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Improvement of a telecommunications company tariff policy taking into account subscribers' preferences

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Abstract

According to most analysts, the era of extensive growth in the telecommunications market has almost finished. The ongoing competition between leading telecommunications companies is bringing the problem of developing a rational telecommunications policy to the forefront.

The ever-changing telecommunications market, subscribers' preferences, the expanding variety of services, the need for updating user data, the inadequate efficiency of the existing systems to form exact subscriber definitions demonstrate the need for more flexible tariff methods and policy. In spite of Russian and foreign scientists taking into consideration the pricing problems in forming tariff plans, the main accent is placed on price formation according to the profits either of the whole telecommunications field or company expenses in most attempts. The problem of differentiation of tariff plan characteristics with the purpose of subscribers' preference calculations has not been sufficiently explored. Moreover, the structural problems of tariff plans, where phone subscribers' preferences should be taken into consideration, and the whole tariff policy, in which formation of the entire complex of existent and prospective tariff plans should be taken into consideration, have not been properly researched. For solving these problems, we have offered a model of forming telecommunications company tariff policy using methods of intellectual data analysis and taking into consideration discovered preferences of subscribers and investors.

Introduction

Until now the telecommunications services market has been growing rapidly both around the world and in Russia. The first commercial mobile communications appeared in Russia only in 1991 (NMT 450 and GSM standards) [1], however in 2007 3G, and in 2012 4G technologies were introduced. The history of mobile communications development before 2007 is associated primarily with voice communication. However, active development of the data transmission

market with Internet access started with 3G technology and mobile phones. The main limits on development of the mobile communications market are technical and the high prices for network development of data transmission.

However, these days the level of mobile communications development in Russia has reached the technical level of development of the advanced countries, and this has happened in a shorter period of time than in other countries around the world. The number of subscribers using mobile communications in Russia has grown 80 times over 11 years, from 2000 till 2011 [2] (*Figure 1*).
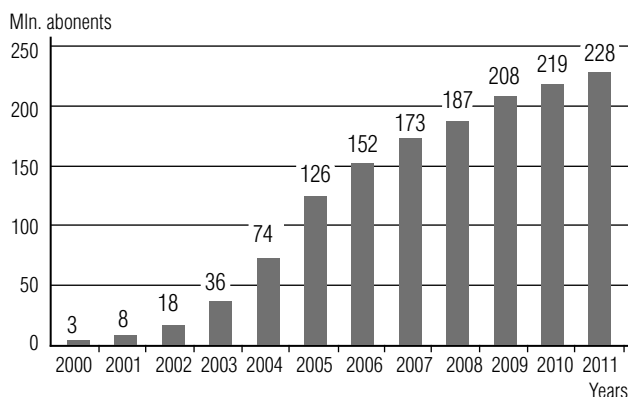
Fig. 1. Dynamics of growth
in Russia's mobile communications subscriber base
Source: Analytical reviews of AC&M Consulting, 2004 – 2012

Nowadays the telecommunications services market is one of the main sectors critically important for many fields of the Russian economy and the functioning of the State. According to J'son & Partners Consulting, the total value of the Russian telecommunications field was 1.28 trillion rubles in 2014 [3]. According to preliminary results of growth in this field in 2015 presented by TMT Consulting in a report entitled "Russian telecommunica-

tion market in 2015–2020", the value of the telecommunications market is going to reach 1.67 trillion rubles [4].

The rate of profit growth was 2.1% in 2015, which is a bit higher than the rate in 2014 (1.7%) (*Figure 2*). The reasons for minimal growth of the market rate was the substantial profit increase from TV paid services: 21.3% in 2015 in comparison with 6.9% in 2014. Taking into consideration that the penetration of pay TV was 71% at the end of 2015 and the growth of user numbers was also small, less than 4%, at the same time that it had been 9% in 2014, the high profit growth may be explained only by the increase of tariffs. As a result, the average invoice for one subscriber has increased 14% to 151 rubles over a year.

The rate of exchange growth in payments for some inter-operational services has had a positive effect: 4% growth. At the same time, the rate of mobile communications growth decreased by 0.7% in 2015, internet access by 0.9%. All of that happened when mobile communications was 58% in the telecommunications field in 2014, meaning more than half of the profits of the field. Internet access was 11%, paid TV and interoperational services – only 4% each.

At the same time, statistics claim that 1.8 million subscribers have reduced phone services in 2015. Although new services came in the place of the traditional telephone and in future, it is going to be demanded, however, according TMT Consulting prognosis, its volume falls from 45% in 2015 to 34% in 2020. In the next 5 years, TMT Consulting predicts a decrease in the rate of growth of the Russian telecommunications market. The average growth will be 1.3% in 2015–2020 (CAGR). Profit growth from Internet access and other services is going to be offset by the reduction of voice communication profits in fixed as well as in mobile communications [4].
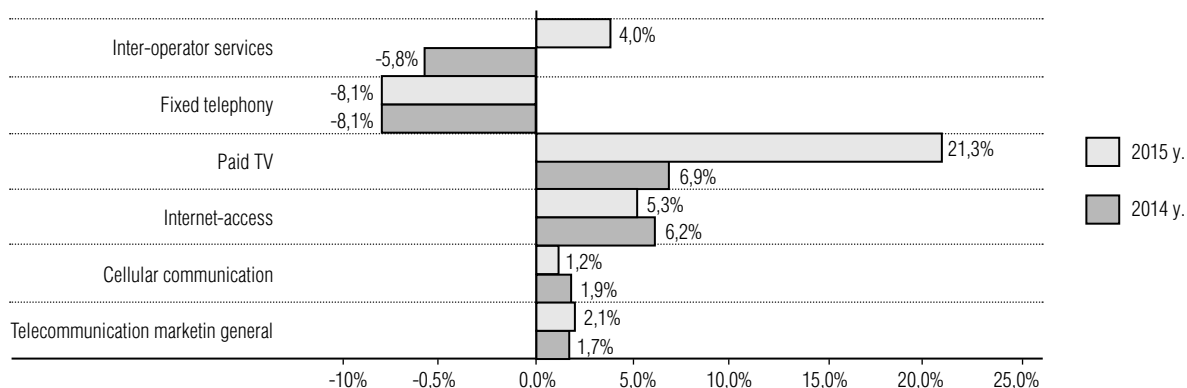
Fig. 2. The structure of the telecoms market

The expenses for equipment and software are the most important budgetary items in the whole structure of expenses in the telecommunications field. The part of decisions built on the basis of imported equipment and software constitutes more than 80% of total volume of consumption. Due to ruble devaluation, ruble cost of main expenses is increasing, which is very negative for the financial stability of telecommunications services market players. Undoubtedly, in this situation companies that can afford not to make considerable short-term investments will have profited.

Although the analysts of J'son Partners Conculting [3] give a "stable" prognosis for the telecommunications field, they stress that in the near future we should expect a decline in profits from voice services, an increase of expenses for currency debt payment and potential problems connected with the holding of the same level of main expenses. An uneasy situation is getting worse because the era of extensive growth of telecommunications services is almost over and the competition between the main market players is getting stronger. It is especially caused by the appearance of new players (like Tele2) implementing a very aggressive marketing policy on the telecommunications market in Moscow and its region.

1. Tariff policy as part of a telecommunications company's marketing policy

The main elements of the mobile communications market are the subscriber, the mobile operator, tariff plan and mobile communications network. The subscriber is actually a SIM-card (Subscriber Identification Module), which doesn't belong completely to a mobile communication device and in fact can be used by one person or a group of people it although it is registered to private individuals and corporate entities. The mobile operator is a company, which offers mobile communications services for both private and corporate clients with a contract (tariff plan). It extends the area of mobile communications coverage and improves its functioning. The mobile communications network is a set of stations, which forms a coverage zone. Any subscriber has an opportunity to be registered in a mobile communications network of any operator [5].

The tariff plan is a form of a commercial offer for mobile communications services from the company of the operator to the subscriber. It contains not only prices but also the structure of possible traffic usage and various juridical information regulating the relationship between the operator and the subscriber. Without doubt, price is

the main part in the agreement. The tariff is the price, which the client pays for an item, for all service fields.

The important metric characterizing commercial efficiency of a telecommunications company is ARPU (Average Revenue Per User) [6]. This metric allows us to understand how much money on average a subscriber spends during the service period. This index can be calculated if the whole profit is divided by the number of active subscribers. According to TMT Consulting [4], an increase of the subscriber base size by 10 million is predicted in 2015, however, a decrease has been determined for all mobile communications major operators in 2015 (Q3) in comparison with the Q3 2014 ARPU (*Figure 3*).
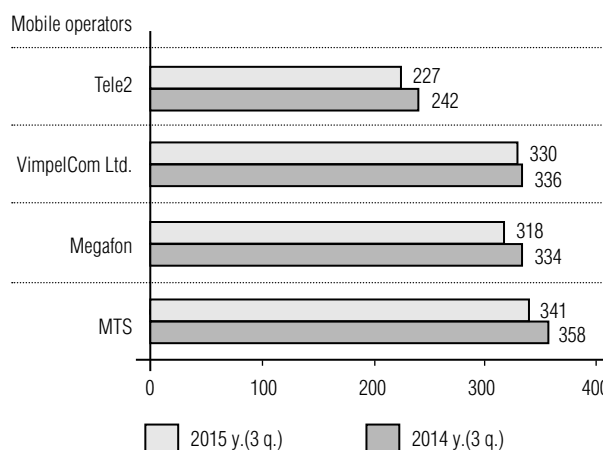
Fig. 3. ARPU of federal Russian mobile operators (rubles)

The decrease in growth is continuing also in wideband access to the Internet. The illustration that the market is fully served not only in cities but also in towns is the growth of 3% in private user numbers — almost the same increase has been seen in the profits of the companies. ARPU growth is difficult in highly competitive conditions and also because of the tendency to package services (Internet + Internet TV + TV + phone). The result of increased profit and loyalty from a subscriber is a fact that the subscriber pays less for each part of the package than when he or she got it one by one.

The analysts of all telecommunications companies stress that for the last several years there has been significant decrease in consumer loyalty as seen in the outflow of subscribers. In this situation, company managements came to the conclusion that to be competitive when forming the tariff policy they need to take into consideration subscriber prefers instead of forcing them to get new tariff plans which are more interesting for companies by any means. In this situation, we can also talk about the increase of tariffs.

When forming tariff policy at telecommunications companies, one of the main conditions is the firm strategy. Among the main strategies of the service field are keeping stability on the market, enlarging the market, maximizing profits and forming the image of an elite service provider. For a major telecommunications company in a condition of oligopoly rivalry when extensive growth is almost over, the most preferred strategy is profit maximization. Within the context of strategy implementation, the most difficult parts are correct calculation of the demand for a company service, expense appraisal of the telecommunication service, segmentation of the target audience and customer preferences.

An important part of marketing policy in a telecommunications company, which is developing its strategy of prices [7], is the tariff and price policy. We can point out several ways of price formation strategy: premium and defense price strategy, depletion and penetration strategy, price differentiation and balancing strategy. Thus, in 2007 MegaFon applied a price break strategy. Dumping of market prices increased their subscriber base and expanded the market but as a result, competition became more acute between the telecommunications companies. At present, using the urgent repayment strategy, Tele2 is rapidly increasing its share of the market, first in the regions, and since 2015 in Moscow and the Moscow region. This strategy has been continually used by Tele2 for entering the telecommunications market.

The strategy of forming different prices for the same product for different groups of customers or horizontal price differentiation is fairly widespread in the telecommunications field. This method of differentiation supposes the discovery of customer specialties and taking them into consideration when forming price policy.

The methods of intellectual data analysis by which you can find out latent patterns in subscriber activity by monitoring personal and consumer characteristics of subscribers are used in practice to understand customer preferences. The methods of intellectual data analysis are used during analysis of the consumer communications service market but their use is fragmentary and has an unsystematic character. During consumer cluster analysis for discovering a group of customers who have the same consumer characteristics, as a rule, the quantity of clusters comes from expert thoughts and tasks [8]. The sets of researching consumer and personal characteristics are often created intuitively based on common sense. In a situation of crisis, with ruble devaluation, difficult access to foreign capital and the fall of purchasing power, it is very important for telecommunications companies to find potential points of growth and to optimize their business.

2. Moscow telecommunications services market

Changes in the Moscow telecommunications services market are characterized by the same process as the whole telecommunications field. The worldwide trend of falling consumption of voice communications and SMS influenced very visibly changing profit volume earned in this field in 2014. According to J'son & Partners Consulting [3], beginning in Q2 2014 a decrease of profit volume was ascertained in the Moscow telecommunications services market compared with the same periods in 2013. The trend remained consistent for the first quarter of 2015 (*Figure 4*).

This is the result of the saturation of the Moscow telecommunications market, i.e. all possible clients have gained access to mobile service. But as shown in *Figure 5*, the consumer base is growing. This can be explained by each individual getting a greater number of SIM-cards.
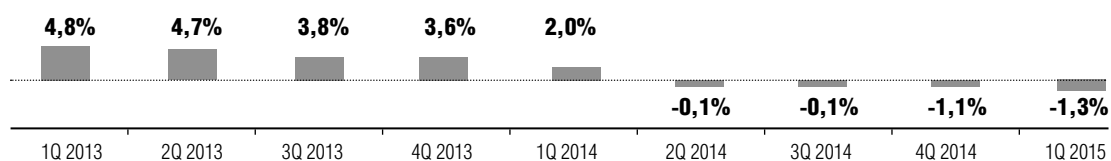
Fig. 4. Profit volume of Moscow telecommunications services in comparison with the previous year
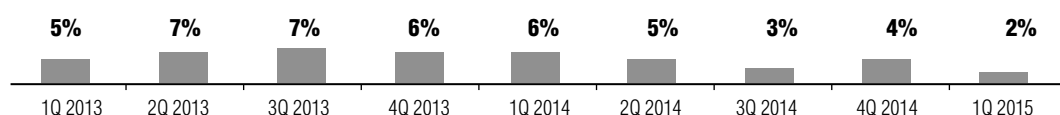
Fig. 5. Moscow telecommunications market volume in comparison with the previous year

It is believed that the number of consumers is continually growing and when the 5G network is introduced to the market the number of consumers can rapidly increase. The main reason is a special technical development. Previously one customer used one SIM-card and that was enough. These days the quantity of actively used devices per person is increasing. The arrival on the telecommunications market of the fifth generation network and development of the field with M2M (Machine to machine) and IoT (Internet of things), characterized by smart electronic equipment interconnected with the Internet – can practically move situation to rapid growth in consumer numbers [9]. At the same time, consumer growth is not going to influence the growth of profit volume. New equipment, especially from the IoT field, is characterized by extremely low traffic consumption, and M2M devices can be used without any telecommunications operator. This allows us to reach a conclusion about important rapid change of the whole telecommunications services market and its function. From this standpoint, the most competitive players of the market will be companies that not only have new technologies, but also develop a tariff policy based on consumer preferences. All of this makes it necessary to use a combined approach to improving the existing mechanisms of forming a rational tariff policy in telecommunications companies and developing informational and logical shaping of the tariff policy model on the basis of intellectual analysis and mathematical modeling.

3. A model for forming the tariff policy of telecommunications companies

As a rule, company managers of the "big three" (Beeline, MegaFon, MTS) are guided by similar things when forming new tariff plans: their own active tariff plan, the tariff plans of competitors, their relationship with business partners, by strategic purposes of the company and investors' preferences, by consumer preferences and the actions of the State regulating this field. Less importance is assigned to consumer preferences. At this moment, there is no strictly objective methodology for forming the whole policy and new tariff plans in Russian telecommunications companies. This situation is the result of the manifold nature and complexity of the given task [10].

The consumer telecommunications base accounts for more than dozens of millions of customers. It can be extended without attracting new individuals but increasing the quantity of electronic devices, which are the channels of consumption served by a mobile operator. In this situation, the use of methods pointing to work with one customer is irrational because the creation of each consumer operated model is going to be more expensive eventually than its use. Thus, it is more effective to create models, which take into consideration the preferences not only of one group of consumers, but also of those who have the same characteristics and consumer profiles. In addition, when creating new tariff plans, it is important to take into consideration consumer preferences, which have similar consumer profiles and the demands formulated by investors in relation to the time intervals at which profit should be maximized [11].

In order to form a consumer profile, it is necessary to create a set of indicators, which together allow you to identify consumer preferences. This set consists of:

✦ the different traffic types by consumption volume: voice communications, text messaging, Internet access, additional services;

✦ call direction: incoming and outgoing connections;

✦ the operator of the called consumer: inside the network, competing mobile operator, municipal phone number;

✦ called consumers' geography: home network, long-distance call, international call;

✦ calling consumers' geography: home region, roaming in Russia and abroad.

As has been shown in the set above, only indicators calculated in natural units (minutes, megabytes, goods) are used for forming consumer profiles, and in the same way, no social and demographic characteristics are taken into consideration because as the consumer isn't seen as an individual but as a SIM-card. It is very useful to apply a cluster algorithm, for example, the method of self-organized cards by Kohonen [12].

The price characteristics of tariff plans are used for forming groups of tariff plans. Using the total charge for every consumer and total traffic, it is possible to get the real cost for each consumer product of all customers for every tariff plan. Offering a method for forming tariff plan cost characteristics is the main difference of this research compared to other works where the nominal declared traffic cost of each consumer is used. Because there is a possibility of multicollinearity of the initial price indexes (rubles per minute, per megabyte, per unit) when characterizing each tariff plan one should use stable, latent factors obtained, for example, with the main component method for emerging tariff plan groups on the basis of these price characteristics. Moreover, on the basis of these independent factors using the cluster analysis method it is possible to identify tariff plan

groups which have similar characteristics and those mainly different between them.

The present paper analyzes the influence of the company tariff policy on the profit from its business. For estimating the company profit, we propose to use client life-time value (*CLV*), which shows the discounting profit from the customer for all the time used for consuming the company service [13]. *CLV* indicators also describe the satisfaction of the customer with the company and allow one to take into consideration the part of consumer flow-out during the analyzed period [14].

The results of customer cluster and tariff plans can be tabled which is matrix where on the lines there are consumer clusters, characterizing consumer profiles, on the columns there are groups of tariff plans. There are *CLV* indexes of consumer cluster for each group of tariff plan (*Table 1*) in the cells on the lines and column crossing, where:

$k_i \in K$, $i = 1, ..., I$ — consuming profiles of mobile company's subscriber clusters;

K — set of the all subscriber profiles;

$p_j \in P$, $j = 1, ..., J$ — clusters of the tariffs having similar price characteristics;

CLV_{ij} — client life-time value, $i = 1, ..., I$; $j = 1, ..., J$.

Table 1.

**CVL cluster subscriber
for each group of tariff plans**

Subscriber clusters	Group of tariff plans			
	p_1	p_2	...	p_j
k_1	CLV_{11}	CLV_{12}	...	CLV_{1j}
k_2	CLV_{21}	CLV_{22}	...	CLV_{2j}
...	...	...	...	...
k_i	CLV_{i1}	CLV_{i2}	...	CLV_{ij}

The client life-time value can be calculated according to the formula:

$$CLV(t_s) = GC(t_s) \cdot \sum_{m=1}^{t_s} \frac{r^m}{(1+d)^m} - M(t_s) \cdot \sum_{m=1}^{t_s} \frac{r^{m-1}}{(1+d)^{m-0,5}}, \quad (1)$$

where $t_s \in T$, $s = 1, ..., S$ — sub-periods defined by investors;

T — maximal planning period;

$CLV(t_s)$ — client life-time value till the moment t_s;

d — discount rate;

$GC(t_s)$ — revenue from subscribers till the moment t_s;

$M(t_s)$ — expenses on a subscriber till the moment t_s;

r — part of the subscribers outflow on period from t_0 to t_s;

t_0 — the beginning of the planning moment.

Hypothesis. It is possible to suppose that in spite of the same consumer profile subscribers who have chosen different tariffs and have different payment plans will bring different long-term profit to the company. This directly affects the summary period of consuming company services by subscribers, i.e. this affects subscriber outflow. By analyzing this matrix, it is possible to estimate which groups of tariffs are most preferable for each subscriber consuming profile, i.e. which tariffs group will have maximal *CLV* value till the moment t_s with a given consuming profile. This will make it possible to make conclusions about the expedience of transferring subscribers who have a given consuming profile to tariffs for other groups.

Statement 1. Subscribers from the same cluster have the same consumption behavior. It is supposed that when subscribers who belong the same cluster are changed from one tariff group to another then characteristics of subscriber consumption are kept the same but income and subscriber outflows are changed according to the subscribers' chosen tariff group characteristics. Possible changes could only stimulate traffic consumption, because the tariff should match the subscriber's consumption profile. Therefore, by defining for each subscriber consumption profile those groups of tariffs, which bring the biggest profit it is possible to stimulate subscribers to choose corresponding tariffs groups.

It is possible to reveal investors' preferences based on one of the decision making support methods of usage results They are characterized by part of voting shares v_b, which provides maximal profit in each planning period a_s. Partial preferences are calculated the following way:

$$\sum_{s=1}^{S} a_s = 1, \quad a_s \geq 0, \quad (2)$$

where a_s, $s = 1, ..., S$ — part of voting shares which provides maximal profit for the planning period;

S — number of planning periods.

The criteria are: lobar rating of preferences of each investor by different period of profit maximization, also — the rate of risk for the given period in three categories (low, middle, high risks). Preferences discovery by profit maximization periods including risks allows us to consider interests of the investors more objectively.

For each investor, it is necessary to distribute his preferences on each period S. with assessment by two criteria: f_p — lobar preference of profit maximisation for the period s and f_r — rate of the risk. Let Z_p — set of values or gradation of criteria f_p, Z_r — set of values or gradation of criteria f_r. In this research, it is admitted that the importance of criteria is distributed over the whole scale

of measures evenly. The total number of investors is B, $b = 1, ..., B$. The type of criteria "folding" function is defined as multiplicative, because this type of connection is obvious for the value of risk and profit for the period:

$$F(f|w,s,b) = f_{p,s,b}^{w_p} \cdot f_{r,s,b}^{w_r}, \qquad (3)$$

where w_p and w_r are coefficients of importance of the corresponding criteria ($w_p + w_r = 1$), with normalization for each investor

$$\sum_{s=1}^{S} f_{p,s}^{w_p} \cdot f_{r,s}^{w_r} = 1.$$

Ratios w_p and w_r are defined by the fraction of voting shares of investors.

The general type of calculation a_s is described by the following formula:

$$a_s = \sum_{b=1}^{B} (v_b \cdot f_{p,s,b}^{w_p} \cdot f_{r,s,b}^{w_r} / \sum_{s=1}^{S} (f_{p,s,b}^{w_p} \cdot f_{r,s,b}^{w_r})). \qquad (4)$$

To calculate CLV with consideration of the "planning horizon" (period of time which characterizes preferences of investors), it is necessary to split all planning periods into sub- periods. Then for each sub-period and subscriber consumption profile, you need to define the optimal group of tariffs according to the formula:

$$CLV_{ijs} = GC(t_s) \cdot \sum_{m=1}^{t_s} \frac{r^m}{(1+d)^m} - M(t_s) \cdot \sum_{m=1}^{t_s} \frac{r^{m-1}}{(1+d)^{m-0.5}}, \qquad (5)$$

where K − set of subscriber clusters consisting of I clusters, $k_i \in K$, $i = 1, ..., I$ − subscriber consumption profiles of the telecommunications company;

P − set of clusters of tariffs, consisting of J clusters;

$p_j \in P$, $j = 1, ..., J$ − price characteristics of persistent groups of tariffs;

T − maximal planning period of the tariff policy, consisting of S sub-periods of different length;

$t_s \in T$, $s = 1, ..., S$ − sub-periods which are the defined time period to calculate profit of the company (the value of t_s is defined by investors);

$CLV_{i,j,s}$, $i = 1, ..., I$; $j = 1, ..., J$; $s = 1, ..., S$ − client life-time value;

d − discount rate. In this article it is supposed that the discount rate is the same for each month of planning. Possible differences in the discount rate are not considered in this paper;

GC − revenue from subscribers;

M − costs of subscriber;

r − volume of outflow of subscribers.

For each subscriber consumption profile in a given planning period there is a defined tariff group, which is maximizing CLV according to the formula:

$$p_{is}^* = p_j \, (\max_{1 \le j \le J} CLV(t_s|k_i, P)), \qquad (6)$$

where $p_j \in P$, $j = 1, ..., J$ − tariff groups having similar price characteristics;

$p_{i,s}^* \in P$ − is a group of tariffs, which has maximal CLV for subscriber cluster i at the period s;

$k_i \in K$, $i = 1, ..., I$ − subscriber clusters which have consumption profiles of the mobile company;

K − set of all subscriber profiles;

$t_s \in T$, $s = 1, ..., S$ − planning periods;

T − the whole planning period;

$$\max_{1 \le j \le J} CLV(t_s|k_i, P) -$$

maximal client life-time value cluster k_i at the period t_s from the whole set of tariffs groups P.

