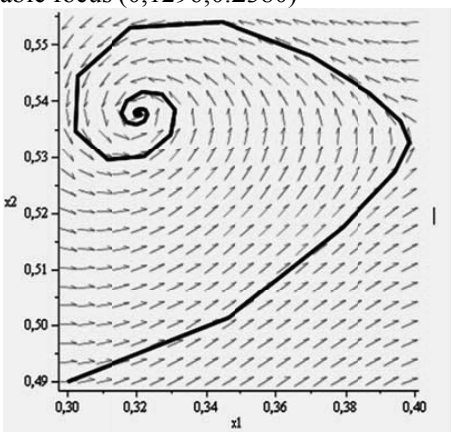
a)



b) x1(0)=0.009,x2(0)=0.001,t=0..200, Stable focus (0,1296;0.2380)



c) x1(0)=0.01, x2(0)=0.01,t=0..110, Stable focus (0.4608;0.2868)



d) x1(0)=0.3, x2(0)=0.49,t=0..100, Stable focus (0.3206;0.5379)

Figure 8: a) domain of attraction, b)-d) phase trends of the system (3) at various initial conditions

1) system has several stable states of equilibrium;

2) dynamics depends on the competitors' strategies;

3) final state of the system is sensitive to initial conditions.

Table 4: Equilibrium points of system (3)

Equilibrium points	Types
(0,0)	Unstable node
(0,1)	Stable node
(1,0)	Stable node
(0.4841,0.0326)	Saddle
(0.1296,0.2380)	Stable focus
(0.1856,0.2462)	Saddle
(0.4608,0.2868)	Stable focus
(0.4065,0.5324)	Saddle
(0.3206,0.5379)	Stable focus
(0.0489,0.5498)	Saddle

Conclusions

Internet is unique self-organizing system with complex forms of interaction between participants, which interests are served by diverse services. Some services are pushed to the background, some of them continue to develop rapidly, but the appearance of qualitatively new trends in World Wide Web started to be discussed when communication services have come to replace the information and trade services. Among the communication services the social networks are growing most rapidly, nowadays there are over thousands of the SNs in the Internet.

The most important pricing factor of social networks monetization is the total number of its participants. Despite the fact that a lot of relationships between the number of the SN users and its value have been proposed, the estimating and forecast the SN users' number is still an urgent task.

To estimate the number of the SN users we have used the tools of nonlinear dynamics; Maurer and Huberman's Model has been chosen as the base of research.

It was shown that the system with constant coefficients had described the users' dynamics quite well in the short term, but the appearance of new services, changes in network strategy and its competitors significantly affected on the long-term dynamics. So it has been proposed to introduce of variable coefficients of competition between the networks as a function of the market share as follows.

The results have shown that the introduction of variable coefficients allows describing the dynamics of real data more qualitative — the system can have several stable states of equilibrium; dynamics depends on the competitors' strategies; the final state of the system is sensitive to initial conditions.

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ЕВОЛЮЦІЙНА WEB-ДИНАМІКА

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Для оцінки і прогнозування числа користувачів соціальних мереж запропонована нелінійна динамічна модель. Було показано, що модель Маурера і Губермана досить добре описує динаміку користувачів в короткостроковій перспективі. Однак поява нових послуг і зміна стратегії мережі призводить до дрейфу параметрів системи, що істотно впливає на динаміку користувачів в довгостроковій перспективі. Завдання дослідження – модифікація моделі Маурера і Губермана з метою моделювання числа користувачів соціальних мереж у довгостроковій перспективі. Результати показали, що введення змінних коефіцієнтів дозволяє описати динаміку реальних даних більш якісно – система може мати кілька стійких станів рівноваги; динаміка залежить від стратегій конкурентів; кінцевий стан системи чутливий до початкових умов.

Ключові слова: цінність соціальної мережі, оцінка числа користувачів, нелінійна динамічна модель, змінні коефіцієнти конкуренції.

ЭВОЛЮЦИОННАЯ WEB-ДИНАМИКА

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Для оценки и прогнозирования числа пользователей социальных сетей предложена нелинейная динамическая модель. Было показано, что модель Маурера и Губермана достаточно хорошо описывает динамику пользователей в краткосрочной перспективе. Однако появление новых услуг и изменение стратегии сети приводит к дрейфу параметров системы, что существенно влияет на динамику пользователей в долгосрочной перспективе. Задача исследования – модификация модели Маурера и Губермана с целью моделирование числа пользователей социальных сетей в долгосрочной перспективе. Результаты показали, что введение переменных коэффициентов позволяет описать динамику реальных данных более качественно – система может иметь несколько устойчивых состояний равновесия; динамика зависит стратегий конкурентов; конечное состояние системы чувствительно к начальным условиям.

Ключевые слова: ценность социальной сети, оценка числа пользователей, нелинейная динамическая модель, переменные коэффициенты конкуренции.

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