Statement 2. It is considered that company is able to stimulate subscribers to choose the tariff, which is the best in terms of all his preferences based on real consumption profile analysis. The influence of the marketing policy of the company and the effectiveness of marketing actions is not taken into consideration in this work.

Statement 3. Costs of stimulating the subscriber to move to a different tariff in this research is not taken into consideration because the influence of marketing actions also is not taken into consideration.

The calculation of the planning profit of the telecommunications company on the whole planning period T is defined by the formula:

$$P_r(T) = \sum_{s=1}^{S} \sum_{i=1}^{I} a_s \times Abon(k_i) \cdot CLV(T \mid k_i, max P_{i,s}), \qquad (7)$$

where $P_r(T)$ − the profit of the mobile company on the whole planning period T;

$Abon(k_i)$ − number of subscribers of k_i subscriber consumption cluster.

The profit of a telecommunications company on any sub-period of planning can be calculated in the same way.

Conclusion

Analysis of telecommunications services conditions has shown that the market is in the state of completing extensive growth. The existing methods of telecommunications company policy need improving. We offer a way to make a model for forming the telecommunications company tariff policy, taking into consideration subscribers' and investors' preferences and giving a chance to rationalize tariff policy formation. ∎

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Совершенствование тарифной политики телекоммуникационной компании с учетом предпочтений абонентов

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Аннотация

По мнению подавляющего числа аналитиков, эра экстенсивного роста рынка телекоммуникационных услуг практически закончилась, а постоянно усиливающаяся конкуренция среди ведущих телекоммуникационных компаний выдвигает на первый план проблемы формирования рациональной телекоммуникационной политики. Постоянная изменчивость рынка телекоммуникационных услуг, как и предпочтений абонентов, расширение многообразия предоставляемых сервисов, необходимость обновления данных пользователей, недостаточная эффективность существующих систем выявления и формирования рациональных предпочтений абонентов вызывают необходимость достаточно точного определения абонентских

предпочтений, а также разработки более гибких методов и моделей формирования тарифной политики телекоммуникационной компании.

Несмотря на то, что проблемы ценообразования при формировании тарифных планов затрагиваются как отечественными, так и зарубежными учеными, основной акцент в большинстве исследований делается на формировании цены с точки зрения доходности либо всей телекоммуникационной отрасли, либо издержек компании. В то же время проблема дифференциации ценовых характеристик тарифных планов, отражающая абонентские предпочтения как российскими, так и зарубежными авторами, исследована недостаточно глубоко. Кроме того, остаются не затронутыми проблемы тарифной политики в целом, при формировании которой должен учитываться весь комплекс существующих и перспективных тарифных планов и предпочтения потребителей. Для решения сформулированных проблем предложен подход и разработана модель формирования тарифной политики телекоммуникационной компании с применением методов интеллектуального анализа данных, учитывающая выявленные предпочтения абонентов и инвесторов.

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Definition of the concepts of conventional and non-conventional projects

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Abstract

The term "non-conventional" project or "project with non-conventional cash flows" was introduced into economic literature after the internal rate of return (IRR) was shown to have multiple values or not exist at all in some projects. A project is considered to be conventional if it has only one change in the cash flow sign, no matter whether minus to plus or vice versa. A conventional project has a unique IRR. However, not all projects with a multiple sign change in cash flow are non-conventional, i.e. have problems with IRR determination. To ascertain the project type, the generally accepted approach recommends investigating monotony of the net present value (NPV) depending on the discount rate in order to find out how many IRRs the project has. On the other hand, neither the monotony of the NPV function nor a unique IRR guarantee that the project is conventional. The IRR is known to be a rate of return for a conventional investment project rather than a non-conventional project. Moreover, it was shown that the rate of return of a non-conventional project cannot be determined within the framework of the NPV method, and therefore the concept of profitability cannot be formulated. The recently proposed generalized net present value (GNPV) method allows us to determine the rate of return of a non-conventional project.

This paper presents a method to determine the rate of return for an investment project of any type and proves that in the case of a conventional project the rate of return is the IRR, while in the case of a non-conventional project it is the generalized internal rate of return (GIRR). The necessary and sufficient conditions of conventional and non-conventional projects have been formulated.

Introduction

The term "non-conventional" / "non-normal" project or "project with non-conventional cash flows" was introduced in economic literature after it had been discovered that the internal rate of return (*IRR*) could not be used to assess project effectiveness (i.e. the *IRR* is not the rate of return of a project in the classic sense). A project is considered to be conventional if its cash flows have only one change in sign, no matter whether minus to plus or plus to minus [1, 2]. According to this definition, all projects with cash flows having multiple changes in sign are automatically referred to as non-conventional projects. However, this cannot be justified from the methodological point of view: multiple changes in sign are a property (necessary condition) of non-conventional projects, but not a definition (attribute) allowing us to clearly differentiate between

conventional and non-conventional projects. In order to determine the project type, the generally accepted approach recommends considering the property of the function $NPV(r)$: its monotony and existence of a multiple-valued IRR or absence of an IRR. However, neither monotony of the function $NPV(r)$ nor the unique real-valued IRR is an attribute of a conventional project. This proposition is refuted by Gronchi [3] when describing a project with the following cash flows: $(-100, 270, -270, 170)$. This project has a monotonically decreasing function $NPV(r)$, a unique real value $IRR = 70\%$, but is not a conventional project[1].

A sufficient condition is considered to be an attribute in logic and mathematics. Among the researchers who formulated a sufficient condition of a conventional project are de Faro & Soares [4], Soper [5], Gronchi [3], Cannaday et al. [6], Bussey & Eschenbach [7], Teichroew et al. [8], Bernhard [9], Hajdasinski [10], Hazen [11], Beaves [12], Lohmann [13], Kulakov & Kulakova [14]. The majority of economists consider the same sign of the present (or future) value of a project at the rate equal to the IRR to be a sufficient condition of a conventional project [9–13]. Some economists believe that the project type depends on the discount rate. For example, Teichroew et al. [8] and Hazen [11] determine project region changes of the discount rate for a non-simple project, where the projects are termed as a pure investment, mixed and pure financial regions. At the same time, Magni supposes that by choosing a discount rate in each period at discretion one can convert a conventional project into a non-conventional one [15]. In our opinion, this proposition is erroneous: the project type should not depend on the discount rate. Besides, the existence of different versions is based on the fact that there is no mathematical definition of conventional and non-conventional projects. To-date no criterion or necessary and sufficient condition identifying a project type has been formulated. This paper offers a solution to the problem in question.

It has long been recognized that non-conventional projects have problems with determination of the IRR as the rate of return of a project. However, it is the imperfections of the NPV method that lie at the root of the problems with the IRR [14, 16]. The rate of return of a non-conventional project cannot be determined within the framework of the NPV method. Generalization of the NPV to the $GNPV$ by using different rates when at-tracting and reinvesting funds instead of a single rate allows us to resolve the problems with the NPV wrongly attributed to the IRR. In the next section, we formulate the mathematical formulae determining the rate of return for any project type, both conventional and non-conventional, and we prove that in the case of a conventional project the rate of return is the IRR, and in the case of a non-conventional project it is the $GIRR$ [17]. After that, we define and formulate the necessary and sufficient condition for conventional and non-conventional projects. In the fifth section, we present examples of two types of projects with comments followed by conclusions.

1. Determination of the rate of return of an investment project

Since the IRR is the rate of return of a conventional project, it is necessary to start with the definition of the rate of return of an investment project. Bierman and Smidt have suggested the following definition: "The internal rate of return of a conventional investment represents the highest rate of interest an investor could afford to pay on debt without losing money if all funds to finance the investment were borrowed and the loan (principal and accrued interest) was repaid by application of the cash proceeds from the investment as they were earned" [18]. Based on this definition, the interest rate on a loan can be determined as follows: "The loan interest rate (rate of cost) represents the minimum rate of return of an external project in which the borrowed funds can be invested to generate sufficient income to repay the loan with the accrued interest".

In order to avoid excessive repetitions, we will consider only investment projects. First, let us take a simple project consisting of only two cash flows: negative CF_0 and positive CF_1. As the initial cash flow is negative ($CF_0 < 0$), additional capital has to be raised to finance the project. Suppose a loan $S_0 = -CF_0$ with an interest rate r per period is granted. After a period, the loan with the accrued interest will be equal to $S_1 = S_0(1+r)$. The rate r^* at which the total amount of debt will be equal to the income CF_1 is the rate of return of the investment project $S_1(r^*) = CF_1$, the rate r^* being the highest interest rate an investor can afford without a loss. We next prove the proposition.

Proof: The function $S_1(r)$ monotonically increases as the discount rate increases because

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[1] The cash flow considered by Gronchi is a special case project: $-A, A(2+r), -A(2+r), A(1+r)$, where A is the initial investment, and $r = IRR$. This project is non-conventional, because the present values changes sign: $PV_3 = A(1+r) > 0, PV_2 = -A(2+r) + A = = -A(1+r) < 0, PV_1 = A(2+r) - A = A(1+r) > 0, PV_0 = -A + A = 0.$

$$\frac{dS_1}{dr} = S_0 = -CF_0 > 0.$$

Indeed, for $\delta > 0$ and $r = r^* + \delta$ we have: $S_1(r) - CF_1 = = S_0(1+r) - CF_1 = S_0(1+r^*) + S_0\delta - CF_1 = S_0\delta > 0$. QED. The debt will not be repaid.

Now let us consider an investment project containing more than two cash flows. Let CF_i be the project's cash flows in period i, where $i = 0, 1, ... , N$. Suppose that the flows are formed at the beginning of every period. If the project balance is negative in some period, a loan will be borrowed to finance the project, and the resulting debt (loan with accrued interest) is repaid at the beginning of the next period. Payments on the current debt are made from cash inflow or a new loan covering the previous debt and outflow of this period. Thus, the debt balance S_i in period i is determined as follows:

$$S_0 = -CF_0, S_{i+1} = \begin{cases} -CF_{i+1} + S_i(1+r) \; if \; S_i \geq 0, \\ -CF_{i+1} + S_i \qquad if \; S_i < 0, \end{cases} \quad (1)$$

$$i = 0, ... , N-1,$$

where r — an interest rate.

Technically, the debt balance of the project corresponds to the investment stream [11], the negative un-recovered investment balance stream [7], the project balance [8], the capital invested [13]. It should be noted that no interest is charged on the negative debt balance. The rate r^* at which the debt will be repaid at the end of the project $S_N(r^*) = 0$ is the rate of return of the project. Let us prove that r^* is the highest and unique rate. We will calculate a derivative of the debt balance for every period from the beginning to the end of the project. In period 1 we have:

$$\frac{dS_1}{dr} = S_0 = -CF_0 > 0.$$

In period i:

$$\frac{dS_i}{dr} = \frac{d}{dr}\left(-CF_i + S_{i-1}(1+r)\right) = S_{i-1}.$$

Let the debt balance be positive in every period from 0 to i-1, and negative in period i.

As $S_i = -CF_i + S_{i-1}(1+r) < 0$ then $S_{i+1} = -CF_{i+1} + S_i$.

Let us calculate a derivative of the debt balance in period $i+1$:

$$\frac{dS_{i+1}}{dr} = \frac{d}{dr}\left(-CF_{i+1} + S_i\right) = \frac{d}{dr}\left(-CF_i + S_{i-1}(1+r)\right) = S_{i-1} > 0.$$

By calculating the debt balance derivative for subsequent periods until the end of the project, we will obtain

$$\frac{dS_N}{dr} = \frac{d}{dr}\left(-CF_N + S_{N-1}(1+r)\right) = S_{N-1} > 0.$$

Therefore, the debt balance $S_N(r)$. is a monotonically increasing function of an interest rate r; so if the equation $S_N(r) = 0$ has a solution, then the solution is unique. For a solution to exist, the sum of all cash flows has to be positive, in which case the debt balance at a zero interest rate will be negative.

$$S_N(0) = -\sum_{i=0}^{N} CF_i < 0$$

(Corollary of the Intermediate Value Theorem).

Thus, **the definition of the rate of return of an investment project is as follows:** Let CF_i where $i = 0, 1, ... , N$ be the project's cash flows. If there exists a rate r^* such that $-1 < r^* < \infty$ and the following conditions hold:

$$S_0 = -CF_0, \qquad\qquad\qquad (2.1)$$

$$S_{i+1} = \begin{cases} -CF_{i+1} + S_i(1+r^*) \; if \; S_i \geq 0, \\ -CF_{i+1} + S_i \qquad if \; S_i < 0, \end{cases} \; i = 0, ..., N-1 \quad (2.2)$$

$$S_N(r^*) = 0 \qquad\qquad\qquad (2.3)$$

then rate r^* is the rate of return of the investment project.

The given definition is suitable for both conventional and non-conventional projects. We can now go on to define a conventional project.

The definition of a conventional project: If the *IRR* is the rate of return of an investment project, then the project is conventional. The converse is also true: if the project is conventional, the *IRR* is its rate of return.

Although the above definition is not new, it enables us to formulate a necessary and sufficient condition for the conventional project, namely: for the *IRR* to be the rate of return of an investment project, it is necessary and sufficient that all project present values discounted by the IRR should be positive in every period except the initial one.

2. Necessary and sufficient conditions signifying that a given project is conventional (the IRR is its rate of return)

2.1. Sufficient condition

Let CF_i be project's cash flows, where $CF_0 < 0$ and $\sum CF_i > 0$, $i = 0, 1, ... , N$. If for $\forall \, i$ there exists $-1 < r < \infty$ and the following conditions hold:

$$PV_{i+1} > 0, \text{ where} \qquad\qquad (3.1)$$

$$PV_N = CF_N, PV_i = \frac{PV_{i+1}}{1+r} + CF_i, \qquad (3.2)$$

$$NPV(r) = PV_0(r) = 0. \qquad\qquad (3.3)$$

Then the discount rate r is the rate of return of the project and the project is conventional.

Proof: We will calculate a derivative of the present value with respect to the discount rate. The derivative of the present value at time i with respect to rate r is equal to:

$$\frac{dPV_N}{dr} = \frac{dCF_N}{dr} = 0, \quad i = N,$$

$$\frac{dPV_i}{dr} = \frac{d}{dr}\left(\frac{PV_{i+1}}{1+r} + CF_i\right) = \left(-\frac{PV_{i+1}}{1+r} + \frac{dPV_{i+1}}{dr}\right)\frac{1}{1+r},$$

$$i = N\text{-}1, \dots, 0.$$

Thus, if for $\forall i\ PV_{i+1} > 0$, then the derivative $\frac{dPV_i}{dr} < 0$, consequently the function $PV_i(r)$ monotonically decreases as the rate r increases. Continuing the calculation until time $i = 0$, we get $\frac{dNPV(r)}{dr} < 0$. Thus, the $NPV(r)$ monotonically decreases as the discount rate increases. Therefore, the equation $NPV(IRR) = 0$ can have a single real root.

Note that r^* from the equation $S_N(r^*) = 0$ (2.3) coincides with (is the same as) the IRR. It is evident that $S_N(r^*) = -NPV(r^*)(1+r^*)^N$. So, if $NPV_0(r^*) = 0$, then $S_N(r^*) = 0$. Therefore, if conditions (3) are met, the IRR is the project's rate of return.

2.2. Necessary condition

Let CF_i be the project's cash flows, where $i = 0, 1, \dots, N$ and the project's IRR be its rate of return. Then we have

$$NPV(r^*) = \sum_{i=0}^{N} \frac{CF_i}{(1+r^*)^i} = 0 \text{ and}$$

$$S_N(r^*) = -NPV(r^*)(1+r^*)^N = 0.$$

Let us prove that for

$$\forall i < N : \ S_i(r^*) \geq 0.$$

Proof: Let $\exists k \neq N$ for which $S_k(r^*) < 0$ then:

$$S_{k+1} = -CF_{k+1} + S_k \Rightarrow S_N =$$
$$= -\sum_{i \neq k}^{N} CF_i(1+r^*)^{N-i} \Rightarrow S_N(r^*) = f((1+r^*)^{N-1}). \tag{4}$$

But then the equation $S_N(r^*) = -NPV(r^*)(1+r^*)^N$ is wrong. Therefore, every S_i should be positive.

The proof provided of a necessary condition perhaps is not strict enough to define a non-conventional project. Another proof can be found in [19].

The definition of a non-conventional project: Replacing "is" with "is not" might seem logical: If the IRR is not the rate of return of an investment project, then the project is non-conventional. However, the IRR may not exist either at all or in a given interval of the discount rate range. This case will be considered in the next sec-

tion of the paper. Let us now consider a case when the IRR does exist.

Necessary and sufficient conditions signifying that a given project is non-conventional:

Let us have a project with cash flows CF_i, where $i = 0, \dots, N$, $N \geq 3$ and the following conditions hold:

If for $0 < r < \infty\ \exists\ i, j \in N, \dots, 1;\ (i \neq j)$ so that:

$$PV_i \geq 0 \text{ and } PV_j < 0 \text{, where}$$

$$PV_N = CF_N, \ \ PV_i = \frac{PV_{i+1}}{(1+r)} + CF_i, \ \ PV_0(r) = 0 \tag{5}$$

Then the project is non-conventional.

The $NPV(r)$ is a function of the Nth degree of the discount rate r. However, the debt balance function $S_N(r)$ will have the maximum power of r which is less than N according to (4). Therefore, the rate r defined by conditions (5) is not the rate of return.

The converse is also true: If $r^* \neq IRR$ then $\exists PV_i < 0$.

Proof: According to conditions $NPV(IRR) = 0$, $NPV(IRR)\cdot(1+IRR)^N = 0$, since $IRR \neq -1$. Let us assume that for $\forall i\ PV_i(IRR) > 0$. Then

$$0 = NPV(IRR)\cdot(1+IRR)^N = \sum_{i=0}^{N} \frac{CF}{(1+IRR)^i}(1+IRR)^N =$$
$$= \sum_{i=0}^{N} CF_i(1+IRR)^{N-i} = -S_N(IRR) = 0. \tag{6}$$

But r^* from (2) is not equal to the IRR, which means that $S_N(IRR) \neq 0$; as a result, we have got a contradiction of $\exists k$ for which $PV_k(IRR) < 0$.

Unfortunately, it is impossible to use this definition in the case when the non-conventional project has no the IRR. Nevertheless, the rate of return of the non-conventional project does exist and can be defined in terms of the $GNPV$ method.

Generalizing the NPV
(the GNPV method)

Several researchers point out the advantages [16] and even justify [17] the application the NPV method to non-conventional projects. Kulakov and Kulakova [14] have recently proposed the $GNPV$ method, which generalizes the NPV method by using two discount rates (finance and reinvestment).

The $GNPV$ function is determined by consistently discounting cash flows from the end to the beginning of the project. If the present value of the project in a certain period is positive, we use the internal discount rate, otherwise – the external one. The internal rate determines

the cost of funding an investment, and the external rate determines the return on the investment. The *GNPV* function is determined as follows [14]:

$$PV_N = CF_N \qquad (6.1)$$

$$PV_i = \begin{cases} \dfrac{PV_{i+1}}{(1+r)} + CF_i, \text{ if } PV_{i+1} > 0, \\[2mm] otherwise \\[2mm] \dfrac{PV_{i+1}}{(1+p)} + CF_i, \text{ where } i = N-1, \ldots, 0; \end{cases} \qquad (6.2)$$

$$GNPV(r, p) = PV_0 \qquad (6.3)$$

where CF_i is the project's cash flow in period i, ($i = N, \ldots, 0$); PV_i is the project's present value in period i; r and p are the internal and the external discount rate, respectively.

To find the roots of the *GNPV* function it is necessary to solve the equation:

$$GNPV(r, p) = 0 \qquad (7)$$

The solution of this equation can be sought in the form of $r = r(p)$ or $p = p(r)$ depending on the purpose of non-conventional project evaluation. The *GIRR* is a rate of return and represents the maximum interest rate on the loan borrowed to finance the project, with the resulting income of the current project used to repay the principal amount and the accrued interest. The *GIRR* (*p*) is the function of the reinvestment rate *p*. The *GERR* (*r*) is a rate of cost and represents the minimum rate of return of an external project in which the borrowed funds can be invested to generate sufficient income to repay the loan with the accrued interest.

The systems of the equations (2) are equivalent to (6-7) if rate *p* is equal to 0.

3. Discussion

Let us consider several projects using the above approach.

3.1. A project
(cash flows change sign more than once)

Let us consider a project with cash flows having multiple changes in sign (*Table 1*).

Table 1.

A conventional project

Period	0	1	2	3
Cash flows	−100.0	111.7	−90.0	120.0
NPV at *r* = 20%	0.0	120.0	10.0	120.0
GNPV(*r*, 0)	0.0	120.0	10.0	120.0

Although the cash flows change sign more than once, the project's *IRR* is unique and equal to 20%. As all project present values are positive in every period except the initial one, the project is conventional.

The highest loan interest rate *r** at which the project income covers the loan and accrued interests without loss is 20% per year (*Table 2*). Therefore *r** is the rate of return of the project. The *IRR* is equal to *r**, so the project is conventional.

Table 2.

Cash flow statement
(the loan interest rate is 20%)

Period	0	1	2	3
Operating	**0**	**91.7**	**−1.7**	**100.0**
Interest payments	0	−20.0	−1.7	−20.0
Cash received from project	0	111.7	0	120.0
Investing	**−100**	**0**	**−90.0**	
Cash paid to project	−100	0	−90.0	
Financing	**100**	**−91.7**	**91.7**	
Borrowing loan	100	0	91.7	
Loan repayment	0	−91.7	0	−100.0
Debt balance	**100**	**8.3**	**100.0**	**0.0**

3.2. Two similar projects of different type

Let us consider two similar projects (*Table 3, Table 4*), which have the same changes in sign and cash flows in every period except the last one.

Table 3.

A conventional project

Period	0	1	2	3
Cash flows	−100.0	120.0	−100.0	120.0
NPV at *r* = 20%	0.0	120.0	0.0	120.0
GNPV(*r*, 0)	0.0	120.0	0.0	120.0

The project's *IRR* is unique and equal to 20%. As all project present values are not negative in every period, the project is conventional.

Table 4.

A non-conventional project

Period	0	1	2	3
Cash flows	−100.0	120.0	−100.0	110.0
NPV at *r* = 15.7%	0.0	115.7	−4.9	110.0
GNPV (15,4%, 0)	0.0	115.4	−4.6	110.0

The *IRR* of the project is equal to 15.73%. The present value in period 2 is negative therefore the project is non-conventional. *Table 5* presents the calculation of the highest loan interest rate *r** at which the project income covers

the loan and accrued interests without loss. As the rate r^* is 15.4% and is not equal to the *IRR*, the project is non-conventional. While the $GIRR(0) = 15.4\%$ is the same as r^*.

Table 5.

Cash flow statement (loan interest rate is 15.4%)

Period	0	1	2	3
Operating	**0**	**104.6**	**0.0**	**95.4**
Interest payments	0	–15.4	0.0	–14.6
Cash received from project	0	120.0	0	110.0
Investing	**–100**	**0**	**–100**	**0**
Cash paid to project	–100	0	–100	0
Financing	**100**	**–100.0**	**95.4**	**–95.4**
Borrowing loan	100	0	95.4	0
Loan repayment	0	–100.0	0	–95.4
Debt balance	**100**	**0**	**95.4**	**0**

3.3. A project without IRR

Let us consider a non-conventional project without an IRR (*Table 6*).

Table 6.

A non-conventional project without an IRR

Period	0	1	3
Cash flows	–100.0	195.0	–100.0
NPV at r = -5% (no the *IRR*)	–5.5	89.7	–100.0
GNPV (-5%,0)	0.0	95.0	–100.0

As the project does not have an *IRR*, it is non-conventional.

Table 7.

Cash flow statement (the loan interest rate is -5%)

Period	0	1	2
Operating	**0**	**200.0**	**0**
Interest payments	0	5.0	0
Cash received from project	0	195.0	0
Investing	**–100**	**0**	**–100**
Cash paid to project	–100	0	–100
Financing	**100**	**–100.0**	**0**
Borrowing loan	100	0	0
Loan repayment	0	–100.0	0
Debt balance	**100**	**0**	**0**

The loan interest rate r^* at which the project income covers the project outflows is -5% (*Table 7*). Therefore r^* is the rate of return of the project. An *IRR* does not exist, while the $GIRR(0) = -5\%$ is the same as r^*.

Conclusion

Generally, all projects with cash flows having multiple changes in sign are referred to as non-conventional projects. That is just a property, but not a definition of a non-conventional project. Most economists consider the same sign of the present (or future) value of a project at the rate equal to the *IRR* to be a sufficient condition (attribute) of a conventional project. However, the determination of conventional and non-conventional projects has not been formulated yet.

It is known that non-conventional projects have problems with determination of *IRR* (a multiple-valued *IRR* or no real-valued *IRR* at all). On the other hand, if a project has a single *IRR*, this does not mean that the project in question is conventional. The *IRR* for a conventional project is its rate of return. Therefore, it is logical to conclude with a definition that the project is conventional if the *IRR* is the rate of return, and conversely, if the *IRR* is not the rate of return, the project is non-conventional. However, the rate of return of a non-conventional project cannot be determined within the framework of the *NPV* method. Generalization of the *NPV* to the *GNPV* by using two different rates when attracting and reinvesting funds instead of a single rate allows us to determine the rate of return of a non-conventional project.

This paper presents a mathematical determination of the rate of return for an investment project of any type and proves that in the case of a conventional project the rate of return is the *IRR*, while in the case of a non-conventional project it is the *GIRR*. The necessary and sufficient conditions of the conventional and non-conventional projects have been formulated. We hope that application of the proposed methodology to investment project profitability assessment will simplify calculation processes and help to avoid possible errors resulting from the imperfections of the *NPV* method. ∎

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Определения типичного и нетипичного проектов

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Аннотация

Понятие «нетипичный», «нестандартный» проект или «проект с нетипичными денежными потоками» введено в экономическую литературу после того, как было показано, что для некоторых проектов внутренняя нома доходности (internal rate of return, IRR) может иметь несколько значений или не существовать вовсе. Проект считается «типичным», если его денежный поток только один раз меняет знак, независимо от направления: с минуса на плюс или наоборот. Типичный проект имеет единственное значение IRR. Однако не все проекты с многократным изменением знака денежного потока являются «нетипичными», т.е. имеют проблемы с определением IRR. Поэтому теория рекомендует для определения типа проекта исследовать зависимость функции чистого дисконтированного дохода (net present value, NPV) от ставки дисконтирования на монотонность с целью выявления множественности или отсутствия IRR. С другой стороны, монотонность NPV и единс венное значение IRR не гарантируют того, что проект типичный. Более того, было показано, что доходность нетипичного проекта в рамках подхода NPV не может быть определена, а, следовательно, и понятие доходности не может быть сформулировано. Недавно был предложен метод обобщенной чистой приведенной стоимости (generalized net present value, GNPV), на основе которого может быть рассчитана доходность «нетипичного» проекта.

В данной статье сформулировано понятие доходности для инвестиционного проекта любого типа и доказана ее тождественность обобщенной внутренней норме доходности (generalized internal rate of return, GIRR), вытекающей из метода GNPV. Дается определение и формулируются необходимое и достаточное условия типичного и нетипичного проекта.

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The concept of reference models of automated planning and budgeting systems

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Abstract

The article proposes a concept of reference models for automated budgeting systems designed to highlight the cross-subject area between information technologies and budgeting theory. The paper identifies methods of automation of budgeting systems, their reference elements and interaction with the organization budgeting system. In particular, the extension of functionality of spreadsheets, the development of functionality of ERP-systems, customized development of automated budgeting systems, task-oriented budgeting systems and systems available within the "software as a services" (SaaS) model are considered as the main approaches to budgeting automation.

Reference models are taken to mean models of automated budgeting systems which describe the information system configuration for certain sectors or types of production, i.e. a meta description based on which a specific system can be configured and implemented.

For description of a reference model, such documents as a directory of budget items grouped within the analytical dimensions, album of forms (including data entry forms and report forms), as well as passport of algorithms, which describes methods of calculation of budget accounts are proposed to be used. This documentation covers three main areas within which the information systems are designed, namely, design of data objects, design of screen forms and reports, and record of the technology being used.

Reference models of the budgeting systems enable consulting companies to formalize and systematize the project experience to achieve a competitive position through reduction of terms and enhancement of the system integration.

Introduction

Currently budgeting technology has become an indispensable element of management systems for organizations relating to big business, and it continues to gain popularity among medium-sized companies. As a rule, the area covered by the modern budgeting system comprises a significant amount of financial, natural and quality metrics and accounts [1]. Therefore, the concept "corporate planning and budgeting" is often used on the same basis as the term "budgeting". The concept of corporate planning and budgeting originated abroad and was borrowed by the domestic budgeting and management accounting practices.

Planning and budgeting represent a system of more important accounts describing the organizational status at a given time. Moreover, budgeting makes it possible to reflect both the enterprise state in real time (actual), and the target state for a certain time in the future (plan, forecast). Furthermore, budgeting opens up historical data, i.e. actual values of the historic budget accounts.

Budgeting reflects the state of the entire organization that is required for the top management. It also enables us to set benchmarks for mid-level managers. Therefore, the budget items represent aggregative accounts, without inherent itemization at the operational management level, but sufficient to describe all high-priority elements in terms of the management system. However, despite a relatively low level of accounts breakdown, operational budgeting, collection and consolidation of data across the organization (especially in respect to a holding company consisting of multiple, often geographically dispersed organizational units), and especially business analysis turn out to be impossible without automation of the budgeting system [2, 3].

1. Automation specifics
of the budgeting system

Automation of the budgeting system is an important issue, one of the key elements of the information support system (system complex) for corporate and strategic management [4]. It allows us to achieve a synergistic effect of the consolidated information space, all of which greatly enhances business analysis and planning capabilities. This is due to the fact that in the budgeting process of large organizations up to several tens of thousands of budget accounts are used. They are introduced in several versions for different reporting periods (years, quarters, months, etc.), according to different scenarios by a variety of organization units and affiliates. In other words, in the course of the budget process a significant amount of data is generated. It is analyzed and processed by means of classical spreadsheets, and this is extremely nonproductive, as noted in most of the studies on this issue, for example, in papers [2, 5–7]. Analysis of research in the area of approaches to automation of the budgeting systems enables us to identify the following groups of solutions:

✦ automation by extending the functionality of spreadsheets via macros (e.g., table editor MS Excel and VBA);

✦ extension (improvement) of functionality of ERP systems (e.g., SAP R/3, 1C: Enterprise, MS Dynamics AX, and others);

✦ automated budgeting system developed by company IT department or a contractor;

✦ customized application issued by the software company (for example, Oracle Hyperion Planning, SAP BPC and others);

✦ customized application provided by software companies using the SaaS model (software as a service) (Oracle PBCS, IBM Cognos TM1 on Cloud et al.).

The automated budgeting systems included in each of the above groups have their own advantages and disadvantages. Therefore, the company management making decisions on implementation of one or another option is tasked with searching for an optimum relationship of functionality, reliability, risks, time and cost of the implementation. An extended analysis of this issue is presented, for example, in paper [8]. The following key characteristics of approaches to automation of the budgeting systems can be highlighted:

◆ Extension of functionality of the spreadsheets is the lowest cost option per totality of factors, such as user training, license cost, qualification and services cost of IT specialists. However, such solutions have the lowest functionality, performance and reliability. It is worth noting that the maintenance of such a solution is extremely labor-intensive, considering the need to make changes to hundreds of separate documents.

◆ Improvement of functionality of the ERP system is characterized by an average cost through reduction of expenditures connected with purchasing new licenses and retraining specialists. However, the functionality and performance of this solution are significantly limited, because the systems of this class were originally developed to solve another scope of tasks, namely, operational accounting and management tasks.

◆ The customized automated budgeting system (unique system) is characterized by high cost and labor content (if the system is developed by its own IT department), as well as risks in implementation and maintenance. Theoretically, systems of this kind should cover the company needs in functionality as much as possible, but for that to be so a staff of highly qualified IT specialists and methodologies providing for their development and support has to be maintained. In addition, high time expenditures are required to put such systems into commercial operation in comparison with the purpose-built solutions. In addition, performance comparable to the solutions of software companies can fail.

❖ Task-oriented systems a priori have broad functionality and high performance, as they were originally designed specifically for budgeting tasks. In addition, software producers from one version to another extend the system capabilities, increase system stability and reliability, drawing on feedback of the system integrators and companies which have implemented and are using this system. Systems of this group generally have a wide range of tools of integration with solutions of other classes: a software company often offers a broad range of its products with seamless interaction. The relatively high cost of implementation of such solutions and the need for user training can be identified as negative factors.

❖ Task-oriented systems using the SaaS model of large software producers tend to have a similar, though slightly lower functionality as compared to classical task-oriented budgeting systems. For smaller software companies, such systems could serve as a main product. The systems of this class are cheaper than the classical purpose-built solutions, due to the fact that the infrastructure and technical support are transferred to the software developer, and the licenses are purchased via a subscription model. This segment is offered primarily to medium-sized business.

From the foregoing, it follows that there is a wide range of methods of budgeting automation and providing solutions. However, from the perspective of technical implementation, task-oriented budgeting systems based on information on-line analytical processing technology (OLAP) [5] are in fact an automation standard for planning and budgeting systems of big business; this term was introduced by B. Codd in 1993 [9]. Thus, according to Gartner research, for a market of corporate performance management (CPM) class systems, which include budgeting systems, such software giants like SAP, Oracle and IBM have become absolute leaders. Their products (both classical applications, and SAS) are based on OLAP technology [10].

The unconditional dominance of OLAP in budgeting automation is explained by the fact that this technology is perfectly suited to collection and consolidation of large volumes of data from various sources, providing an analytical slice with minimal processing time, representing information in a data structure accessible for understanding and analysis by users, and so on [11]. This functionality is present in all major automated budgeting systems.

2. Reference automated budgeting systems

The market of automated corporate planning and budgeting systems is mature and highly competitive [10]. At the same time, business competition is observed not only among software companies, but also among consulting companies specializing in implementation of this class of systems. The remarkable thing is that one and the same integrator company can often automate budgeting systems by software products of different vendors.

The following factors may act as a competitive advantage in the system integration market:

● price of implementation of the information system;

● reputation of the integrator company, which can be expressed in a large number of successfully completed projects implementing automated budgeting systems, including in the industry sector relevant to the customer;

● partner status of the software company (usually there are several ratings: platinum partner, gold partner, etc.);

● duration of the life cycle of automated budgeting systems after implementation: if after a few budget cycles the system was taken out of service and was replaced by another solution, this is evidence of negative integration results.

However, the factors listed above for the domestic market are often depreciated due to overrepresentation of the companies involved in this market for a long time. These integrators already have a high partner status of vendors and large project experience. This narrows the range of price changes due to the fact that the major part of the design prime cost is made up of payroll budget of the advice-givers who can move freely among competitive companies, so that a reduction of wages leads to a loss of specialists.

Consequently, competition among integrators goes into the plane of quality and time of implementation. For time- and quality-based competition, many consulting companies offer reference automated budgeting systems — pre-configured versions of the budgeting system, implemented by a product of one vendor and positioned as solutions for a particular industry sector. It is assumed that such an information system meets the basic business needs, so after deployment on servers all that is left to do is to bring it into line with the company's budget model. However, such solutions are most often either very common (only de-

scribe the framework of master budgets), or based on only one successful project and can be irrelevant to a specific industry as a whole. In addition, in this approach a potential customer is limited by the choice of the software product of one specific vendor. This may motivate cancellation of implementation, especially if the entire information infrastructure of the organization has been built based on solutions of another software company, so that a seamless integration becomes impossible.

3. Assumptions to formation of the reference model of automated budgeting system

A significant role in formation of marketing automation standards is played by consulting companies [12, 13], which develop their practice in accordance with the customer's demands. This is embodied both in the form and in the content of the budgeting systems. Most often the budget system itself is subject to changes, and the area of automation is also extended or narrowed down. This leads to the fact that the automation task of the budgeting process is limited to methodology adaptation and its implementation in an information system based on OLAP technology, using a product of one of the software companies. Therefore, in terms of automation, in general, the budgeting system can be represented in the form of one or more data cubes (multi-dimensional representation of budget accounts grouped into analytical dimensions), a set of report forms and calculation algorithms. Based on this abstraction, a concept of reference models of the automated budgeting systems may be proposed. The reference models are taken to mean models of the automated systems, which describe the "information system configuration for certain industries or types of production", i.e., meta description, on which basis configuration and implementation of a particular system can be accomplished [14].

The reference model (meta description) does not have most of the disadvantages specific to the reference solution (specific automated information system), because it is not linked to a particular software product; it is built on the basis of analysis and synthesis of industry specifics drawing on information from various sources (project documentation, industry standards etc.). It is also an intermediate link between the budgeting procedure and the implemented information system. Let us consider the assumptions of forming the concept of the reference model of automated budgeting systems.

It is obvious that a set of budget items grouped within dimensions of data cubes (for example, the dimension of periods may include January, February, March, first quarter, etc., and dimension of scenarios — budget, actual, and forecast) is primary for any automated budgeting system. Definite sets of budget items form "slices" that are presented in the form of input of primary data for users and "mappings" to load data from other systems (e.g., the actual data for the elapsed periods can be loaded from the accounting systems). The input data is processed by certain algorithms and transferred to other analytical slices (groups of budget accounts) which are made available to users in the form of reporting forms. For example, the Profit and Losses (P&L) budget consolidated per the company corporate divisions may be formed on the basis of budgetary assumptions entered in the input forms by the users.

The system of budget items should describe all important company accounts at a microeconomic level, as well as some macroeconomic measures. These items are directly or indirectly embodied in three consolidated budgets of the company (master budgets): Cash Flow (CF), Profit and Losses (P&L) and Balance. Master budgets are generated on the basis of more detailed budgets, which can be divided into two groups — operational and financial [15].

In the course of the budget process, any company, irrespective of the industry sector, needs to get three master budgets (in some cases, it may be limited to developing only P&L or CF). It is obvious that many accounts and dimensions of the budgeting system are universal in some degree. Thus, time periods, budget scenarios, versions, types of data (depending on the source - manual entry, import, calculation etc.), budget items (revenues, expenses, EBITDA and others) organizational structure, internal and external contracting parties, exchange rates can be referred to as universal dimensions. These dimensions are necessary to describe any complicated economic system in competitive market conditions that corresponds to the conceptual budgeting framework. [16] As a natural result, a similar set of dimensions is a mandatory (not variable-based) component of the task-oriented budgeting systems, such as, for example, Oracle Hyperion Planning.

The remarkable thing is that the level of detail and structure of the dimensions noted above are mainly determined by company managerial decision and the budgeting methodology adopted at the company, as well as non-industry specifics. The exception is the dimensions of items and organizational structure. On frequent occasions, it is the industrial sector in which

the company operates that defines the organizational structure of the grouping of its business units. At the same time, as a general rule the company assets or any other units on which the planning is implemented, can be broken down by types of activity which determine the list of primary budgets and a set of their constituent items. For example, electric power holding companies can include generating and sales assets; oil and gas companies can include upstream, supply and processing; and retail trade can include trade outlets.

The item dimensions for most companies include a hierarchy of accounts conventional for budgeting. For example, the balance sheet incorporates assets, assets incorporate current and non-current assets; non-current assets are divided into fixed assets, intangible assets, etc. The industry sector specifics usually show up in the low-level items breakdown. For example, the item "Supplies" in the balance sheet of an electric power holding company will include coal, fuel oil, etc., while the automaker's reserves include finished products and in-progress inventory. The general rule is that this dimension includes groups of items of the inventory balance of resources and engineering-and-economical performance. These items depend heavily on business specifics, while they owe their existence to industry standards and formats of the state statistical reporting. With regard to the foregoing, the greatest part of measures breaking down the budget items is provided by their removal into separate cube dimensions, which often represent the directions of activities and products. For example, for a car dealer the item "Revenues from sales" can be broken down by type of "Auto sales" activity, and the quality of products can be represented by car and motor trucks, with appropriate model details.

A similar approach is applied to measure business units. As a rule, additional analytic areas (alternative hierarchies) are introduced, thereby allowing us to group the company data in the context of market outlets (for example, "Russia", "neighboring countries", "overseas countries", etc.), types of organizational units (for example, subsidiaries, joint ventures), projects, etc.

It is worth noting the impact of the regulator represented by the state on the models of company automated budgeting systems. A particularly striking example of this impact is taxation: it generates items which are taken into account when calculating the master budget accounts and are used to prepare different variations of budget versions. It can be both items required for any business (VAT, income tax), and specific for certain industry sectors, such as mineral extraction tax (MET) for the mining sector (this item can occupy a significant share of business expenditures). These items are generally calculated (the algorithm is automated). Thus, business can analyze the tax effect on the company in the long term based on the assumptions. This group of measures usually falls within the analytical direction of items or assumptions.

4. Reference models of automated budgeting systems

In the foregoing, consideration was given to general assumptions of forming budget items for the reference model of an automated budgeting system. As noted above, the measure sets or groups predetermine the structure of budget forms (budgets). In so doing, rules for item calculations result from their titles, and the algorithms correspond to the financial theory (e.g. EBITDA), or are taken directly from the industry (for example, for the measure "Well water cut, %" for the oil and gas sector).

Based on the above, let us produce a list of documents corresponding to the concept of a reference model of automated budgeting systems and enabling us to define it. The model can be described by the following documents:

✦ directory of budget items grouped under the analytical measures. The location of the items in the areas (hierarchy relations) and their properties should not be contrary to OLAP principles;

✦ album of forms: the document should present data entry forms and report forms (budgets). The album rows, columns and analytical slice are built based on the item directory;

✦ passport of algorithms: the passport describes algorithms for calculating budget accounts (the accounts must also comply with the directory), and it also provides data processing rules.

It is true that the proposed documentation describes data input in the OLAP-cube, as well as data processing and reporting. It covers three main areas in which information systems are designed, i.e. design of data objects, design of screen forms and reports, the account of specific technology [14].

We can thus proceed to the issue of usefulness and approach to the implementation of the solution. Integrator companies can become beneficiaries of the proposed concept application, for which the presence of

the reference model of the automated system can be used as a competitive position.

Let us consider the process of developing the reference model of the automated budgeting system. No doubt, the development of such a solution calls on the integrator to have highly qualified specialists represented by methodologists having a deep knowledge in the area of budgeting and management accounts, IT specialists (analysts, advice-givers, software researchers), as well as wide project experience in various industries. The remarkable thing is that project experience is represented not only in the form of specialist knowledge, but also in the form of documentation obtained in the course of implementation of the systems in organizations of various industries. As a rule, the integrator company has a large amount of documents, including information applicable to the development of item directories, albums of forms and passports of algorithms. A reference model can be synthesized based on the analysis of this documentation and industrial literature (including scientific literature). Based on expert analysis, specialists need to compare the hierarchical directories and on their basis design new analytical dimensions. In this case the depth of breakdown of certain groups of measures must be determined by a degree of entropy: if a certain group of measures has great variability in different companies, it is recommended to give up a few levels of breakdown, since the presence of items in the model unclear to most customers will not give a positive result.

The model building process cannot be substantially automated, and cannot be implemented by a mathematical tool. This is due to the fact that the titles of budget items in the database of analyzed solutions of different companies can vary widely and be in different languages (especially if a sample for analysis is based on international experience). The level of nesting and descending relations may also differ; in addition, in different projects certain directories can be spread across different analytical areas. As a consequence, the automatic development of calculation rules based on such initial data seems to be even less probable. It follows that the need for semantic analysis and comparison of items distributed in different structures, as well as assessment of their significance makes it impossible to present algorithms for model construction procedures due to the extremely high complexity and uncertainty of the analysis criteria.

Conclusion

The concept proposed in this paper makes it possible to identify, formalize and systematize the industry sector specifics in the form of a reference model of an automated budgeting system based on project experience and documentation, as well as the industry and general budgeting theory.

The reference model can become a starting point for project work on implementation of the automated budgeting system. Firstly, it allows a potential customer to show the integrator company what exists in budgeting automation in his industry sector. Secondly, based on the model, a system display stand can be developed (the specific software product can vary depending on the buyer requests), which uses the forms and measures familiar to the customer. Thirdly, the presence of a ready-made solution can be a starting point for development of a real system that makes it possible to avoid a number of system design errors, reduce the implementation time and increase its quality, all of which fully interest the commercial client and integrator company. ∎

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Концепция типовых моделей автоматизированных систем планирования и бюджетирования

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Аннотация

В статье предложена концепция типовых моделей автоматизированных систем бюджетирования, которая призвана осветить междисциплинарную область между информационными технологиями и теорией бюджетирования. В работе выявлены способы автоматизации систем бюджетирования, их типовые элементы и взаимосвязь с бюджетной системой организации. В частности, в качестве основных подходов к автоматизации бюджетирования рассмотрены расширение функциональности электронных таблиц, развитие функциональности ERP-систем, разработка автоматизированных систем бюджетирования под заказ, специализированные системы бюджетирования и системы, доступные в рамках модели «software as a service» (SaaS).

Под типовыми моделями понимаются модели автоматизированных систем бюджетирования, которые описывают конфигурацию информационной системы для определенных отраслей или типов производства, то есть метаописание, на основе которого может осуществляться конфигурирование и внедрение конкретной системы.

Для описания типовой модели предлагается использовать такие документы, как справочник бюджетных статей, сгруппированных в рамках аналитических измерений, альбом форм (включая формы ввода данных и отчетные формы), а также паспорт алгоритмов, в котором описываются методы расчета бюджетных показателей. Эта документация охватывает три основные области, в рамках которых проектируются информационные системы, − проектирование объектов данных, проектирование экранных форм и отчетов и учет применяемой технологии.

Типовые модели систем бюджетирования позволяют консалтинговым компаниям формализовать и систематизировать проектный опыт для достижения конкурентного преимущества за счет сокращения сроков и повышения качества системной интеграции.

Ключевые слова: корпоративное планирование, бюджетирование, автоматизированная система бюджетирования, управление эффективностью бизнеса, системная интеграция, типовая модель, консолидация, анализ, OLAP, отраслевая специфика.

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Estimated aggregate cost of ownership of a data processing center

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Abstract

Under current conditions, we see growth in demand for IT outsourcing services. This implies the activation of design and construction processes for data processing centers (DPC). Since a DPC is a complicated and expensive system, there arises the issue of justifying selection of the future project based on the estimated costs of designing and operating data processing centers.

This paper analyzes one of the possible complexes of measures to estimate costs for development and operation of data processing centers. The analysis identified main groups of capital cost in development of data processing centers which were not fully taken into account in assessments of the total volume of capital investments in previously proposed methods. The article proposes regression models to evaluate processing center construction projects based on two measures. We propose to estimate the capital cost as a function of the projected floor space of service platforms and projected number of server racks. On the basis of the models developed, analysis of the construction sites of processing data centers was conducted. This showed the model's suitability to real data. The main groups of operating costs for DPC maintenance were established, and a regression model of their evaluation was proposed. Based on the regression equation, we propose to calculate the processing center's power consumption depending on the area of the service platform or the number of server racks. The operating cost of the data processing center is determined by the power value. Analysis of information on the operating cost of various data processing centers is in fairly good agreement with the calculations obtained on the basis of the model developed.

The proposed models make it possible to evaluate with reasonable accuracy the project characteristics of development and subsequent operation of a data processing center.

Introduction

Under current conditions of market relations, we see expansion of the tertiary industries sector along with an increase of the outsourcing share. Services like IT outsourcing are becoming very attractive. The main producers and suppliers of IT outsourcing services are modern data processing centers (DPC), which provide a sufficiently wide range of different IT services for consumers. By using a DPC, the customer can make effective administrative decisions under conditions of limited abilities to attract financial resources for development of the company's own IT infrastructure while finally ensuring a stable and break-even point in the company's business. Thus, it can be assumed that the demand for IT outsourcing services will be growing. Therefore, the task of developing tools for pre-estimated costs to implement such expensive and resource-intensive projects as development of data processing centers becomes a subject of great current interest.

The appearance and development of DPCs are directly linked to a multiple increase of processed and stored information volumes, the need to ensure high operational capability of mission-critical applications and business continuity processes.

Based on the implemented functions and core requirements for data processing objectives and processes, a DPC can be defined as a complex solution intended for high-performance and reliable data processing, storage and transmission having a high operational capability. The solution also includes an engineering infrastructure comprising a significant share of costs both in the course of the center's establishment and operation, i.e. in the aggregate cost of the system's ownership. On the other hand, the DPC is a combination of a large number of software and hardware platforms of various kinds – servers, data storage networks, operating systems, workload management systems and data backup built in according to specific business needs of its owner.

Based on the high level of complexity of the data processing system, it is necessary to select a set of measures for estimating costs on a reasonable basis which may occur in the processing center's development and operational phases.

Similar problems have already been solved. The solution results are presented in papers [1–3]. In the solution, the indicated problems of foreign experience were primarily considered. Let us consider the data relating to national DPC development projects.

1. Structure of cost for DPC development

Analysis of papers [4–6] enables us to identify the following four main groups of capital costs:

1. Building construction. A high-quality DPC (beginning with level Tier 3) should be located in a freestanding building with special characteristics. For this reason, the construction cost can differ from similar projects for building storage premises. However, the building can be taken on lease. In this case it should be brought into compliance with all technical requirements.

2. Grid connection. Data processing centers are distinguished by large amounts of power consumption. Therefore, they need a separate power input from the power plant. If for level Tier 1 and 2 DPC one power input line is sufficient, a Tier 3 DPC requires one active and one standby power input line, and a Tier 4 DPC needs two active lines.

3. Optical cable. It is important to note that every year the server throughput capacity is growing. In this regard, requirements for optical cables and their cost are increasing. It is assumed that there is increased demand for link capacity of communication lines (assuming an increase by a factor of about 4).

4. DPC engineering systems. The cost of backup power supply, procurement of uninterruptible power supplies, provision of the cooling system, raised floor, routing of electrical networks and purchase of equipment (racks, etc.) can be referred to this article.

Having summarized the investigation results on the cost structure [1, 7, 8], the following components of the data processing center construction costs can be identified:

1. Building construction (~ 10-15%);

2. Grid connection (~ 20-25%);

3. Optical cable (~ 0-5%);

4. DPC engineering systems (~ 60-70%).

Capital costs are generally determined by DPC surface area (associated with a number of racks) and Tier level reliability. The data provided in article [9] makes it possible to estimate the cost parameters for construction of the engineering infrastructure for a certain representative project of a data processing center (*Table 1*) and evaluate the dependence of these parameters on the DPC reliability level.

However, these costs do not fully reflect the total capital investment in building a DPC. If we take into account construction of additional premises required for secured assurance of center operation reliability, the cost

Table 1.

Cost of DPC

Cost of DPC construction		
Tier II level	Tier III level	Tier IV level
Cost of 1m² of DPC		
$10 579	$13 941	$25 767
Cost per rack		
$26 447	$34 852	$64 417

of construction of 1 m² (main area) increases by a factor of 2.2, and costs per rack increase by a factor of 2.4. The cost of 1 m² of one level Tier DPC construction can vary significantly depending on the total surface area of the center. In addition, the proposed evaluations do not make it possible to extend this data to the DPC project of another configuration and do not allow us to take the

construction region into account, which also has a significant impact on the cost.

Therefore, estimation procedures based on the cost detalization are untenable for project evaluation in the initial phases.

2. Regression model of capital costs

All the cost components listed above are directly or indirectly related to such characteristics of the data processing center as the surface area or number of racks. In this connection, it is reasonable to develop a model which would enable us to conduct the project assessment via these two measures.

To meet the target, data on 70 processing center construction projects was collected in Russian for the period from 2008 to 2014 (*Table 2*).

Table 2.

Original data sample for DPC construction project

Name	Year	City	Project cost	Total area, m²	Area of service platform, m²	Number of racks, pcs.	Power, MW	Level, Tier
Irkutsk-Energosvyaz	2014	Irkutsk	2.5 bln. Rub	10000	3200	1300	NIA	3
Government of Chelyabinsk region	2014	Chelyabinsk	27 269 000 Rub	12000	NIA	1600	16	NIA
Ministry of Health of Tula region	2013	Tula	no information available (NIA)	NIA	NIA	NIA	0.8	NIA
Gazprom Neft	2013	St. Petersburg	NIA	NIA	NIA	NIA	NIA	3
Irkutsk region	2013	Irkutsk	30 bln. Rub	NIA	NIA	NIA	30	NIA
VimpelCom	2013	Yaroslavl	4 bln. Rub	15000	3000	1200	10	3
Rostelecom	2013	Moscow	30 mln. US$	11500	10000	NIA	40	3
Sibirtelecom	2012	Novosibirsk	70 mln. Rub	215	NIA	60	3	NIA
Inoventica	2012	Vladimir region	90 mln. Rub		300	60	0.45	3
Rostelecom	2012	Stavropol	NIA	280	250	20	NIA	NIA
Electronic Moscow	2012	Moscow	114.5 mln. Rub	530	250	93	1	NIA
Dataline	2012	Vladivostok	NIA	NIA	1000	509	NIA	NIA
Transinfo	2012	Moscow	NIA	NIA	600	200	NIA	NIA
I-Teco	2012	Krasnoyarsk	NIA	NIA	120	40	NIA	NIA
Ikselereyt	2012	Moscow	NIA	NIA	580	200	NIA	NIA
Stack	2012	Kazan	$37 mln	NIA	NIA	376	2,5	NIA
Stack	2012	Moscow	NIA	NIA	250	30	NIA	NIA
Storedata	2012	Moscow	NIA	250	125	30	0,3	NIA
Rostelecom	2012	Sochi	1 bln. Rub	2000	400	92	NIA	NIA
Rostelecom	2012	Kaliningrad	33.5 mln. Rub	NIA	150	20	0,1	NIA
Megafone	2012	Orenburg	NIA	NIA	270	110	NIA	NIA
Fianco	2012	Krasnoyarsk	NIA	NIA	370	80	NIA	NIA
Fianco	2012	Ekaterinburg	NIA	NIA	56	12	NIA	NIA
Inoventica	2012	Tatarstan	NIA	NIA	300	60	NIA	NIA
Sberbank	2011	Moscow	$1.2 bln	16500	5000	1500	25	3
DataSpace	2011	Moscow	$85 mln	6000	3000	1000	4,8	3

Name	Year	City	Project cost	Total area, m²	Area of service platform, m²	Number of racks, pcs.	Power, MW	Level, Tier
Rostelecom	2011	Vladivostok	110 mln. Rub	320	100	15	1,2	3
Yandex	2011	Moscow	NIA	4500	NIA	NIA	8	NIA
Linxdatacenter	2011	St. Petersburg	20 mln. Euro	7500	NIA	250	NIA	3
KROK	2011	Moscow	$100 mln.	5000	2000	800	NIA	3
BSTelehouse	2011	Moscow	NIA	NIA	1000	75	NIA	NIA
Selektel	2011	St. Petersburg	NIA	NIA	800	250	NIA	NIA
Megafone	2011	Khabarovsk	NIA	NIA	390	50	NIA	NIA
TEL-Hosting	2011	Moscow	NIA	NIA	350	60	NIA	NIA
Permenergo	2011	Perm	14.6 mln. Rub	44	34	14	0,06	NIA
Bank "Neiva"	2011	Ekaterinburg	6.9 mln. Rub	34	25	4	0,04	NIA
OBIT	2011	St. Petersburg	15 mln. Rub	400	NIA	60	0,3	NIA
Bashneft	2011	Ufa	342.76 mln. Rub	400	NIA	NIA	0,56	3
Oversan Mercury	2010	Moscow	400 mln. Rub	950	500	200	4	3
Oversan Luna	2010	Moscow		NIA	120	50	0,5	NIA
Megaphone Samara	2010	Samara	930 mln. Rub	6912	2400	720	8	3
MDM-bank	2010	Moscow	100 mln. Rub	350	100	50	0,5	
Miran	2010	St. Petersburg	80 mln. Rub	NIA	NIA	100	3,5	3
Storedata	2010	Moscow	60 mln. Rub	NIA	250	100	1	NIA
Sibirtelecom	2009	Novosibirsk	124 mln. Rub	900	300	70	1,5	3
General DataComm	2009	St. Petersburg	$5 mln	2000	500	NIA	NIA	NIA
Komkor (Acad Telecom)	2009	Moscow	400 mln. Rub	NIA	NIA	140	NIA	NIA
Dataline	2009	MR - Korovin high road	NCA + 217.5 mln. Rub	NIA	2700	800	7	2
Dataline	2009	Moscow – Borovaya	NCA + 122 mln. Rub	1855	900	360	4	2
IT-park	2009	Kazan		3500	1000	294	5	3
Megafone (Synterra)	2009	Kazan	100 mln. Rub	229,5	170	48	0,5	NIA
PiN Telecom	2009	St. Petersburg	18 mln. Rub	200	NIA	38	NIA	NIA
ISG	2009		140 mln. Rub	700	NIA	150	3	NIA
Trastinfo	2009	Moscow	NCA + 176 mln. Rub	3000	1600	800	6,4	NIA
OKB Progress	2009	Moscow	NCA + 4 bln. Rub	480	480	100	NIA	NIA
Infobox	2009		NCA + 7.9 mln. Rub	NIA	600	NIA	25	NIA
Selektel	2009	Moscow	4.5-5 mln. US$	500	300	80	NIA	2
Uralsvyazinform	2009	Ekaterinburg	300 mln. Rub	NIA	432	250	NIA	NIA
Dataplanet	2009	Zelenograd	NCA + 9.8 mln. Rub	170	160	40	0,3	NIA
Raduga -2	2009	St. Petersburg	NCA + 2.2 mln. Rub	NIA	60	20	NIA	NIA
Rostelecom	2008	Ekaterinburg	10 mln. Rub	155	100	36	NIA	NIA
Troika Dialog	2008	Moscow	$10 mln	200	NIA	NIA	0,5	NIA
Peter-Service	2008		$20 mln	480	480	50	0,3	3
OBIT	2008	St. Petersburg	NCA + 10.1 mln. Rub	400	300	120	NIA	3
Selektel	2008	St. Petersburg	NCA +69.5 mln. Rub	1500	700	200	2	2
YUTK	2008		320 mln. Rub	1000	300	NIA	1,5	NIA
M1, Stack	2007	Moscow	$15 mln	2500	NIA	NIA	NIA	NIA
Tehnogorod	2007	Moscow	NCA + 10 mln. Rub	1500	NIA	NIA	1	3
Karavan	2008	Moscow	$7 mln	1000	NIA	NIA	2	NIA
Ixcellerate	2008		NIA	15000	6200	NIA	NIA	NIA
Zelenograd	2008	Zelenograd	3 bln. Rub	16000	14000	1215	21	3

In some projects, the abbreviation NCA is seen in the column "project cost". This means that the project cost has not been revealed by the company, but when analyzing the data from the SPARK-Interfax system, an increase in value of the noncurrent assets (NCA) to include the specified amount can be found when constructing the data processing centers.

After collecting data on DPC construction projects, a procedure of adjusting them to a single currency (in our case the US dollar was selected) and prices of one year (2013 was selected) was carried out. This has been done using the price index for engines and equipment used in construction.

Unfortunately, in some cases data on projects was incomplete: for example, with the known cost of the construction and area of engineering sites, the number of racks was unknown. In such cases correlations identified in market research [8] and presented in *Table 3* were used for data recovery.

Table 3.

**DPC market dynamics
in 2011—2016**

	2011	2012	2013	2014	2015	2016
Racks, '000 units	15.9	18.7	23.1	28.7	34.5	42.2
Area, '000 sq. m.	52.8	62.6	84.6	103.7	121.8	146.8
Sq. m. / rack	3.3	3.3	3.7	3.6	3.5	3.5

After processing, the original sample regression models were constructed with breakdown across DPC construction projects in Moscow and in the regions.

A planned DPC surface area (S) and planned number of racks (N) were selected as independent variables.

Capital costs (CAPEX) across all projects in Russia are determined by the following correlations:

1. CAPEX $= -2856583 + 22136 \cdot S$ (in which case $R^2 = 0.72$; P-value for the coefficient of variable S is 4.7E-11. P-value of free constant is 0.76). Low P-value for the coefficient at variable S makes it possible to predictably say that the construction cost of one square meter (with a root-mean-square error of 2 339 dollars) is in the range between 19 797 and 24 475 dollars. This agrees with the expert assessments of 15—25,000 dollars [10].

2. CAPEX $= -3375063 + 78751 \cdot N$ (in which case $R^2 = 0.8$; P-value for the coefficient of variable N is 2.03E-13, P-value of free constant is 0.67). With a root-mean-square error of the coefficient at N=, the construction cost in terms of a rack is in the range from 71 994 to 85 508 dollars. Therefore, the obtained construction cost of one rack is approximately 3.5 times higher than the construction cost of one square meter of DPC. This more or less equals the correlation obtained from marketing research.

To refine the cost, separate regression models depending on DPC location can be constructed:

✦ Moscow: CAPEX_Moscow $= -2651754 + 22612 \cdot S$ or CAPEX_Moscow $= -3315038 + 73616 \cdot N$;

✦ Regions: CAPEX_Regions $= -8077885 + 26586 \cdot S$ or CAPEX_Regions $= -6171183 + 95935 \cdot N$.

Summarizing the construction of regressional relationships and comparing the calculation results by a model with real data, one may conclude that the model rather suitably describes real data. Deviations of the estimated data from the averaged data for all selection of values are shown in *Table 4.*

Table 4.

Geographical segmentation DPC construction cost

DPC location	Moscow	Regions	Russia
Average cost of building 1 sq.m (aggregate CAPEX of sample / aggregate S)	19 686	22 890	22 291
Average cost of building 1 rack (aggregate CAPEX of sample / aggregate N)	62 080	85 400	80 407
Unit cost of building 1 sq.m (regression)	22 612	26 586	22 136
Unit cost of building 1 rack (regression)	73 616	95 935	78 751
Confidence interval – cost of building 1 sq.m (regression)	17 388 – 27 836	24 153 – 29 019	19 797 – 24 475
Confidence interval – cost of building 1 rack (regression)	59 201 – 88 031	93 366 – 98 502	71 994 – 85 508
Average surface area of DPC	1 583	1041	1258
Average number of DPC racks	509	242	349
Deviation of construction cost of 1 sq.m	13%	14%	-1%
Deviation of construction cost of 1 rack	16%	11%	-2%

A very interesting pattern can be derived from this table: the cost of DPC construction per 1 sq.m (or 1 rack) in Moscow is lower than in the regions by approximately 20%. This can be explained by the fact that the dimensions of a statistically average Moscow DPC exceed the dimensions of regional DPC by 80%, and with the project scaling-up the unit cost significantly goes down for each new rack or square meter.

These correlations can be used in evaluating the cost in the initial construction phase, and in the cost estimation for further development of the DPC, if it is foreseen.

Due to insufficient representativeness of the sample, it turned out to be impossible to include such parameters as Tier level and build time for the center in the regression model.

The impact of Tier level on the price of 1 sq.m can be taken into account by multiplying the CAPEX value on correction factor Kт, the values for which were obtained based on *Table 1*:

Kт = 0.8 for level Tier 2; Kт = 1 for level Tier 3; Kт = 1.8 for level Tier 4.

To take into account the price dynamics over time, the research results presented in paper [11] can be used. These show that the construction cost of 1 sq.m increases by approximately 30% per year.

Thus, the DPC construction cost in year G is determined by the ratio:

$$CAPEX_G = CAPEX \cdot K_T \cdot 1.3^{(G-2013)}.$$

3. Breakdown of DPC maintenance costs

Operating costs for DPC maintenance can be divided into five main groups:

1. Payment for power consumption. In calculating this parameter, one should rely not only on the value of kWh consumed by racks, but take into account the power consumption structure.

2. Rent of premises. This parameter depends heavily on the geographical location of the DPC and vary with time.

3. The payroll budget can depend heavily on the processing centers, irrespective of the level of reliability, on the basis of the operation continuity requirements.

4. Maintenance. The maintenance cost is determined by the composition of the systems used.

5. Other costs: appreciation of equipment, processing center insurance, etc.

Considering the research results of various companies, significant differences in the structure of operating costs

of Russian and foreign processing centers should be noted. In particular, the Russian market is characterized by distribution of costs [1, 12, 13] presented in *Table 5*.

Table 5.

Structure of cost of Russian DPC composition

	Krok	Data-dom	CNews	Radius Group
Payment for electrical power	42%	25%	25%	42%
Rent of premises	9%	24%	20%	16%
Payroll budget	36%	40%	40%	35%
Maintenance	5%	11%	-	7%
Other costs	8%	-	15%	7%

American companies use a different structure of operating costs [9]. The difference is due to a different approach to clustering of costs subgroups among all operating costs, as well as the specifics of the Russian economy, in particular the wage gap, power cost and so on. Nevertheless, in all research the DPC maintenance cost includes expenses involved in electrical power (average 30%) and rent of premises. Typically, DPC maintenance cost also includes personnel costs and maintenance costs. Further articles of expense items for the processing center operation can differ widely.

The operating costs can be derived from the capital costs at the expense of such a key indicator as the DPC power, and subsequently based on the DPC power and power consumption costs.

From analysis of the power consumption structure in various centers [9, 12], it is apparent that the IT equipment used consumes about half of the power used by the data processing center. This means that all DPC racks consume power, and their cost is approximately 15% of all operating costs. At the moment, most DPC suse 5 kW racks for 42U, but the cost of 1 kWh of power in different regions differs widely.

Thus, let us assume that the operating costs are divided into five groups, each of which contributes to the overall cost:

1. Payment for power consumption (~ 30-35%).

2. Rent of premises (~ 15-20%).

3. Payroll budget (~ 25-30%).

4. Maintenance (~ 10-15%).

5. Other costs: appreciation of equipment, insurance, etc. (~ 10-15%).

To estimate the value of the operating costs, you can use a regression model. Before we start developing it, we have to highlight the main principles used to estimate

these costs. Let us consider DPC power as a central variable for calculation, because:

✦ it can be quite accurately determined from the initially claimed technical characteristics (in particular, number of racks and DPC surface area)

✦ costs associated with the payment for electric power are the most notable group of the operating costs.

Thus, let us introduce new variables to generate regression enabling us to estimate the structure of the operating costs:

✧ OPEX – operating costs within a year, dollar

✧ M – DPC power, mW

✧ e – electrical power cost, doll./kW/h (different for each region of Russia).

Let us consider the relationship between the power of the processing center and its characteristics, having constructed appropriate regressions:

● $M = -0.17797 + 0.01192 \cdot N$ ($R^2 = 0.93$, P-value for the coefficient at N is 6.61E-16);

● $M = 0.24135 + 0.002671 \cdot S$ ($R^2 = 0.66$, P-value for the coefficient at S is 2.28E-07).

It is interesting that the specific power of each additional rack in DPC became 11.9 kW. Considering the fact that in the power consumption structure in-house equipment uses about 50% of all power, a generic rack in 42U has a power of 5 kW. This confirms the suitability of the data obtained.

As is clear from the regressions obtained, it is better to use the number of racks to assess the power. In assessing capital costs, it was proposed to build separate regressions for Moscow, the regions and Russia as a whole. In this case, it is inexpedient because such a key index (except for DPC power), as the cost of electrical power is significantly different for each Russian region and should be chosen separately.

In summary, proceeding from the previous analysis of the operating cost structure (about 30% OPEX is accounted for by electric power), the assessment can be conducted by the following formula:

OPEX = M·[365 days]·[24 hours]·e/0.3 or

OPEX = $(-0.17797 + 0.01192 \cdot N) \cdot 29200 \cdot e/0{,}3$

OPEX = $(0.24135 + 0.002671 \cdot S) \cdot 29200 \cdot e/0.3$.

Conclusion

Obviously, all data processing centers differ from each other. Thus, there is no multipurpose tool which could exactly calculate money flows. The proposed procedure makes it possible with appropriate accuracy to estimate the characteristics of data processing center development projects. ∎

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Оценка совокупной стоимости владения центром обработки данных

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Аннотация

В современных условиях наблюдается рост спроса на услуги ИТ-аутсорсинга, что влечет за собой активизацию процессов проектирования и строительства центров обработки данных (ЦОД). Поскольку ЦОД представляет собой сложную и дорогостоящую систему, возникает задача обоснованного выбора будущего проекта на основе показателей оценки затрат, которые могут возникнуть на этапе проектирования и эксплуатации центров обработки данных.

В работе анализируется один из возможных комплексов показателей для оценки затрат на создание и эксплуатацию центров обработки данных. В процессе анализа выявлены основные группы капитальных затрат при создании ЦОД, которые не в полной мере учитывались при оценке суммарного объема капитальных вложений по ранее предлагаемым методикам. В статье предложены регрессионные модели оценки проекта строительства центра обработки по двум показателям. Предложено оценивать капитальные затраты в зависимости от проектируемой площади технических площадок и от проектируемого количества стоек серверов. На основе разработанных моделей проведен анализ строительных площадок центров обработки данных, который показал адекватность модели реальным данным. Были установлены основные группы операционных затрат на содержание ЦОД и предложена регрессионная модель их оценки. На основе регрессионного уравнения предлагается рассчитывать мощность центра обработки в зависимости от площади технической площадки или количества стоек серверов. Стоимость эксплуатации центра обработки данных определяется, исходя из величины мощности. Анализ информации о стоимости эксплуатации различных центров обработки данных достаточно хорошо согласуется с расчетами, полученными на основе разработанной модели.

Предложенные модели позволяют с приемлемой точностью оценить характеристики проекта создания и последующей эксплуатации центра обработки данных.

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Modeling a balanced scorecard of an enterprise: The scenario approach

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Abstract

Implementation of a balanced scorecard in an enterprise requires a significant investment of time and resources. Modeling parameters substantially improves their design process and allows us to specify a situation and to track changes adjusting the strategy in parallel. It is possible to identify and, if necessary, to correct causal relationships of a complex of strategic goals, as well as to pre-define actions, resources, timelines and responsibility necessary to implement the defined goals. In this case, the analysis of scenarios obtained when modeling allows us to choose an optimal trajectory for developing the enterprise over a certain period.

Using of the method of cognitive modeling opens the possibility to create a simple and intuitive algorithm to achieve this goal. This is a safe way to form an image of its future, to see the possibilities and consider the risks before beginning active operations.

This method of modeling facilitates combination of elements of the enterprise's internal and external economic environment into a single system, as well as analysis of the system as a whole and of its separate components without losing the relationships between them and taking into account both quantitative and qualitative characteristics of the processes.

Introduction

The Balanced Scorecard (BSC) methodology was proposed by D.P. Norton and R.S. Kaplan in 1992 to supplement the limited representation of the organization's effectiveness only on the basis of measuring its financial performance. It is proposed to measure in BSC the performance of a company in three additional areas, outside the sphere of finance (customers, internal business processes, training and development) to get a more balanced view of development of the organization [1].

Quality measurement of work in these areas expands the factor space to evaluate enterprise performance. BSC complements the financial parameters system as already accomplished, and also indicates the origin of revenue growth, which clients provide it and why, what key business processes the company should focus on for improvement in order to convey its unique proposition to the client. BSC helps to direct investments and orient work with personnel in this direction, as well as development of internal systems, corporate culture and climate [2].

BSC development entails formulating strategy in several outlooks, setting strategic goals and measuring the achievement of these goals by using indicators. BSC is projected onto the entire organization through development of individual goals within the framework of the already developed corporate strategies and stimulates the understanding by employees of their place in the company's strategy.

By using BSC, it is possible to implement the strategy with regular activities of all units managed through planning, accounting, control and analysis of the balanced scorecard, and motivating staff to achieve them.

When designing BSC, developers actually model situations of implementing possible strategic goals on strategy maps describing scenarios as a set of strategic goals and causal relationships between them. However, the vast majority of tools that implement the concept of Business Process Management (BPM), cannot model BSC for assessment of possible development of processes in the enterprise that would enable us to choose the effective scenario and most precisely match the strategic goals [3, 4].

The situation described exists in the framework of the methodology of "soft" system analysis [5]. Formalization of "soft" systems is not based on accurate quantitative measurements but on qualitative, fuzzy and hypothetical concepts about the system in the form of expert assessments and on heuristic reasoning [6]. The task of management decision-making support in the "soft" dynamic situation is defined as development of a strategy to transfer a situation from its current state to the target on the basis of a subjective model of the situation. This model includes expert measured values of factors of the situation and a functional structure which describes the laws known to the analyst and regularities of the situation observed. This subjective model is recorded as a directed signed graph — cognitive map [7].

1. Proposed methods and approaches

Due to the fact that in BSC there are both quantitative and qualitative characteristics, the estimation of efficiency of the enterprise by modeling becomes an extraordinary task. Analysis of the modeling methods shows that this task can be solved only by cognitive models, which allow us to combine elements of internal and external economic environment of the enterprise into a single system, as well as to analyze the system as a whole and in its separate components without losing the relationships between them. In addition, the model can incorporate both quantitative and qualitative characteristics of processes [8].

When doing cognitive modeling, the following sequence of actions is usually applied [9, 10]:

✦ determination of initial conditions, trends characterizing development of the situation at this stage, which is necessary to ensure the appropriateness of the model scenario to the real situation;

✦ setting desired target directions (increase, decrease) and strength of process trend changes (weak, strong);

✦ selection of a set of measures (combination of control factors), determination of their possible or desired strength and direction of impact on the situation;

✦ selection of a complex of possible influences on the situation (activities, factors) the strength and direction of which must be defined;

✦ selection of observable factors (indicators) that characterize development of the situation is carried out depending on the purposes of the analysis and user's desires.

The aforementioned stages of cognitive analysis are basic and are successfully implemented by using existing software systems, such as "Situation", "Compass", "KIT" (V.A. Trapeznikov Institute of Control Sciences, Russian Academy of Sciences), systems of decision-making support based on cognitive modeling "Igla" [11], the Software System of Cognitive Modeling (SS CM CogMap TTI Southern Federal University) [12] and many others [13]. In the present study we used for our modeling processes SS CM CogMap.

The simplest cognitive model is a sign directed graph — cognitive map [10]:

$$G = <V, E>, \text{ where}$$

V is a vertex set, wherein vertices $V_i \in V$ ($i = 1, 2, ..., k$) are elements of the system under investigation — strategic goals;

E is an arc set, wherein arcs $e_{ij} \in E$ ($i, j = 1, 2, ..., N$) reflect the relationship between vertices V_i and V_j (positive relationship: when increasing the value of one factor, the value of the other increases; negative relationship: when increasing the value of one factor, the value of the other decreases and vice versa).

The cognitive map is a result of cognitive-targeted structuring of knowledge about strategic goals of the enterprise and external environment that allow us to identify and systematize internal and external factors that have quantitative and qualitative certainty (vertices V_i), as well as setting causal relationships (arcs e_{ij}) between them.

The constructed directed graph reflects the influence of factors taking into account arc weights w_{ij} (for example, from interval -10 to $+10$) established by experts. The arc weights can be determined on the basis of functional dependence (if any), as well as a coefficient b_{ij} of linear regressive dependence of factors like $y_j = a + b_{ij} x_i$ [12].

Thus, the direct (quantitative) and indirect (qualitative) influence of factors on the indicators selected for effectiveness evaluation are taken into account. This makes it possible to provide a substantially more complete description of the problem area and resultant effect of implementing certain activities or projects.

2. Example of BSC modeling of a company. Development scenarios

In the beginning of BSC design, a base scenario was determined which includes certain concepts of the BSC model of the enterprise established by expertise and the

relationships between them (*tables 1 and 2*) [14, 15]. The base scenario includes what the developer understands to be a full understanding of the set of the strategic goals of enterprise development.

Table 1.

Concepts of a model

Prospects	Vertexes	Contents of the Vertex
Finance	v_1	Profit
	v_2	Costs
Clients	v_3	Number of clients
	v_4	Client satisfaction
Processes	v_5	Control of construction and installation works (CIW)
	v_6	Purchase of quality materials, components, tools (MV)
	v_7	Timely shipping of MV
	v_8	Optimization of MV inventory
	v_9	Quality of project works
	v_{10}	Accurate project planning
	v_{11}	Introduction of process management
Training and development	v_{12}	Qualified employees
	v_{13}	Creation of a corporate training center
	v_{14}	Development of corporate information systems (CIS)

Figure 1 shows a cognitive BSC model of the enterprise for the base scenario.

The next step is modeling the possible impulse processes in vertexes V of the built card when introducing perturbations (pulses $q_i = \pm 1$) and the variations of the arcs conversion functionality of the cognitive map $f(x_i, x_j, e_{ij})$.

The impulse process on the graph in this software system is described by the formula proposed by F.S. Roberts [16]:

$$x_{v_i}(n+1) = x_{v_i}(n) + \sum_{v_j : e = e_{ij} \in E}^{k-1} f(x_i, x_j, e_{ij}) P_j(n) + Q_i(n+1),$$

where $x_i(n)$, $x_i(n+1)$ — value of parameter x_i at vertex v_i in the simulation moments n and $n+1$ respectively;

$f(x_i, x_j, e_{ij})$ — arcs conversion functionality of the cognitive map (in the particular case it can be function f_{ij} or weight coefficient w_{ij}), where x_i — parameters of vertices v_i, x_j — parameters of vertices v_j, vertex $v_{ij} \in V$, $i, j = 1, 2, ..., k$, e_{ij} — arc reflecting the relationship between vertices v_i and v_j, rcs $e_{ij} \in E$, $i, j = 1, 2, ..., N$;

P_j — value of impulse at vertex v_j;

$Q_i(n)$ — perturbations coming to vertices v_i.

Implementation of this phase is carried out by defining a list of possible control actions on internal sources
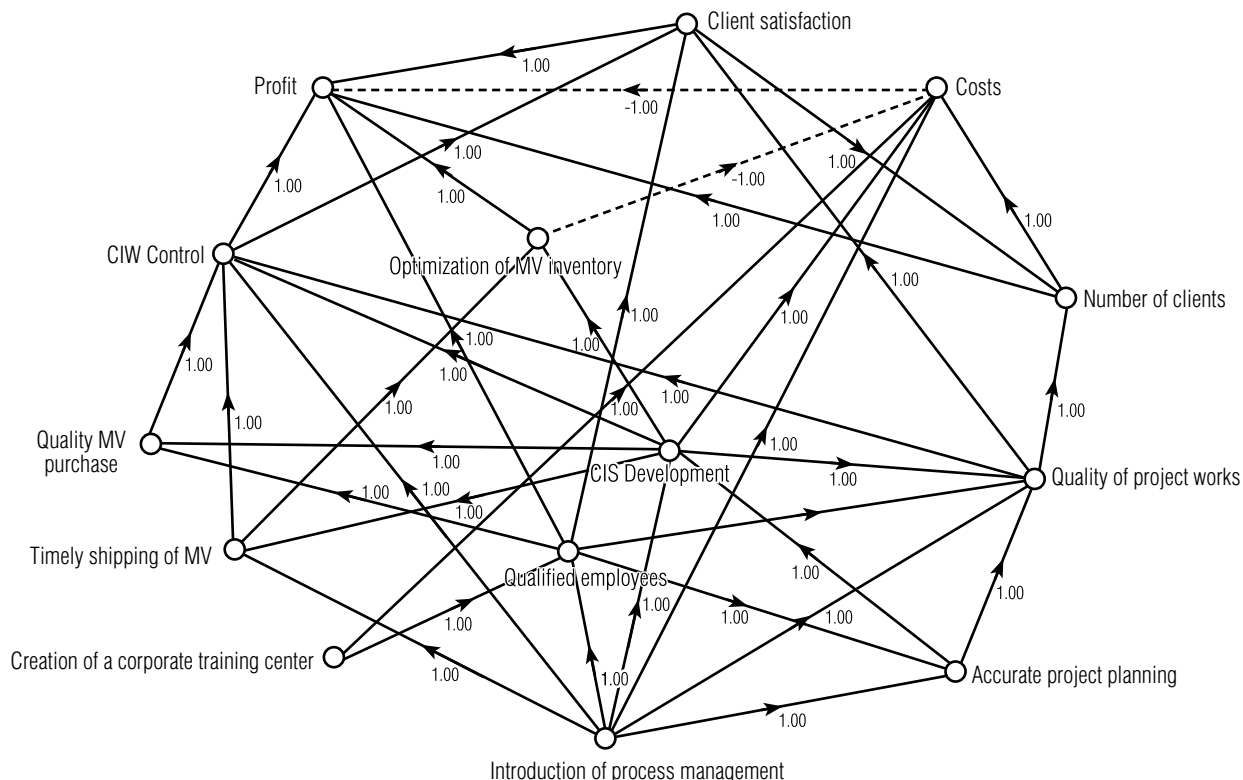
Fig. 1. Cognitive BSC model of the enterprise

Table 2

Cognitive map of a model

	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}	v_{11}	v_{12}	v_{13}	v_{14}
v_1														
v_2	−													
v_3	+	+												
v_4	+		+											
v_5	+			+										
v_6					+									
v_7					+			+						
v_8	+	−												
v_9			+	+	+									
v_{10}									+					
v_{11}		+			+		+		+	+		+		+
v_{12}				+		+			+	+				
v_{13}		+										+		
v_{14}		+			+	+	+	+	+	+				

of factors and further analysis of scenarios of possible development of situations under the influence of simulated perturbations.

The impulse modeling when introducing perturbations q_i at vertex of the cognitive map (v_i) allows us to obtain a sufficient number of realizations of random processes. Existence of such realizations allows us to set up and solve the task of optimum nominal proposed by D.V. Svecharnik for analysis of economic situations selected as the "best" impulse process. These can later be adopted as the desired development strategy of the investigated object [17, 18].

If there is a sufficient amount of statistical or expert data on possible quantitative values of effects (e.g., the volume of investment, volume of production), then when interpreting the results it is possible to speak about a specific quantitative change in the parameters of the vertex of the graph. In this case, a scenario calculation is performed to analyze possible dynamics of development of the process being studied. The arc weights of the graph when qualitative simulation of development scenarios of the object are not set, and impulses are assumed to be equal to fixed values[1]. In this case, the results of impulse modeling reflect only possible trends of the development process.

Thus, under the influence of various disturbances, the values of variables at vertices of the graph may change and the signal received at one of the vertices apply the chain on the rest, amplifying or fading.

As a result of impulse modeling (10 stages), the following process development scenario is received (*figure 2a*).

The graph shows that in this scenario, at first stages all modeling parameters selected for display have a tendency to increase, and at later stages they stabilize.

Other scenarios of processes developing in the enterprise were obtained by successive exclusion of certain strategic goals from the cognitive map and, respectively, from the model:

✦ scenario S_1 − vertex v_{13} "Creation of a corporate training center" is excluded from the base scenario;

✦ scenario S_2 − vertex v_{14} "CIS Development" is excluded from scenario S_1, during which we assumed the implementation process, automation of such business processes as CIW control, quality MV purchase and timely shipping control, optimization of MV inventory, quality control of project works, implementation of programs supporting process management.

The results of the impulse modeling (10 stages) of process development scenarios S_1 and S_2 are shown in the graphs (*figures 2b* and *2c*, respectively).

Visual analysis of the graphs allows us to build a chain of priorities resulting in scenarios according to their effectiveness $S_0 > S_1 > S_2$. Later, the results of development processes can be used for in-depth analysis on the optimum for the selected criteria.

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[1] In our example, to reduce the scale of the display indicators, it is taken that: $q_i = \pm 0,1$
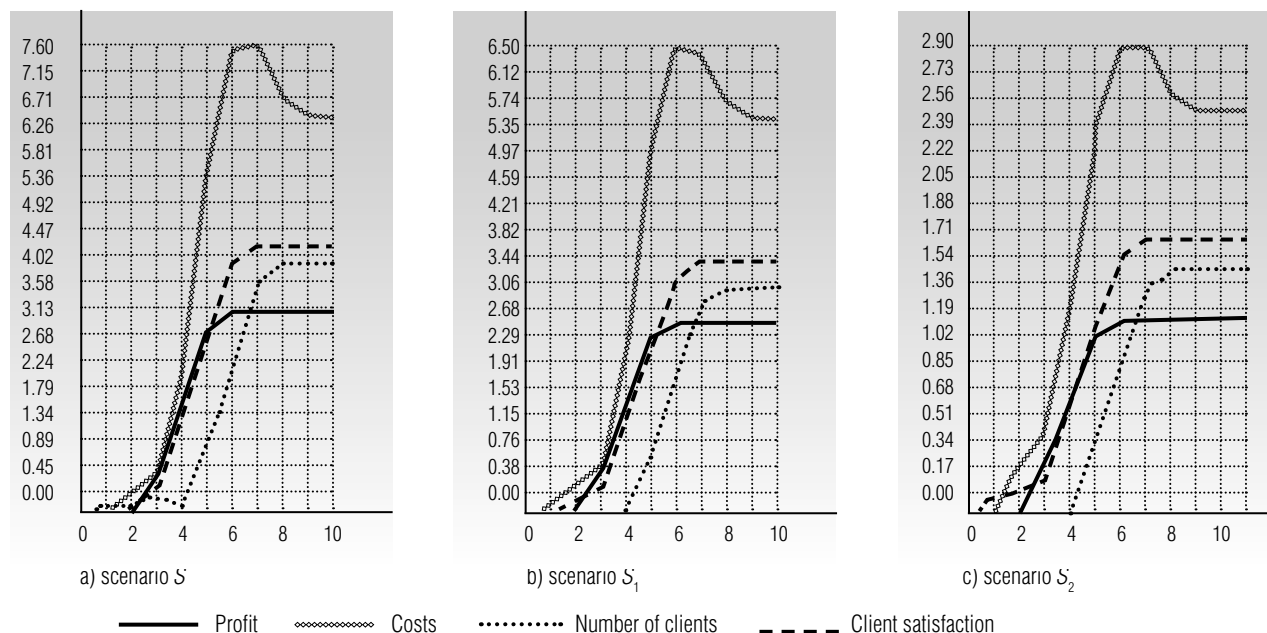
Fig. 2. Dynamics of indicators of BSC modeling of the enterprise for different scenarios

Conclusion

By itself, developing the strategy of an enterprise is a very important stage of management, and starting this process tells us about its maturity and relatively high achievements. Once they have developed a strategy and realized it, enterprises are faced with the need to assess the success of their efforts; particularly as the development process of strategy is cyclical. At this point, the problem of specific change evaluation appears, whether positive or negative, as well as what it should be compared with. In the absence of appropriate data, these questions remain unanswered.

In this case, BSC modeling of the enterprise enables us to:

◇ specify a situation and to track changes in parallel adjusting the strategy;

◇ determine and, if necessary, correct causal relationships of the combination of strategic objectives;

◇ pre-define activities, resources, timing and responsibilities required to implement the established goals.

BSC implementation is a process that requires a significant investment of time and resources. BSC modeling of an enterprise enables us significantly to improve their design process in time and labor. Cognitive modeling is the ability to create a simple and intuitive algorithm to achieve this goal, a safe way to form an image of its future, to see the possibilities and consider risks before beginning active operations.

It has been shown that the BSC cognitive modeling allows us to combine elements of the internal and external economic environment of the enterprise into a single system, as well as to analyze the system as a whole and in its separate components without losing the relationships between them, taking into account both quantitative and qualitative characteristics of the processes. ∎

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Моделирование сбалансированной системы показателей предприятия: Сценарный подход

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Аннотация

Внедрение сбалансированной системы показателей на предприятии требует значительных затрат времени и ресурсов. Моделирование показателей существенно улучшает процесс их проектирования и позволяет конкретизировать ситуацию и отслеживать изменения, параллельно корректируя стратегию. Появляется возможность определить и, при необходимости, откорректировать причинно-следственные связи совокупности стратегических целей, а также предварительно определить мероприятия, ресурсы, сроки и ответственность, необходимые для реализации установленных целей. При этом анализ получаемых при моделировании сценариев позволяет выбрать оптимальную траекторию развития предприятия на определенный период времени.

Использование метода когнитивного моделирования открывает возможность создать простой и понятный алгоритм достижения поставленной цели, безопасный способ сформировать образ своего будущего, увидеть возможности и учесть риски, до начала активных действий.

Данный метод моделирования позволяет объединить элементы внутренней и внешней экономической среды предприятия в единую систему, а также проанализировать систему в целом и отдельные ее компоненты, не теряя взаимосвязей между ними, с учетом как количественных, так и качественных характеристик процессов.

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Construction of a set of harmonized data models in distributed databases based on semantics

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Abstract

When developing projects of integrated enterprise systems with focus on further expansion of functions, it is necessary to remember about continuity of models created and the timeliness of updating them. These refinements relate to the future development of organizations or their units involved in development of information systems (IS) or other software products (SP), extension of functionality of integrated enterprise information systems (IEIS), as well as development environments for design and programming. In this regard, the author proposes to apply the extended level scheme of data and database modeling.

When investigating the functions of each department and building their model description in subsystems (private models), it is possible to identify the same objects for providing functionality. Coherence is one of the advantages of the resulting model, providing typing and standardization of the creative processes of IS.

We use data distribution mechanisms, which today are very topical. The proposed solution is based on a semantic dictionary reflecting the basic terms and concepts of the functional tasks of the business environment of an enterprise being modeled; it allows us to unify the application development and complements the data distribution strategy across the nodes of the enterprise.

This article presents the principles for forming a family of harmonized data models. It provides a formal description of them, the algorithms and the possible core formation practices. The advantages of using this and approaches to possible use are discussed.

Introduction

Issues of distributed databases (data distribution across nodes) are under consideration in quite a lot of designs and mathematical models (e.g., [1−3]). In most cases, the possibilities of optimizing distributed queries of already existing systems are reviewed.

All existing designs in the area of modeling distributed databases can be divided into two common groups considered.

The first and biggest group consists of algorithms for dynamic data redistribution across nodes of the network as described in the works of such authors as D.V. Pav-

lov [4], P.P.-S. Chen and J. Akoka [5], H.I. Abdalla [6]). The disadvantages of this model are the complexity of the algorithms for redistribution, organization of additional computations at the stage of system functioning, locking in databases with respect to user queries at the time of rebuilding its structure, as well as isolation of models from the conceptual domain model.

The second group includes the synthesis algorithms of physical structures of the information system model described in the works of M.T. Ozsu and P. Valduriez [7], A.V. Silin [8], V.V. Beskorovainy [9], V.V. Kulba [2]. These algorithms are based on binding to system users, not functions that affect the system scalability and data consistency in different nodes.

At the same time, none of the considered groups does uses the concept of consistency of models at the design stage of large systems or the concept of a harmonized integration of existing systems based on business functions.

This topic has not lost its relevance today.

Information system which are difficult to model due to their multidimensionality are called large. There are two ways to transfer these systems into a relatively small category. In the first case, it is assumed you use more powerful computing facilities with a developed system of information objects (database) collection, proceed to their direct development and constantly increase. In the second case, it is possible initially, at the level of modeling, to break down the multidimensional system into a set of subsystems of lower dimension while monitoring information communications ensuring the integrity of the system. In this case, distributed system architecture development is originally carried out.

The author proposes a model that at the design stage of the integrated enterprise information systems (*EIS*), on the basis of entity-relationship diagrams (*ERD*), reflects different aspects of activities of subsystems of a large information system that optimizes opportunities for distribution of these data in terms of functional nodes, with allocation of a special node defined as the core of the model. The methodology of distributed database modeling uses a semantic dictionary based on the principles of ontology. The composition of the dictionary includes the information models of systems correlated with each object or business process of the organization model — the business environment. Private models at the moment of their merger into a single system to unify use of the data dictionary form a global entity-relationship diagram (*GERD*).

1. Requirements for the model

In order to ensure the integration of private diagrams into a global entity-relationship diagram, it is necessary to fulfil the following requirements:

1. Entity names representing semantically homogeneous objects in all private diagrams should be consistent;

2. The basic dictionary, based on which the entity names in private diagrams *ERD* are formed, should be compiled on the basis of single classifiers that contain similar subject domain entities and/or their acronyms;

3. Each entity that is part of the private models *ERD* family must have a strong verbal description;

4. The set of entities that comprise the global entity-relationship diagram *GERD* should be submitted in the form of many names without duplication of names and their aliases, i.e. to meet requirements of the first form of set-theoretic representation at the element enumeration level;

5. Relationships between entities in the global entity-relationship diagram *GERD* form a family of overlapping sets of entities, each of which provides support of main and accompanying business processes, control functions and communication functions with the external environment;

6. Selection of entities for the global diagram *GERD* must obey the algorithm for constructing the family of consistent models discussed below.

2. Data model core

Data model core (*DMC*) is a data model consisting of entities of the family of private models bearing the basic characteristics of the subsystems and their functions in the information system management allocated to reduce inconsistencies in distributed data and ensure their coordination.

The data model core is formed by identifying the common entities described in the collection of the *ERD* private models. Subject to uniform rules for naming entities and attributes, the process of creating a *DMC* can be given a formal character through use of set-theoretical operations over a family of entities included in *ERD* private models. The algorithm of *DMC* formation is given below. With regard to the standardized attribute names, their membership in the entities of the *ERD* and *DMC* models agree on the level of projections (in the sense of relational algebra operations), and the completeness of the attributes in each entity of the *ERD* models is specified at the development level of private fully attributed models of design level (*Figure 1*).
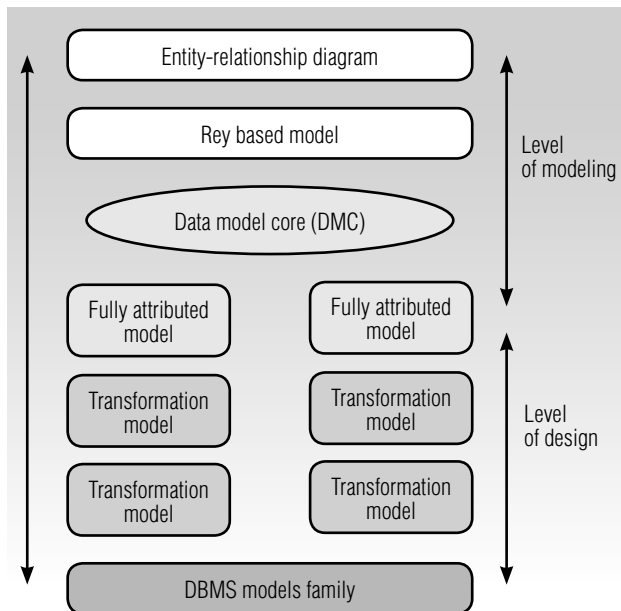
Fig.1. Levels of databases modeling

3. Formalized description of the family of consistent data models

Let us show that there is a formal algorithm to solve both the direct problem of creating consistent models on the base of model data core and private data diagrams that form the basis of separate software subsystems, and the reverse on the basis of private diagrams, to make a data model core of a global system that represents the subject domain. To prove this fact, we will use several provisions of the relational algebra proposed in notation D. Maier [10].

A family of sets is supposed to be given *ERD* composed of sets of entity names E_i private diagrams of data models ERD_i

$$ERD = \{ERD_1, ERD_2, ..., ERD_i, ..., ERD_m\}, \text{ where}$$

$$ERD_i \in ERD, 1 \le i \le m;$$

$$E_i = \{e_{i1}, e_{i2}, ..., e_{ij}, ..., e_{in}\}, 1 \le i \le m, 1 \le j \le n,$$

where m − number of entity-relationship diagrams included in the set *ERD*;
n − number of entities included in each diagram ERD_i.

In addition, let us define a global set *GERD* composed of all entity names e_{ij} included in diagrams $ERD_1, ERD_2, ..., ERD_i, ..., ERD_m$ such that

$$E_1 \in ERD_1, E_2 \in ERD_2, ..., E_m \in ERD_m;$$

$$E_i = \{e_{i1}, e_{i2}, ..., e_{ij}, ..., e_{in}\}, 1 \le i \le m, 1 \le j \le n,$$

i.e. the set $GERD = E_1 \cup E_2 \cup ... \cup E_m =$

$$\{\{e_{11}, e_{12}, ..., e_{1j}, ..., e_{1n}\}, ..., \{e_{i1}, e_{i2}, ..., e_{ij}, ..., e_{in}\}, ...,$$
$$\{e_{m1}, e_{m2}, ..., e_{mj}, ..., e_{mn}\}\}$$

Let us put in correspondence to each of the entity names e_{ij} an interpreting function φ, such that

$$\varphi_{ij} : e_{ij} \in u_{ij}, e_{ij} \in GERD, u_{ij} \in SI,$$

where u_{ij} − a verbal description of the meaning (semantics) of an entity name e_{ij};
SI − a lot of semantic information constituting an interpretation space of elements of the global set *GERD*.

Let us define a functional mapping *F* such that *F*:

$$GERD \times SI \rightarrow DTN,$$

where *DTN* − a lot of twos, such that each entity name e_{ij} is compared to its meaning (semantics) u_{ij}. Then the mapping *DTN* can be interpreted as a dictionary of entity names, where each entity name is endowed with corresponding subject-oriented interpretation (description).

Let us define how to correlate between each other data model core entities *DMC* and private data models entities *ERD* at the development stage of key models. Let us recall that each of the entities is a relationship. Therefore, in the future these entities will be considered as *relations R* defined as subsets of a Cartesian product of family sets A_i.

Let us introduce the following definitions.

Definition 1. Let us call the relationship scheme *R* a finite set of attribute names $\{A_1, A_2, ..., A_n\}$, where each attribute is mapped to the lot D_i called the domain of attribute A_i, $1 \le i \le n$.

It is accepted to designate the domain of an attribute as $dom(A_i)$. The domains are arbitrary non-empty finite (countable) sets.

Let us say $D = D_1 \cup D_2 \cup ... \cup D_n$. Then it is possible to introduce the following definition.

Definition 2. Relationship r with scheme *R* is a final set of mappings $\{t_1, t_2, ..., t_p\}$ *from R* into *D* where each mapping $t \in r$ must satisfy the following constraint: $t(A_i)$ belongs D_i, $1 \le i \le n$. These mappings are called relation schema *r* with scheme *R*. In this case, a tuple is commonly understood as the set of values one for each attribute name from relation schema *R*.

If we interpret *t* as a row in the table, *A*-value $t(A)$ of tuple *t* is the content (value) of tuple *t* in column *A*. Thus, the relation *r* can be viewed as a table with many tuples *t* that satisfy the relation schema *R*.

Based on the definitions above, let us assume that each entity *e* belonging to set *ERD* is based on relation schema

R with set of tuples t, and each specified entity e_{ij} is represented by diagram R_{ij}.

Let a set of entities within the data model core *DMC* be defined some way as e_k^0, $1 \leq k \leq K$, and for each entity a relation schema is defined R_k^0.

Definition 3. Let us assume that entity e_{ij} is fully compatible with entity e_k^0 (*full compatible data*) if the corresponding relation schema R_{ij} and R_k^0 satisfy requirement $R_{ij} = R_k^0$.

Definition 4. Let us assume that entity e_{ij} is partly compatible with (*partial compatible data*) with entity e_k^0, if the corresponding relation schema R_{ij} and R_k^0 satisfy requirement $R_{ij} = S_k^0$, where $S_k^0 \subseteq R_k^0$.

When forming key or fully attributed models of data model core $DMC(KB^0)$ on the basis of private key models $ERD(KB_i)$ (or vice versa), it is necessary to adhere to the following compatibility options:

◆ schema entity-relationship (subsystems) R_{ij} included in a ERD_i , and the relation scheme of the same name analogues R_k^0 in *DMC* may have the property of full compatibility. Otherwise, names and number of attributes, their sequence and domains on which they are defined must be the same;

◆ relation scheme of entities (subsystems) R_{ij} included in an ERD_i, and the relation scheme of the same name analogues R_k^0 in *DMC* may have the property of partial compatibility. Otherwise, in partially-compliant relation schemas, data schema R'_{ij} is a subset of data schema R_k^0, i.e. $R'_{ij} \subseteq R_k^0$, i.e. $R_{ij} = R'_{ij}$.

◆ the relation scheme of entities (subsystems) R_k^0, included in a *DMC*, and the relation scheme of the same name analogues R_{ij} in ERD_i may have the property of partial compatibility. In this case, in partially compatible relation schemas, data schema R_k^0 is a subset of the same name data schema R_{ij}, i.e $R_k^0 \subseteq R_{ij}$.

Of course, the key fields in a compatible data schema from *DMC* and ERD_i should be the same.

When locating attributes in the key models, it is advisable to adhere to the following recommendations. The same name attributes in both schemas must have the same order. This will greatly simplify the data transfer procedure between tables of the data core and private data models when they are processed in a DBMS in the format of fully attributed or transformational models.

The last requirement is not meant to be exclusive. With some complication of the procedure for copying data, the same order of attributes (columns) in the treated models is not required. Moreover, it is possible that in the compared models, the corresponding attribute names are correlated as synonyms defined on the same domains. This renaming of attributes is theoretically permissible and provided for in the relevant theorems of relational theory. Let us note that almost all the models (data transformation services) of data transformation of modern DBMS are built on this basis.

Data transfer in a DBMS between partially compatible entities e_k^0 data model core *DMC* and private data models e_{ij} from set *ERD* is performed by applying the operations of selection σ or projection π to the relationship r_k^0 (tables) with the relation scheme R_{ij} from the set of entities *DMC* and provided by replication mechanisms of modern DBMSs [11, 12].

Selection operation. The result of applying the selection operation σ to relation r is another relation, which is a subset of tuples of relations r with a certain value in the selected attribute. Let r be a relation with scheme R, A is an attribute in R and a is an element of $dom(A)$. Then $\sigma_{A=a}(r)$ is a designation of selection operation ("to select from r tuples in which the value A is equal to a"). Considering the tuples as mappings, it is possible to record: $r'(R) = \{t \in r \mid t(A) = a\}$. Selection operation $\sigma_{A=a,\,B=b}(r)$ on several attributes is possible due to the fact that it is commutative.

A projection operation is an operation which allows us to exchange data between private data models e_{ij} from set *ERD* and r_k^0 from set modal entities *DMC* by cutting the part of attributes from the schema R_k^0 and formation of a new relationship r'_{ij}.

Let r be a relation with scheme R, and X a subset R. Projection r on X written as $\pi_X(R)$ is the relationship $r'(X)$ obtained by crossing out columns corresponding to attributes in $R - X$ (set-difference operation) and with exception of duplicate rows from the remaining columns. Considering the tuples as mappings, $\pi_X(R)$ can be written in the form $r'(X) = \{t(X) \mid t \in r\}$.

4. Formation algorithm of the data model core

The formation algorithm of the data model core looks like the following.

1. Make lot *GERD* of entity names e_i , where $e_i \in R$ by attributing to the entity composition of the first model ERD_1 all entities of other models ERD_2 , ..., ERD_n;

2. Select recurring entity names from set *GERD* registering their names and the number of occurrences of set *GERD*, and bring them to the set of twos G, where each twos is composed of the name entity and the number of occurrences x of this entity in set *GERD*;

3. Perform a ranking of the elements of set G arranging the entities in descending order of number of occurrences x in set G;

4. Select entities that have x occurrences in set G by criterion $x \geq k$, where k is a threshold number of entity names selected by experts for inclusion of their name in the model core DMC.

From the list of requirements above (possibly not complete), it follows that it is possible to satisfy them only on condition of the existence of the expanded business model of the organization – families of models describing its organizational and process structure, business functions, models of the organization's relationship with the external environment and the responsibility function distribution models for performing functionality elements.

Practice of model core forming DMC has shown that in this core, entities representing the following data are often included:

✦ data describing an organizational structure of an enterprise or organization;

✦ data specifying the business direction of the organization;

✦ data specifying a product portfolio or composition of market services of the organization;

✦ data of detailed description of the goods (products) or services;

✦ data specifying a resource component of the organization (personnel, knowledge, material and informational resources);

✦ data supporting management of main and accompanying processes – accounting component of vector of management characteristics;

✦ data defining a classifier of basic documents of the organization and documents comprising its workflow;

✦ data describing external environment including suppliers, customers, consumers etc.;

✦ data, supporting management software of the core DMC;

✦ other data characterizing the industry affiliation of the organization (production, social, administrative, advisory, etc.).

Naturally, the composition of the entities included in the DMC model depends on the profile of the organization, so it is not necessary to include in the model core all of the above groups of entities.

There is another formalized way of entity selection in the DMC core based on the algorithmic approach.

5. Advantages of the proposed approach

Use core advantages are as follows.

Local independence. Getting the data core, each subsystem contains the actual data needed for operation in the appropriate operating environment, at the same time remaining independent from the data core.

The reliability of such a system is enhanced by the independence of subsystems from each other and from the core. Thus, the availability of each of the subsystems increases: low or no productivity of one of them will not affect the availability of the other.

Independence from location. The request receives the required node value from the core and redirects the system to a given piece of data. Such modeling enables developers to unify writing code optimizing it by using agreed schemes of private models.

Independence from fragmentation. Since each subsystem is locally independent and has the relevant data, when the core is restored from fragments, you achieve minimum information loss.

Minimizing the use of networks. Since each subsystem is locally independent, it is possible to minimize the use of distributed queries. As for the tactical and strategic objectives, they, on the contrary, can be more efficiently addressed through the core (*Figure 2*).

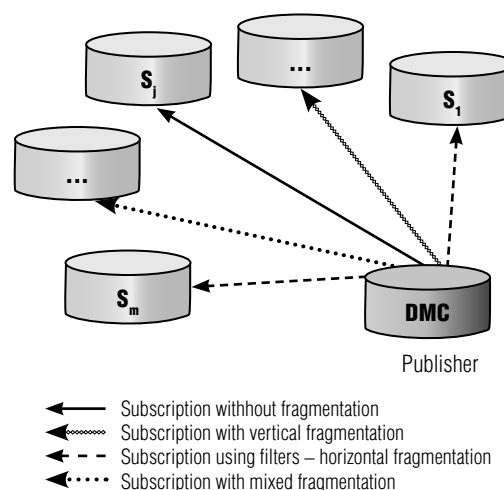*Fig. 2.* Data replication DMC. Possible options for subscriptions

6. Approach to the criterion selection k

Paradoxically, the more information appears in the processes of various subsystems, the less it is susceptible to various changes. In this case, reference to it occurs much less frequently. The value of such information is higher than the cost of its storage. As for information spe-

cific to the tasks of the operational level, it is, on the contrary, more often subject to modification. Therefore, the number of references to such information (such tasks are solved more often than tactical or strategic tasks) increases.

Thus, when solving operational tasks in subsystems, the number of references to the core will increase and the volume of such information will rise. All this can reduce the effectiveness of using distributed data. It is appropriate to store such information in a distributed environment, access to which will take place only when solving this task exactly by this unit.

Therefore, to minimize using networks (the goal of any distributed database), the value of k should be such that the information storage cost of an entity with capacity $|r|$ providing task solving is lower than the cost of necessary references to it (*communication costs* (*CC*) and updating costs (*updating costs* (*UC*). These operations require numerous dispatches of large amounts of data from one node to another (or others) with the aim of necessary updating of the information and expectation of update delay.

The proposed model assumes that there is a distributed database consisting of m sites

$$S = \{DMC, S_1, S_2, ..., S_m\}$$

built on the principles of consistency of models on the basis of the core. The relationship between DMC and S_j has a positive integer of communication costs (*communication costs* $-CC_j$) representing the cost of transfer of data blocks from DMC on S_j, and a positive integer of updating costs (*updating costs* $-UC_j$) that arise with delay l.

For solving a specific task, there are a lot of queries $Q = \{Q_1, Q_2, ..., Q_t\}$ which are the most common queries, and which account for the bulk load processing, the total value of which is defined as QC_j.

Let t be a frequency of solving the task of search, $v -$ data update frequency, $k -$ the number of sites where the entity is distribution.

If we select an entity in the constitution of the core, then the full cost is:

$$TC_c = t\,(CC_j + QC_j) + 2\,v\,UC_j.$$

This is also true for an entity which is not included in the core:

$$TC_s = t\,k\,(CC_j + QC_j) + v\,UC_j.$$

When updating data, it is necessary to update two subsystems − the core and directly the subsystem for which the data is up to date (replication of vertical fragmentation).

Designating $a = t\,(CC_j + QC_j)$, $b = v\,UC_j$ it is possible to see two functions whose growth can be assessed depending on k:

$$TC_s = a\,k + b\,;$$
$$TC_c = a + 2b\,.$$

When $k = 1$, an option of entity placement in one site is more preferable.

When $k = 2$, it is necessary to estimate an amount equal to $a - b$, as well as in time calculations additionally, to take into account the value of l (delay on replication of data from the core).

Excluding such entity from the core, we also reduce the power ($|r|$) of this entity and do not increase costs QC_j.

If system performance is important, then the problem of optimality, according to the proposed model of redistribution, can be defined as minimizing the communication costs in the redistribution process of this relationship from DMC for the required fragments from S.

When $k > 2$, the value TC_s increases the cost of the queries associated with the search for various fragments and data transfer over the network will greatly exceed the efficiency of their storage in one place − the database core.

7. Results

The results of the proposed approach has been tested on test data of an automated control system (*ACS*) of the university in two departments in the first two courses of the I. Razzakov Kyrgyz State Technical University.

When building the model, private models were allocated and a unified vocabulary of attributes was created. When considering the learning process, some sub-models were identified, and the next step model core was established.

All private models are updated at the expense of core data. Therefore, data on directions and plans with their contents as well as about the educational units involved in the educational process will receive the same datasets. The essence of the experiment is to measure what is required for each data management system for the execution of a query to meet the information needs of the *ACS* employee of the university.

For solving problems at the operational level of the system, two options of queries were offered: to the centralized and distributed databases. The following figures show the results indicating a time difference under identical conditions of hardware using a Microsoft SQL Server 2008 on the same computer. Subscriptions are distributed across different databases. The purpose of the request to search for the student by name and number of the record book, outputting a list of subjects and grades at the moment.

Table 1.

Parameters of measurement requests submitted to the centralized database

No	Parameters					
	Total memory (Mb)	Occupied memory (Mb)	Free memory (Mb)	Temperature of the processor (OC)	Voltage of the processor (V)	Current force (A)
1	3071	1559	1512	33	1.072	9.11
2	3071	1569	1502	33	1.072	9.11
3	3071	1569	1502	33	1.072	9.11
4	3071	1572	1499	33	1.072	9.11
5	3071	1618	1453	33	1.072	9.11
6	3071	1571	1500	33	1.064	9.11
7	3071	1563	1508	33	1.128	9.11
8	3071	1578	1493	33	1.072	9.11
9	3071	1570	1495	33	1.072	9.11
10	3071	1583	1488	33	1.072	9.11
average	3071	1575	1496	33	1.077	9.11

Table 2.

Parameters of measurement requests submitted to the distributed database

No	Parameters					
	Total memory (Mb)	Occupied memory (Mb)	Free memory (Mb)	Temperature of the processor (OC)	Voltage of the processor (V)	Current force (A)
1	3071	1630	1441	33	1.072	9.11
2	3071	1581	1490	34	1.072	9.11
3	3071	1585	1586	33	1.072	9.11
4	3071	1559	1512	34	1.072	9.11
5	3071	1578	1493	33	1.072	9.11
6	3071	1579	1492	33	1.072	9.11
7	3071	1621	1450	33	1.072	9.11
8	3071	1581	1490	33	1.072	9.11
9	3071	1578	1493	33	1.072	9.11
10	3071	1575	1496	33	1.072	9.11
average	3071	1586	1494	33	1.072	9.11

The results of the experiment are shown in a graph (*Figure 3*); the query runs 10 times every 30 minutes.
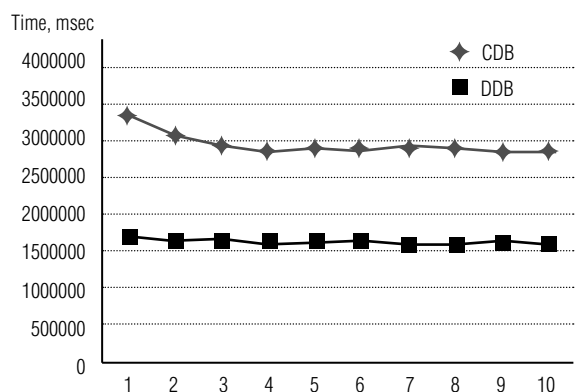
Fig. 3. The results of the experiment

Conclusion

Physically, the architecture can be represented as a family of servers supporting private subschema of data models, one for each category of functional tasks. One of them is the server that contains the schema of the data model core. It is possible to implement one of the following solutions:

✦ the schema of the data model core is the reference model on the basis of which private models of servers are formed;

✦ the schema of the data model core is a model of a database which collects all input and edited data (where they appear) in one place, and then replicates them on private models. In other words, the database assumes

the dispatching functions that support the integrity and non-redundancy of data in private *DBMS*. All functionality of this *DBMS* is directed only to the maintenance of the dispatching functions (replication, maintenance of integrity and non-redundancy).

♦ the schema of the data model core is the base model of DBMS that supports the main business and management functions of the organization implemented in the *IEIS* framework. All other *DBMSs* provide (accompany) the business and management functions of the organization implemented in the form of data for various applications.

There are other possible architectural solutions that are a combination of the listed structures.

Selection of a particular structural organization of data space may be performed either on the basis of expert assessment, or by mathematical solution of the optimal choice task.

The advantages of the proposed approach, first of all, consist in coherence of distributed data, scalability of the system and its rapid adaptation to the changing environment, as well as in the binding of the system not to specific users but to business functions. ■

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Построение семейства согласованных моделей данных в распределенных базах данных, основанных на семантике

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Аннотация

При разработке проектов интегрированных корпоративных систем с ориентацией на дальнейшее расширение функций необходимо помнить о преемственности создаваемых моделей и своевременности их уточнений. Эти уточнения соотносятся с перспективой развития организаций или их подразделений, занимающихся разработкой информационных систем (ИС) или других программных продуктов (ПП),

расширением функциональности интегрированных корпоративных информационных систем (ИКИС), а также развитием сред проектирования и программирования. В связи с этим автором предлагается применение расширенной схемы уровней моделирования данных и баз данных.

При изучении функций каждого подразделения и построении их модельного описания в подсистемах (частных моделях) можно выделить одни и те же объекты для обеспечения функциональности. Согласованность является одним из преимуществ создаваемой модели, обеспечивая типизацию и стандартизацию процессов создания ИС.

В работе используются механизмы распределения данных, которые на сегодняшний день являются весьма актуальными. Предложенное решение на основе семантического словаря, отражающего основные термины и понятия функциональных задач бизнес-среды моделируемого предприятия, позволяет унифицировать разработку приложений и дополняет стратегию распределения данных по узлам предприятия.

В статье изложены принципы формирования семейства согласованных моделей данных, приведены их формальные описания, разработаны алгоритмы и возможные практики формирования ядра. Рассматриваются преимущества использования и подходы к возможному применению.

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The choice of control points of projects taking into account possible change of structure of works

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Abstract

This article is devoted to a problem of controlling implementation of multiscenario projects when it is necessary to provide not one, but several scenarios of performance differing from each other in structure of works. As a control method, we propose carrying out intermediate checks. The task is to determine after which works you have to carry out the checks. A heuristic method of the solution of this task is offered on the basis of an information approach. The places of performance of checks (control points) are defined step by step. Each check is chosen so that it gives maximum information (according to Shannon) concerning the work from those already completed that has been performed incorrectly. In calculations, we consider not only previously established control points, but also probabilities of implementation of various scenarios of implementation of the project under examination.

The solution for two very important practical cases is proposed: when the number of admissible intermediate checks is set and when their number is not set but achievement of a certain level of information completeness of control is required. In practice, the number of intermediate checks is limited from above by the budget for costs of control which is selected by the sponsor of the project. Information completeness of the diagnosis, in turn, is inversely proportional to the risk that the wrong implementation of the project will be revealed only after it ends. In this regard, the project manager demands that information completeness of control be no lower than a certain level.

The results received are sought, first of all, by heads of design offices of large construction companies realizing standard projects in various natural and climatic conditions (in their practice practically all projects are multiscenario). Results can also be requested in the practice of the Ministry of Emergency Situations.

Introduction

The main feature of many projects is uniqueness of the structure of works. At the same time, a project plan is created in advance. For exact implementation of the project plan and to reduce the probability of making a mistake, intermediate inspections (checks) of results of performance of work are carried out. This type of control differs from internal checks of works. Along with the high cost and considerable duration, such control allows us to get the best idea of the correctness of implementation of the project. Furthermore, such checks cover not only concrete work, but also works which logically preceded the one being checked. Considering their characteristics, inspections of this kind can seldom be carried out after each work. There are methods of arranging control points in the

project according to the available plan; however, they are inapplicable in cases when the plan changes during implementation of the project.

One of the possible solutions is to try to foresee possible changes of structure of works. In this case, for some possible situations different scenarios of project implementation are created. This line is characteristic of projects having a possibility of serious change in the structure of works depending on the situation arising during implementation of the project. The standard mathematical model of the project is a directed graph whose tops correspond to works, and arches — to logical links between them. This model does not provide scenarios, but they are necessary to consider when planning the project's possible changes of structure of works at the stage of its realization. The GERT analysis (Graphical Evaluation and Review Technique) [1—3] is devoted to these questions.

Research shows that modern methods of analysis, including GERT, do not touch on the issue of arrangement of control points in multiscenario projects. Because of this, in projects with already allocated resources for carrying out checks with certain places of arrangement, you have to spend additional resources — for re-planning and carrying out other checks on the change in the structure of works.

The research objective is to create a method of arranging control points applicable to multiscenario projects. For this purpose, it is necessary to create a method of arranging control points in a situation when it is necessary to maximize information completeness of control at a set number of control points and when you must define the minimum set of control points providing the required information completeness of control.

1. Theoretical bases for defining control points in projects

Work [4] offers an approach to the choice of the set number of control points of the project based on calculation of entropy of the result of checking according to Shannon. Points are chosen one after another. On each step of the choice from the graph of the project you de-

lete the subgraphs consisting of the tops corresponding to those works whose results influence the result of earlier checked work. The number of points of control is considered initially set, (for example, for economic reasons) and unchangeable. The possibility of a change in the structure of the works is not considered. With these restrictions, an arrangement of control points whereby minimal time is spent searching for incorrectly performed work is considered optimum. On the basis of imitation modeling, it has been established that the heuristic approach offered in work [4] yields results close to optimum.

If there is a need to consider possible changes of structure of works of the project, then the method offered in work [4] is inapplicable. At the same time, as will be shown below, it is necessary not only to reject the assumption of an invariable quantity of control points, but also to change the criterion of optimality. However, in this case it is possible to apply ideas of the information approach.

2. Formal delivery of a problem of formation of control points

Let's consider a standard project about which it is known that it can pass in concrete realization according to various scenarios $\{1, 2, ..., r\}$. Each scenario j can put in compliance the plan displayed by the graph of G_j whose tops correspond to works, and arches — to logical links between them, the "finish to start" type. Let's further call such a model the scenario graph. The scenario j can be realized with probability of p_j. Scenario graphs have common tops. For simplicity, we will consider that there is one general output top. The work corresponding to it is carried out under any scenario and is the final planned work of the project. Works and the tops corresponding to them are numbered, so that each work gets a number once even if it enters several scenario graphs. In total, there is n of works (tops).

An example is given in *figure 1*, where scenarios are possible with probabilities, $p_1 = 0,8$ and $p_2 = 0,2$ to which there correspond the graphs $G_1 = \{1; 2; 3; 4; 5\}$ and $G_2 = \{1; 2; 6; 7; 4; 5\}$.
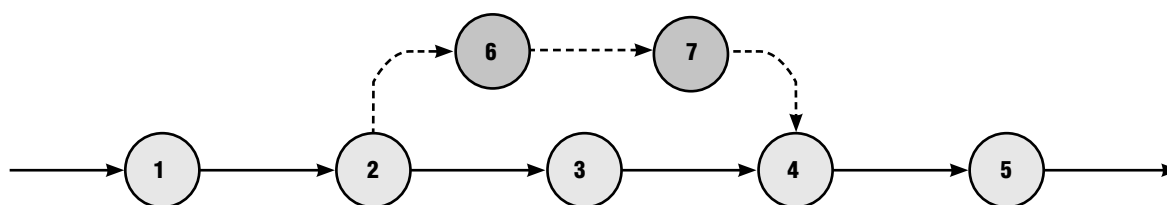

Fig. 1. Example of scenario graphs

After finishing the work, a final inspection of compliance of the result of the project with the established requirements is always carried out. If its result is negative, then we begin the search for the work which was executed incorrectly. At the same time, it is already precisely known according to what scenario the project passed. Accordingly, the scenario graph is unambiguously defined and it is known among what works it is necessary to look to find what was incorrectly executed.

There is an opportunity to plan no more than $m < n$ intermediate checks − control points. A check on the work corresponding to the top of i, yields a negative result if this work is performed incorrectly or if at least one of the previously performed works to which the tops from which the top of i is achievable was incorrectly executed. Let's consider further the setting of a task for two cases: in the conditions of initial and residual entropy. Moreover, we shall consider the information entropy estimated on Shannon's formula [5].

The task: to construct an optimum set of control points of the project.

2.1. Determination of initial information entropy of a multiscenario project

Before implementing the project, we do not know according to which scenario it is necessary to realize it. Accordingly, any of n of the works which are part of it can be executed incorrectly. Let's consider the project as the object of a diagnosis [6]. Let's enter a random variable of N − the number of the work which can be executed wrongly; the area of its possible values − $\{1, 2, ..., n\}$. At the same time, when the project is complete, it is already precisely known according to what scenario j it was realized. If the finishing check yielded a negative result, then only those works to which there correspond i tops belonging in the graph G_j could be performed incorrectly. Accordingly, provided that the realized scenario j is known, entropy of a random variable of N is defined by the expression:

$$H\left(N \mid G_j\right) = -\sum_{i \in G_j}\left(p_{ij} \cdot log_2 p_{ij}\right), \qquad (1)$$

where p_{ij} − probability that work of i is incorrectly performed in case implementation of the project took place according to the scenario j and the finishing check yielded negative result.

Since at the planning stage it is only possible to assume with probability of p_j that the scenario j will be realized, the initial entropy of $H\left(N \mid J\right)$ a random variable of N is the mean value for $H\left(N \mid G_j\right)$ and also is defined by expression

$$H\left(N \mid J\right) = \sum_{j=1}^{r} p_j \cdot H(N \mid G_j). \qquad (2)$$

Let's assume that in our example all works are identical in terms of the possibility of making a mistake. Then at the first scenario ($j = 1$) for all i we have $p_{i1} = 1/5$. In the second scenario ($j = 2$) for all i we have $p_{i2} = 1/6$. As a result, we get:

$$H\left(N \mid J\right) = 0,8 \cdot log_2 5 + 0,2 \cdot log_2 6 = 2,37 \; bit.$$

2.2. Determination of an optimum set of control points in conditions of residual information entropy

Control points are established for the purpose of revealing in a timely manner incorrectly performed work or, at least, reducing uncertainty concerning what work is performed incorrectly if the finishing check yields a negative result. The last will allow us to reduce time searching for incorrectly performed work.

Let's denote the planned set of m of control points through K_m. The number of various possible sets is equal in our case to the number of combinations from $(n - 1)$ on m. To each of them there corresponds the residual entropy of a random variable of N. Let's denote this value as $H(N \mid J) \mid K_m$. Calculation of this value on the basis of the general determination of entropy according to Shannon demands performance of a large number of bulky calculations. At the same time, the author found a rather easy way of her calculation: it is generalization of the method offered in work [7].

To the concrete option of arrangement of the K_m control points at each of possible scenarios j there corresponds a multitude of works whose wrong performance this set cannot define accurately before the concrete work. Let's designate this set through F_j. Only these works create residual uncertainty.

For example, K_2 set = {2; 4} under the scenario $j = 1$ to which there corresponds graph G_1 = {1; 2; 3; 4; 5} defines unambiguously only the wrong performance of work to which there corresponds the top 5. Therefore, F_1 = {1; 2; 3; 4}.

The large set F_j consists of subsets of works the accuracy of which the K_m set defines as incorrectly executed. In other words,

$$F_j = \bigcup f_{lj}. \qquad (3)$$

So, in the case under consideration

$$F_1 = \left\{1; 2\right\} \bigcup \left\{3; 4\right\}.$$

It is possible to show that

$$H[(N|J)|K_m)] = \sum_{j=1}^{r} p_j \times \{ \sum_{f_{ij} \in F_j} [(\sum_{i \in f_{ij}} p_{ij}) \times$$
$$\times log_2(\sum_{i \in f_{ij}} p_{ij})] - \sum_{i \in F_j} p_{ij} \, log_2 p_{ij} \}. \quad (4)$$

Let's carry out on a formula (4) the calculation of residual entropy for our example.

The large set F_1 is defined above. The set of F_2 has an appearance

$$F_2 = \{1;2\} \bigcup \{6;7;4\}.$$

Applying the formula (4), we obtain:
$$H[(N|J)|K_2)] = 0{,}8 \cdot [(4/5) \cdot log_2(2/5) - (4/5) \cdot log_2(1/5)] +$$
$$+ 0{,}2 \cdot [(2/6) \cdot log_2(2/6) + (3/6) \cdot log_2(3/6) -$$
$$- (5/6) \cdot log_2(1/6) = 1{,}03 \, bit.$$

2.3. Maximizing information completeness of controls

As a measure to reduce the uncertainty corresponding to a set of the K_m control points, we propose to reduce entropy of the random variable N with respect to the initial value expressed as a percentage

$$W = \frac{H(N|J) - H[(N|J)|K_m]}{H(N|J)} 100\%. \quad (5)$$

Let's call this size the information completeness of control (ICC).

For the example being reviewed

$$W = (2{,}37 - 1{,}03)/2{,}37 \cdot 100\% = 57\%.$$

Information completeness of control (ICC) is maximum with minimal residual entropy. However, it is precisely ICC which is intuitively a clear measure of quality of the intermediate control of works which the curator of the project can set as the initial requirement.

3. Modeling the distribution of control points

Now, when the problem defining the optimum arrangement of the set number of control points executed earlier is specified by defining the criterion of optimality, it is possible to offer a method for finding the solution.

The method consists of the following steps.

1. On the first step, we will determine the check i_1 to which there corresponds the minimum value of residual entropy of $H[(N|J)|K_1]$. At the same time, we use a formula (4).

2. We also find the second check i_2 from the principle of a minimum of residual entropy provided that i_1 enters a required set.

3. We continue adding to the set taking into account the checks which are earlier included in i_t up to m control points is established.

With such an heuristic approach to searching for possible combinations C_{n-1}^m is replaced with consecutive consideration $(n-1)$; $(n-2)$; ...; $(n-m)$ of options of arrangement. In total for m of steps it is necessary to compare

$$S = m \frac{(2n-m-1)}{2}.$$

options. So, at $n = 100$ and $m = 10$ it is necessary to compare $S = 945$ options, each of which assumes performance of calculations for a formula (4). At the same time, full search would demand comparison of $1{,}73 \cdot 10^{13}$ options of arrangement of control points.

One must pay attention when implementing the project that it is not necessary for each of m planned checks be executed, since some of them can correspond to the works performed under scenarios which will not arise under this concrete implementation of the project.

Presently the author is developing a program complex for realizing the method proposed. One of the main elements of component checking efficiency of the heuristic approach is based on ideas of modeling implementation of the project [8, 9]. As alternatives in terms of efficiency, search methods on graphs [10] are being considered.

If the curator of the project sets the required ICC, then under the conditions formulated in section 2, the problem of arranging control can be formulated as follows: to establish the minimum numbery of control points so that the ICC reached was not less than required.

The problem can be solved by a method similar to the one offered above, with the difference that addition of a set continues until the required ICC is reached or exceeded.

Conclusion

In this article the following new results are set out:

1. We introduced the concept of information completeness of control of the project, realization of which makes several scenarios possible.

2. We have proposed methods of choosing the points of control in multiscenario projects for two cases:

♦ when it is necessary to maximize information completeness of control with a given number of control points;

♦ when it is required to define the minimum set of control points providing the required information completeness of control.

The results obtained will be in demand, first of all, among heads of design offices of large construction companies realizing standard projects in various natural and climatic conditions. In their practice practically all projects [11] are multiscenario. Such results can also be of use the practice of the Ministry of Emergency Situations.

A program complex compatible with the main CASE control facilities projects which observe the principles of the Project Management Body of Knowledge (PMBoK) is being developed for realization of the methods offered by the author. The basis of a complex is provided by methods of imitation modeling for the implementation of multiscenario projects. ■

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Выбор контрольных точек проектов с учетом возможного изменения состава работ

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Аннотация

Статья посвящена проблеме контроля реализации мультисценарных проектов, при планировании которых необходимо предусмотреть не один, а несколько сценариев выполнения, отличающихся друг от друга составом работ. В качестве метода контроля предлагается проведение промежуточных проверок. Задача состоит в том, чтобы определить после выполнения каких работ эти проверки необходимо осуществлять. Предложен эвристический метод решения данной задачи на основании информационного подхода. Он состоит в том, что места выполнения проверок (контрольные точки) определяются последовательно. Каждая проверка выбирается так, чтобы она давала максимум информации (по Шеннону) относительно того, какая работа из уже завершенных выполнена неправильно. В расчетах учитываются не только ранее установленные контрольные точки, но и вероятности реализации различных сценариев выполнения диагностируемого проекта.

Предложено решение для двух наиболее важных практических случаев: когда число допустимых промежуточных проверок задано, и когда их число не задается, но требуется достижение определенного уровня информационной полноты контроля. На практике число промежуточных проверок ограничивается

сверху бюджетом затрат на контроль, который выделяет спонсор проекта. Информационная полнота диагноза, в свою очередь, обратно пропорциональна риску того, что неправильное выполнение проекта будет обнаружено только по его завершении. В связи с этим руководитель проекта требует, чтобы информационная полнота контроля была не меньше определенного уровня.

Полученные результаты востребованы в первую очередь руководителями проектных офисов крупных строительных компаний, реализующих типовые проекты в различных природных и климатических условиях (в их практике мультисценарными являются практически все проекты). Результаты также могут быть востребованы в практике Министерства по чрезвычайным ситуациям (МЧС).

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Multicultural teaching environment: Problems and specifics of knowledge transfer

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Abstract

In contemporary society, teachers often have to deal with a multicultural student audience, both in a traditional format, and in the process of online training. In general, the culture of each country has an impact on the educational process and largely determines is. This, in turn, implies a uniqueness of the educational content, objectives, value and tasks of education, teaching methods, pedagogical discourse, specifics of building an educational path, etc.

This paper traces the relationship between the cultural influence and educational practices expressed in target, value and communication formats. Many teachers call attention to the problem of constructive knowledge transfer in a multicultural teaching environment as the main problem in this context, in addition to the specifics of cognitive, communication and psycho-pedagogical factors. However, the multicultural environment is taken to mean not only national differences, but also a different previous professional "background" (this refers to students of master's programs, etc.).

In this paper, we share the experience of selecting criteria for the possibility of building a cultural cognitive model of communication with students (tactical and strategic methods of developing various types of discourse) in order to optimize the teaching process in the multicultural environment. The criteria based on which a new-generation multicultural educational environment is to be built and which is able to provide constructive knowledge transfer are presented as follows: communication criterion (change of traditional communication forms in the "teacher – student" system), methodological criterion (emergence of the cultural and adaptive methods of work with educational information), content criterion (differentiation and possible inhomogeneity of the educational content in the educational process) and information criterion (development and use of educational resources taking into account cultural specifics of information perception and handling). The aforementioned points, in turn, cannot but affect the transformation of some institutes of the existing information and pedagogical environment.

Introduction

Currently a multicultural student audience is by no means an unusual occurrence. This applies both to the traditional educational format and to remote educational practices. As a result of a survey of teachers carried out by the authors, who have professional experience in a multicultural teaching environment, a number of difficulties have been identified. They are specific in particular to these types of student audiences and have no place in monocultural environments. Among these are various familiar models of communication with a teacher, specific features of presenting teaching information and educational content, decision-making, the attitude towards creative approaches in the course work, an ambiguous understanding of the academic pursuits and terminology, the preferred type of monitoring and measuring materials, etc. In this case, we face such the phenomenon of educational cross-culture. In the context of interest to us, educational cross-culture is a combination of three elements:

1. teacher culture (national and professional);
2. student culture (national and professional);
3. semiotic environment (of educational institution or online resource) and thesaurus of the course unit.

A multicultural education environment is essentially an educational cross-culture. *Educational cross-culture* is an environment covering a collection of heterogeneous information and pedagogical environments which are interacting in the format of educational communication and learning activity and are in a "diffuzziness" state. *The original cross-culture* (culture "native" to an individual) is a semiotic education, discursively expressed in the form of thesauruses and elementary knowledge dictionaries and reflecting the pragmatic specifics of educational communication processes.

In this context, it is reasonable to bear in mind the etic and emic approaches [1] — as approaches providing a means for a both culture-specific and invariable look at the teaching process in the multicultural environment (*Table 1*).

Table 1.

Differences between etic and emic approaches in the educational context

Emic approach	Etic Approach
Studies behavior in the "teacher – student" system within the system	Studies behavior in the "teacher – student" system outside the system
Studies only one culture	Studies a variety of cultures in the comparative context
Criteria are correlated with the internal system characteristics	Study criteria are considered as absolute and universal

The method of cross-cultural study in the educational process has become an "environmental" method expressed in the study of student micro- and macro-environments. Inasmuch as any study of a person's environment is associated with the re-direction — from an individual to the environment and from the environment to an individual — in order to optimize communication processes in the multicultural teaching environment G. Hofstede's parametric model was selected and is presented in the context of educational situations [2]. The purpose of this article is to present possible diffusion processes in educational environments or knowledge transfer in a multicultural environment using the environment-education language, so that the teaching process may predict reactions of people from different cultural environments. The problems of student adaptation to a foreign environment will be understandable if we are able to adjust our professional pedagogical behavior in communication when communication difficulties come up. In other words, a constructive pedagogical action minimizes culture shock and semantic distortions in the communication environment of the educational cross-culture. What does a teacher need to know for this? The answer to this question is one of the research objectives of cross-cultural didactics.

In previous papers, the authors have formulated the basic provisions of cross-cultural didactics, including the concept of a cultural-cognitive personality and audience profile, national and professional styles of thinking, information handling, culture-specific educational discourse, etc. [3, 4]. Depending on these parameters, an adaptive style of teaching can be selected to understand the cultural and cognitive specifics of a student and, thus, the selection of appropriate content, methods, discourse, monitoring and measuring materials, as well as motivational and axiological determination.

1. The problem of knowledge transfer in a multicultural audience. The specifics of communication in the "teacher — student" system in different cultural groups

It is culture that largely determines the communication specifics in the "teacher-student" system. In the East, the teaching process is initiated by the Teacher; in the West, the Teacher acts more as a coach, an accompanying person. The theory of G. Hofstede [2] considers all cultural components and determines their impact on the interaction in the learning process (*Table 2–5*). This data indicates that the higher the power distance, the greater the need to recognize the status of a teacher,

and the fewer discussions can be conducted with him. In the countries with a very high power distance, a teacher should guide every step of a student, whereas when the distance is reduced the initiative passes to the student. The higher the index of community spirit, the worse the activity in group discussions, and a student should be more involved in the process by the teacher. When teaching in masculine society, a competition and result are encouraged; in feminine society, the student's behavior alone is often awarded. In countries trying to avoid uncertainty, the teacher should clearly define the problem as much as possible, the method of its resolution, terms and criteria of evaluation of students. In cultures focusing on a long-term time horizon, students are seeking higher education, primarily because of their commitment to parents and society, and not due to their needs or desires.

Table 2.

**Distance power in the context
of the educational process**

Low distance power	High distance power
Student-centered model. Initiative is encouraged.	Teacher-centered model. Initiative is not encouraged and comes from the teacher.
Communication is initiated by students.	Communication is initiated by the teacher.
The teacher encourages his students to select their own way of leaning.	Students build an educational path based on pre-agreed models.
Students are allowed to come into conflict with and criticize the teacher.	Students are not allowed to come into conflict with and criticize the teacher.
The learning efficiency is a two-sided process. Permanent feedback and interactivity are important.	Learning efficiency depends on the teacher and is subject to him.

Table 3.

**"Individualism – collectivism" parameters
in the educational process**

Collectivists	Individualists
Students speak only when asked and encouraged by the teacher.	Any question may be a discussion in nature.
Individual speaking is encouraged only in small groups	Individual speaking and opinions are always encouraged.
Harmony and emotional comfort are dominant in the learning process.	Confrontation, clash of opinions and disagreements are a normal part of the learning process.
Neither the teacher nor the student should "lose face" in educational communication.	"Loss of face" is a sign of professional incompetence.
The teacher can give an easy time in some cases, making allowance for an individual relation.	Common requirements for everybody.

Table 4.

**Feminine and masculine
measures in the context of educational communications**

Feminine cultures	Masculine cultures
Orientation to an average student	Orientation to the best student
A feature like an ability to adapt to the team is considered to be valuable.	Academic success is considered to be valuable.
Conflict-free and ability to work in team.	Ability to present own achievements and unique character.
Correct behavior, moderation in all things are encouraged.	Distinguishing their team is encouraged.
Students select subjects based on their personal interests	Students select subjects, focusing on their benefit for their future career.

Table 5.

**Index of accepting
an uncertainty in the context
of the educational process**

Low	High
Students feel comfortable outside the schedule and regulations.	Students feel comfortable under a tough schedule and regulations.
The teacher may say, "I do not know."	The teacher must be competent in everything.
A good teacher use plain language.	A good teacher uses academic language.
Students prefer an innovative approach.	Students are encouraged to be accurate and compliant with the predefined requirements.
Teachers consider disagreements on subject issues a stimulating factor.	Teachers consider disagreement on subject issues as personal disloyalty.

During the authors' theoretical research and its practical approval, a model cultural cognitive profile of a student is proposed, consisting of cognitive, emotional and cultural components and enabling us to predict specifics of teaching activity in the multicultural environment. This model enables a student to constructively build his individual educational path, and enables a teacher to ensure necessary adaptation of the educational content, methods, test materials, communication strategies, etc.

2. Cultural – cognitive profile
of a multicultural student audience

The tables above make it possible to construct a cultural-cognitive profile of a student (if necessary, a group) and select techniques of effective teamwork. Thus, it is

possible to select a communication strategy in each sub-group of the study group. Based on these tables, the first class assignments for submission can be also done, e.g. in mathematics using the mother tongue for each student (taking into account that the Russian language is almost a mother tongue in the subgroup of students from CIS countries,). The authors always selected mathematics as the first assignment for submission as a carrier of abstract knowledge with the universal semiotic system and, therefore, having the least amount of stress component in communication with students. The assignment for submission is divided into three levels of complexity; the choice is free. Only some parameters of interest to us in terms of a specific situation of the pedagogical process or research can be taken from the proposed scheme for the model.

As a result, the cultural-cognitive models of students and their teaching style can be "derived". Let us cite as an example a quite limited and polar vision of features of the educational communication in a culturally-specific context. In practice, there can be a good many options (*Table 6*).

3. Philosophy of pedagogical constructivism in a multicultural environment

The educational process in a multicultural environment is provided at three levels

1) "Person-to-person" level (face-to-face communication);

2) "Person-to-electronic educational milieu (EEM)" level (remote or mixed communication);

3) "Adaptive learning content — invariable learning content" level.

At the "person-to-person" level, as mentioned above, depending on the cultural-cognitive profile, a learning style, appropriate content, methods, discourse, monitoring and measuring materials, motivational and axiological determination can be selected. In particular, methods and techniques of interactive didactic support of students in a virtual multicultural teaching environment are of great interest. The consideration of cultural and pragmatic aspects in designing the structure, content and interface of electronic textbooks and teaching environment, implying a set of pedagogical instruments

Table 6.

Criteria for building communication in a multicultural educational environment

Criteria	"Western" cultures	"Non-Western" cultures
Forms and specifics of structuring information	A keynote of verbal-audio and visual type of information perception; tendency to abstraction and search for differences; deductive method of thinking; context independence; information framing - accurate classification and the tree of knowledge	A keynote of audio and kinesthetic style of information perception; tendency to search for similarities; inductive method of thinking; context dependence; information framing - full (not always accurate) picture of what is happening; use of intuition and figurative-narrative discourse
Methods used	Heuristic and problem-search techniques; paradigms of handling teaching information - interactive, discussion, debates.	Receptive and reproductive methods; paradigms of handling teaching information - information broadcast.
Specifics of educational content	Interactive, multimedia available for additions and corrections	Basically, text content which usually cannot be adjusted
Teaching process	Interactive, student-centered	One-sided, teacher-centered
Relation to errors during the learning process	Errors are perceived as a natural part of the learning process	Errors are often associated with "loss of face"
General characteristics of monitoring and measuring materials (MMM)	Selection of one possibility or the author's position on the issue	Aimed at broadcasting specific answers, almost complete lack of assignments showing the author's position and creativity
Communication content	"Low-context" cultures	"High-context" cultures
Discourse objectives and values	Expression of individuality	Maximum unity with the team, preservation of harmony
Dominant styles of discourse	Discussions and debates	Narrative
Dominant emotional parameters of discourse	The message content is primary, the context is secondary. Cognitive style of information exchange. Moderation, self-control	Context plays a dominant role. More significant is "as they say", and not "what they say". Avoidance of discursive confrontations
Typical discursive models	Linear argumentation based on facts. "The fact-fact-fact-conclusion" (induction)	An extensive argumentation. "The conclusion is the evidence" (deduction).

(specifics of motivation, specifics of presenting educational materials, processing, monitoring, and feedback) is of no little interest.

At the "person-to-EEM" level, consideration is given to problems of educational cross-culture in the process of remote or blended learning. It is necessary to highlight the main areas of education "smartization":

◆ developing cultural intelligence, forming and building teachers' competence in the area of cross-cultural didactics, learning problems of the best practices with multicultural audiences;

◆ systematic understanding, the constructive building of an individual educational path in EEM, adapting and using the best international practices in this area;

◆ problem of an appropriate selection of multimedia technologies and teaching methods for various cultural groups;

◆ role of unique features of the learning style when interacting with intelligent tutorial systems.

"Adaptive educational content — invariant educational content". Adaptation means an adaptation of educational information, methods and monitoring and measuring materials to the specifics of a student, as well as compilation of cultural-specific elementary dictionaries on the subject (the ambiguity of terminology in different languages). The invariant content implies a compilation of universal elementary dictionaries in subjects or semantic maps.

Therefore, at the first level of the educational process, it is important to develop cultural intelligence in a multicultural environment as an ability of educational communication subjects to understand little-known contexts, and adapt to them; at the second level — EEM having a cultural intelligence should be designed; and at the third level — an adaptive, in some cases, on the contrary, an invariant educational content (elementary dictionaries of knowledge in subjects) should be formed. This multi-step approach enables us to make the knowledge transfer process in a multicultural environment more constructive.

Based on the definitions of relevant subjects of academic disciplines, their connection can be searched for. The educational experience suggests the need to search for subject domain models (either specific or abstract) allowing us to interpret the knowledge studied. Therefore, generally a problem of intersubject connections in various schools, i.e. secondary and higher, comes up. It should be noted that the concept of "interdisciplinary connection" is more general than the concept of "intersubject connections". The latter concept is interpreted

by us as a connection between the scientific knowledge subjects learned in course units. Therefore, the problem discussed in this article can be extended to the inter-subject connection of mathematics with the mother tongue. In other words, at a level of development of the invariant educational content we design an environment of quite predictable set of reactions. While investigating the language relationship, we solve several tasks: determining the performance level (mathematics), defining an emotional component of learning (interest, sociability, goal setting), preference in decision making. Having obtained answers to these questions, we have the possibility to adjust the communication strategy in the real educational process in accordance with the strategies set out in *Tables 3–5*. The cross-curriculum connection is provided at a level of elementary concepts of the subjects, i.e. mathematics and mother tongue. To do this, an elementary dictionary (if possible) or a minimum first-level dictionary should be created, with a correspondence set up afterwards between them. It is known that the elementary mathematics dictionary studied in secondary school was proposed in the paper [5].

The first-level concepts of a minimum dictionary can be formed in a natural way, using elementary concepts. Depending on the learning needs, it is possible to construct the following levels of concepts using from fifteen to nineteen concepts of the elementary dictionary, thereby forming the following levels of knowledge. Further on, the words from the elementary dictionary should be translated into the verbal environment native for a student through examples, thereby fixing the "islands" of stable knowledge in a learning environment new for him. This, in turn, on the one hand, entails a reduction of the stress load on a student in the learning process, and on the other hand, contributes to the study of theoretical and practical material in the new language environment.

The educational environment model can be built as a linguistic model based on papers of K.S. Fu and L.A. Zade [6]. Let us assume that $A = \{a_1, a_2, ..., a_{13}\}$ are words of the elementary dictionary; B_n is a set of words of the natural dictionary, which are not terms, including a universal mathematical semiotic system Q (i.e. $Q \subset B_n$); P are rules of addition (linking, output) of words from A and B_n. As a result of using the rules for elements from A, set

$$B_T = \left\{ x \mid x = a_i \beta_s, a_i \in B_n, \beta_s \in P, \left(i = \overline{1,13}, |s| < \infty \right) \right\}$$

is formed, representing a set of terms obtained as a result of actions with elementary concepts.

Let us call set $G = \{A, P, ..., B_n\}$ a grammar, words $x = a_i \beta_s$ from a higher level (as compared to the elemen-

tary vocabulary) dictionary; B_T — terminological dictionary contained in the thesaurus. Then

$$L(G) = \left\{ x \mid x \in B_T \wedge A \xrightarrow{G} x \right\}$$

will be called a language (in our case a mathematical language of the secondary school). Let us consider a triple $\langle L(G), T, E \rangle$, where $T = \{T_j\}$ are specific instructional devices and their combinations (set T is finite). In this case, the environments: individuals (microenvironments), teaching environment and other environments are combined. Let us bear in mind that a number of sub-environments are finite, and they tend to vary over the course of time. Therefore, the environment under study will be called an educational individual environment.

4. Design philosophy
of educational web-resources
for a multicultural audience

Based on the analysis of parametric theory of G. Hofstede [2] in the context of the educational process, research of A. Marcus [7], and the theory of cognitive styles of R. Nisbett [8], theoretical guidelines to manage the structure and design of cultural and adaptive Web User Interfaces have been developed. Here are some of them.

The following criteria are specific for the indicator **"Individualism – Collectivism"**:

– **Metaphoras:**

✦ *Individualism:* focuses on actions, instruments, objectives;

✦ *Collectivism:* focuses on connections, relations between the objects, content;

– **Mental models:**

✦ *Individualism:* focuses on product, objective; targeting to implementation and maximization of personal goals and achievements;

✦ *Collectivism:* focuses on the role, duty; models directed to socio-political and cultural goals and underestimating the significance of personal achievements;

– **Navigation system:**

✦ *Individualism:* global (overall) and a customized navigation system; individual areas (popular elections, elections of famous people); the system remains unchanged regardless of the user's role; the ability to customize some functions;

✦ *Collectivism:* contextual navigation system; general and official elections focused on groups of people; the systems vary based on the user role*;*

– **Interaction:**

✦ *Individualism:* keyword search; focuses on active measures; possibility of using several devices; user-customized system.

✦ *Collectivism:* limited interaction; officially adopted devices are available; management depends on the user role;

– **Visual component:**

✦ *Individualism:* emphasis on personal success, benefit, objectives and purposes; success is expressed through materialism and consumerism; image of the younger generation, individuals, and active actions; the content is focused on personal achievements, new and unique products and concepts; expression of personal opinion of the users is welcome, discussions are encouraged; generally, users are not required to provide personal information; low context; active dynamic speech; direct access to the user as an individual*;*

✦ *Collectivism:* emphasis on institutional success, objectives and relationships; success is expressed through representation of social and political programs; images of adult and experienced leaders and groups of people are presented; the content highlights group achievements, history and cultural traditions, contains official slogans and elections; expression of a personal opinion is not encouraged; high context; official terminology; formal style of speech; appeal to the user as a part of society, pronounced unity with others.

For all other Hofstede model parameters, conformity expressed in the influence of cultural indicators on the specifics of user interaction with an Internet resource can be also traced.

Conclusion

The appearance of the information environment has initiated the emergence of educational cross-culture, which, in turn, led to a certain kind of system variations that, in one way or other, are reflected in transformation of elements of managing information and the educational environment. The criteria on which to base a new-formation multicultural educational environment able to provide a constructive knowledge transfer are represented as follows: communication criterion (change of traditional forms of communication in the "teacher – student" system), methodological (appearance of the cultural and adaptive methods of work with educational information), content (differentiation and possible inhomogeneity of the learning content in the

educational process), information (development and use of educational resources taking into account the cultural specifics of information perception and management). These points must affect the transformation of some institutions of the existing information and educational environment and will entail the creation of adaptive tutorial centers, cultural online simulators, as well as intellectual tutorial environments possessing a cultural mental capacity.

This multi-stage approach will enable us to make the knowledge transfer process in a multicultural environment more constructive. ∎

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Поликультурная учебная среда: Проблемы и особенности трансфера знаний

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Аннотация

В современном обществе преподавателям часто приходится сталкиваться с поликультурной студенческой аудиторией, как в традиционном формате, так и в процессе онлайн-обучения. Культура каждой страны, так или иначе, отражается на образовательном процессе и во многом обуславливает его. Это, в свою очередь, влечет специфичность учебного контента, целей, ценностей и задач образования, методов обучения, педагогического дискурса, специфики выстраивания образовательной траектории и т.д.

В настоящей работе прослеживается взаимосвязь влияния культуры на образовательные практики, выраженное в целевом, ценностном и коммуникационном форматах. Многие педагоги в качестве основной проблемы в данном контексте, помимо когнитивной, коммуникативной и психолого-педагогической специфики, выделяют проблему конструктивного трансфера знаний в поликультурной учебной среде. При этом под поликультурной средой мы подразумеваем не только национальные различия, но и различный предшествующий профессиональный «бэкграунд» (это касается студентов магистерских программ и т.д.).

В данной работе мы делимся опытом выделения критериев для возможности построения культурно-когнитивной модели общения со студентами (тактических и стратегических приемов развития различных типов дискурса), с целью оптимизации учебного процесса в поликультурной среде. Критерии, по которым должна строиться поликультурная образовательная среда новой формации, способная обеспечивать конструктивный трансфер знаний, представляются следующим образом: коммуникационный критерий (изменение традиционных форм коммуникации в системе «преподаватель — студент»), методический (появление культурно-адаптивных методов работы с учебной информацией), контентный (дифференциация и возможная неоднородность учебного контента в образовательном процессе) и информационный (разработка и использование образовательных ресурсов, учитывающих культурную специфику восприятия и работы с информацией). Перечисленные пункты, в свою очередь, не могут не отразиться на трансформации некоторых институтов существующей информационно-педагогической среды.

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Control system for ecological modernization of enterprises (on the example of the Republic of Armenia)[1]

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Abstract

The article examines a system for controlling the ecological modernization dynamics of enterprises developed with the help of simulation modelling methods and implemented using the example of the Republic of Armenia (RA). The system has been developed for strategic decision-making directed at modernization of enterprises of RA, their transformation from an initial non-ecological state towards the state of ecologically pure manufacturing.

The main feature of the software developed is an original agent-based model describing the dynamics of the ecological-economics system. The system has been implemented using the AnyLogic platform. This model is integrated with a multidimensional data warehouse, genetic optimizing algorithm (modified for the bi-objective optimization problem of an ecological-economics system), a subsystem of simulation results visualization (Graphs, Google Maps) and other software modules designed with use of the Java technologies.

The target functionalities of the bi-objective optimization problem of the ecological-economics system are minimized integrated (accumulated) volume of total emissions into the atmosphere and maximized integrated (averaged) index of industrial production of the agent's population. The problem was formulated and solved for the first time. Moreover, values of objectives are calculated by means of simulation, as the result of activity of all agent-enterprises in a population and taking into account their internal interaction. The 270 enterprises of RA which are the main stationary sources of emissions of harmful substances were selected for the research. In addition, there is a generalized agent-consumer and the agent-government completing ecological regulation through the mechanisms of penalties, subsidies and rates of emissions fees. The simulation core is the developed algorithm of behavior for each agent-enterprise providing the mechanism of agent transition from an initial non-ecological state towards other possible states. At the same time, control of the evolutionary dynamics of agents is implemented with the help of the suggested genetic algorithm. As a result, the system we developed makes it possible to search Pareto-optimal decisions for a bi-objective optimization problem of the agent-based ecological-economics system.

Introduction

Deciding about a modernization (transformation) of enterprises in the direction of ecologically pure manufacturing (low-waste) is a difficult task that requires you to develop an agent-based simulation model in order to consider the agent-enterprises behavior individually [1−2].

The complex solution for such problem requires the creation of a hybrid intelligent system seeking the best trade-offs among possible decisions on the ecological modernization of enterprises.

It should be noted that such intelligent systems can be built on simulation models aggregated with evolutionary optimization algorithms through the target functions, in particular, with genetic algorithms [3−4].

The simulation modelling [5] is a very effective tool for investigating the dynamics of complex systems and it can be applied in support of a mechanism of the adaptive, in particular, strategical control of such systems [6−7, 13].

Designing simulation models can be based on using together the system dynamics methods [8] and agent-based modelling [9] and as well as on the intelligent integration of developed models with evolutionary algorithms type of genetic algorithms intended for a multicriteria optimization [10].

In modern times, a novel direction is taking shape, which is related to the creation of agent-based simulations for ecological-economics systems [12]. The use of such models to form and visualize Pareto optimal subsets [14] has special interest.

Thus, this work is devoted to an original information-analytical system designed with the use of simulation modelling methods and it is intended for control of the dynamics of the ecological modernization of enterprises as implemented in the Republic of Armenia.

The main users of the system are departments of the government ecological regulation, the Ministry of Natural Resources and Environment, the Ministry of Emergency Situations and other regulators.

Initial datasets have been provided for simulation modeling by the Center of Ecological-Noosphere Studies of the National Academy of Sciences of the Republic of Armenia. The system developed has been published on the Internet and is available on the website *http://smartersim.com/ecmodel.*

It should be noted that at this stage we have investigated only problems of minimization of emissions in the atmosphere without taking note of other components (for example, water pollution, soil pollution, etc.).

1. Simulation of the ecological-economics system

The formal description of the model and bi-objective optimization problem of the ecological-economics system will be considered below. Thus, the system has some target functions. They are the Integrated Volume of Total Emissions (expected and accumulated for the simulation period that equals a period of strategic planning) and the Integrated Index of Industrial Production. The main objective consists in searching for the best trade-offs allowing you to maximize the first objective and minimize the second objective through rational control of the dynamics of transformation of agent-enterprises from their initial non-ecological state toward a target state of ecologically pure manufacturing.

There are 270 agent-enterprises characterized by significant emissions levels, the generalized consumer and agent-government that carry out ecological regulation in the model.

Let's denote:

✦ $j \in \{1, 2, ..., J(t)\}$ — the index of the agents-enterprises having stationary sources of emissions;

✦ $s_j \in \{1, 2, ..., S_j(t)\}$ — the index of stationary sources of emissions of j-th agent-enterprise (if the parameter $\omega_{sj} = 0$, then the s_j-th source of emissions is closed, if $\omega_{sj} = 1$, then the s_j-th of emissions is saved);

✦ $t \in \{t_0, t_0 + 1, ..., t_0 + T\}$ — the simulation time by years (T the strategical planning horizon, that equals ten years: 2016 − 2025);

✦ $\delta_j \in \{1, 0\}$ — the matrix of transitions between possible states of for an j-th agent-enterprise − the *control*

parameter, that sets up with the help of suggested genetic algorithm (if $\delta_j = 1$, the transition from the current state to new stats for an *j*-th agent-enterprise is allowed, if $\delta_j = 0$ the transition is blocked);

◆ $st_j(t) \in \{1, 2, 3, 4\}$ — possible states of an *j*-th agent-enterprise (if $st_j(t) = 1$, it is non-ecological manufacturing, if $st_j(t) = 2$, it is partial modernization, if $st_j(t) = 3$, it is ecologically pure manufacturing, if $st_j(t) = 4$, it is a closed enterprise);

◆ $\lambda_j(t)$ — the share of subsidies in the investment expenditure of an *j*-th agent-enterprise that will be paid in the case of transition to the state of a partial modernization. It is set up by an agent-government ($0 \leq \lambda_j(t) \leq 1$);

◆ $\eta_j(t)$ — the share of penalties in the profit of an *j*-th agent-enterprise that will be paid in case the emission limit is exceeded. It is set up by an agent-government ($0 \leq \eta_j(t) \leq 1$);

◆ $E_j(st_j(t))$ — the total emissions of an *j*-th agent-enterprise that depends on its current state $st_j(t) \in \{1, 2, 3, 4\}$. If $st_j(t) = 1$, the volume of the total emissions is a maximum. If $st_j(t) = 4$, there is no emissions;

◆ E_j — the limit of total emissions for *j*-th agent-enterprises, which is set up for each agent-enterprise individually (taking into account the geographic location, remoteness from settlements and other parameters);

◆ $V_j(st_j(t))$ — the volume of output of an *j*-th agent-enterprise that depends on its state $st_j(t) \in \{1, 2, 3, 4\}$. While the state of the agent is changing, its volume of the output that depends on the production capacity and the production efficiency is changing, too. Production capacity is going down and production efficiency is being increased in the process of the ecological modernization of an agent-enterprise.

◆ $V_j(t-1)$ — the volume of output of an *j*-th agent-enterprise for a previous year;

◆ $\sum\limits_{j=1}^{J(t)} \dfrac{V_j(t)}{V_j(t-1)}$ — the index of the physical volume of industrial production for a population of agent-enterprises;

◆ $\sum\limits_{j=1}^{J(t)} E_j(t)$ — the total emissions for the population of agent-enterprises;

◆ $P_j'(st_j(t) \in 1)$ — the profit of an *j*-th agent-enterprise calculated for the first state of a non-ecological manufacturing;

◆ $P_j''(st_j(t) \in 2)$ $P_j'''(st_j(t) \in 3)$ — the profit of an *j*-th agent-enterprise calculated for the second and the third states of a partial and full state respectively;

◆ $z_j(t)$ — the relative ecological ranking of *j*-th agent-enterprise:

$$z_j(t) = \frac{E_j(t)}{\sum\limits_{j=1}^{J(t)} E_j(t)} ; \qquad (1)$$

◆ $p(t)$ — a small random number (generated by the randomizer);

◆ $\{\tau_1, \tau_2, \tau_3\}$ — the known time delays that relate to transitions to new states (in the range of 1–3 years), which are caused by the inertial process of the ecological modernization.

The suggested algorithm of agent-enterprise behavior is based on analysis of potential advantages of transitions to new states through the ecological modernization if appropriate financial possibilities are available. At the same time, the agent-government can incentivize such transitions, in particular, through the subsidies and penalties, and the growth of emissions fee rates. As a result of this, the ecologically regulated profit will be more for a new state for an agent-enterprise. Hence, the new state is preferable for the agent. On the other hand, the agent-government can restrict such transitions with the help of technological and financial limitations.

If $\delta_j(t) = 1$, the speed of the ecological modernization of an *j*-th agent-enterprise will be maximum, however this also causes reduced production capacities and even the full closure of the enterprise if the ecological laws and limitations are exceeded for some years.

Such an effect for the population of agent-enterprises can cause a reduction of the integrated index of industrial production.

Thus, possible states of an *j*-th agent-enterprise are:

$$st_j(t) = \begin{cases} 1, \text{ if } t \in t_0 \text{ or } st_j(t) \notin \{2, 3, 4\}, \\ 2, \text{ if } \delta_j(t-\tau_1) = 1 \text{ and} \\ \left(P_j''\big(st_j(t) \in 2\big) \geq P_j'\big(st_j(t) \in 1\big) \text{ or } z_j(t) \geq p(t) \right), \\ 3, \text{ if } \delta_j(t-\tau_2) = 1 \text{ and} \\ \left(P_j'''\big(st_j(t) \in 3\big) \geq P_j''\big(st_j(t) \in 2\big) \text{ or } z_j(t) \geq p(t) \right), \\ 4, \text{ if } \delta_j(t-\tau_3) = 1 \text{ and } \left(E_j(t) > E(t) \text{ and} \right. \\ \left. \omega_{s_j} = 0 \text{ for all } s_j \in \{1, 2, \dots, S_j(t)\} \right) \end{cases} \qquad (2)$$

The formula (1) means that each agent-enterprise considers its ecological state regarding the whole population of agent-enterprises.

If growth of total emissions for the agent-enterprise regarding other agents is observed, the probability of its transition to a new state is increasing too.

At the same time, the main factor having an impact on such transition is the estimation of the potential profit in comparison with the current profit which is completed by the agent-enterprise, as well as the external control $\delta_j(t) \in \{1, 0\}$.

We can now formulate the bi-objective optimization problem of the ecological-economics system.

The problem. The need to maximize the Integrated Index of Industrial Production and to minimize the Integrated Volume of Total Emissions for the whole population of agent-enterprises:

$$\begin{cases} \max\limits_{\delta_j(t)} \left[\sum\limits_{t=t_0}^{t_0+T} \sum\limits_{j=1}^{J(t)} \frac{V_j(t)}{V_j(t-1)} \right], \\ \min\limits_{\delta_j(t)} \left[\sum\limits_{t=t_0}^{t_0+T} \sum\limits_{j=1}^{J(t)} E_j(t) \right], \end{cases} \qquad (3)$$

under restrictions:

$$\delta_j(t) \in \{1; 0\},$$
$$st_j(t) \in \{1, 2, 3, 4\}$$
$$0 \le \eta_j(t) \le 1, \, 0 \le \lambda_j(t) \le 1$$
$$j \in \{1, 2, ..., J(t)\}$$
$$t \in \{t_0, t_0+1, ..., t_0+T\}.$$

and other restrictions having a clear economic sense (for example, the limit of investment capital).

In work [1] we see the description of the main model characteristics of the ecological-economics system of the Republic of Armenia in more detail.

The problem (3) was solved with the help of the genetic optimization algorithm that was developed, as modified for application in multi-agent large-scale systems [10]

Such an algorithm is related to the type of the SPEA2 (Strength Pareto Evolutionary Algorithm). Its base implementation is described in the work [11]. In contrast to the previously developed algorithms of SPEA и SPEA2, the genetic algorithm suggested in this work was adapted for the problem of binary control of transitions between possible states of agents. Hence, it takes into account the specifics of multi-agent simulation systems under optimization.

As a result, the minimization of agents target functions (on the level of fitness-functions) is carried out without coding (and decoding) of appropriate chromosomes in the discrete decisions space, limited by possible states of an agent.

The aggregation of the genetic algorithm with the simulation model on the agent level allows us to improve significantly the time efficiency of the procedure for seeking non-dominated decisions (Pareto optimal decisions), because it reduces the length of chromosomes and the population size significantly.

Thus, the use of the suggested genetic algorithm for the control of agent transitions is necessitated firstly by the large-scale optimization problem (the evolutionary dynamics of 270 agents having many of their own parameters is optimized for a horizon of planning equal to 10 years). Secondly, it is necessitated by the specifics of the needed evolution of non-dominated decisions without using the difficult operations of coding and decoding chromosomes, which usually precede operations of crossing over and mutation.

2. The software system developed

The system developed is intended for those seeking the best trade-offs in the context of the bi-objective optimization problem (3) considered and it allows us, in particular:

✦ To simulate *"What-IF"* scenarios for the analysis of effects of different parameters of the government ecological regulation system on the main characteristics of the ecological-economics system (for example, on the dynamics of total volume of emissions; on the number of diagnosed diseases caused by emissions in the atmosphere; on the number of non-ecological, partial ecological, closed enterprises; on equilibrium fee rates for emissions by kinds of emissions, etc.).

✦ To form the subset Pareto optimal decisions to seek the best trade-offs. That means to carry out *optimization experiments* for the bi-objective problem of the ecological-economics system considered, target functions of which are the integrated (accumulated for the strategical planning period) volume of total emissions and the integrated index of industrial production (estimated for the whole population of agent-enterprises).

The following main technologies were applied to develop the information system:

✦ *AnyLogic* – a simulation system which allows you to implement hybrid models based on both system dynamics methods and agent-based modelling methods;

✦ *MS SQL Server* – a data warehouse which is used as a data base for statistical datasets (by agents), as well as for saving (rewriting) and transferring the simulation results;

✦ *JSF (Java Server Faces)* – the software platform for web-applications built on Java program language; it is used for the creation of the user interface which is integrated with the simulations on the AnyLogic (they are independent Java-modules), with the data base of the system (through the *JDBC*), with the developed genetic algorithm (*EJB*) and geographical maps (*Google Maps*) to visualize the evolutionary dynamics of agents.

The aggregated architecture of the software system is represented in *Figure 1.*

It should be noted that the system functionality consists of such blocks as "What-If" experiments; optimization experiments, the visualization of scenarios characteristics of the ecological-economics systems; the visualization of the Pareto-front; the visualization and analysis of local decisions which can be picked up on the front; the visualization of the evolutionary dynamics of agent-enterprises on the geographical map.

The respective information is represented on the web-site of the system in more detail *http://smartersim.com/ecmodel.*

3. Results
of simulation modeling

The main result of the simulation modeling is the Pareto-front that was formed with the help of the suggested genetic algorithm for the bi-objective optimization problem of the considered ecological-economics system in the Republic of Armenia (*Figure 2*).

As shown in the *Figure 2*, the best decisions from the government point of view are decisions on ecological modernization (the matrix $\delta_j(t) \in \{1, 0\}$, $j \in \{1, 2, ..., J(t)\}$) characterized by an Integrated Volume of Total Emissions which does not exceed 1.5 million tons and an Integrated Index of Industrial Production which is more than 100%, meaning positive manufacturing growth.

It should be noted that investigations of different scenarios for the development of the ecological-economics system of the Republic of Armenia have been completed. They include the scenario *without modernization* ($\delta_j = 0$ for all $j \in \{1, 2, ..., J(t)\}$), the scenario of *"fast" modernization* ($\delta_j = 1$ for all $j \in \{1, 2, ..., J(t)\}$), and the scenario of the *"Pareto optimal modernization"* $\delta_j(t) \in \{1, 0\}$ calculated with the help of the suggested genetic algorithm.

As the result of the simulation, we obtained the best scenario for the ecological-economics system: the scenario of the *"Pareto optimal modernization"*, whereby the Integrated Volume of Total Emissions has been reduced by 25% compared with the initial scenario (without modernization) while assuring positive growth of the industrial production (when the Integrated Index of Industrial Production is more than 100%).
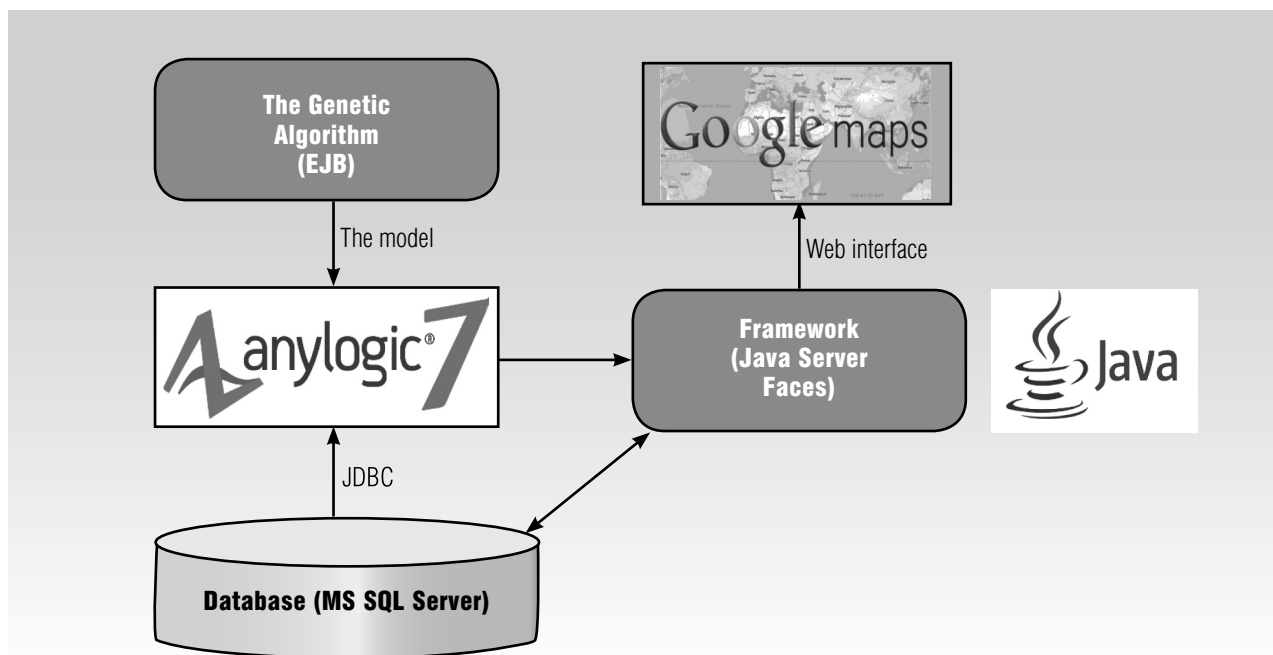

Fig. 1. The aggregated architecture of the software system

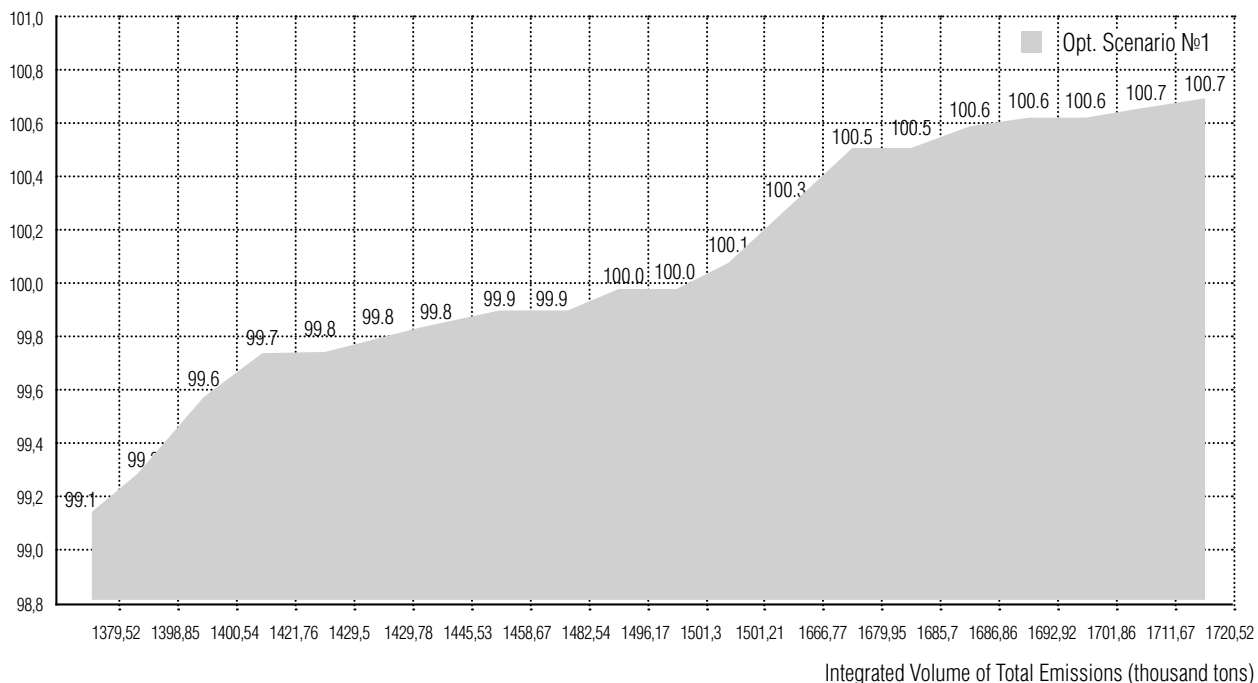Integrated Index of Industrial Production (%)

Fig. 2. The Pareto-front for the bi-objective optimization problem of the ecological-economics system

Conclusion

Thus, we developed a new software system which is intended for researching the impact of important parameters of government regulation on the main characteristics of the ecological-economics system, and it is being implemented in the Republic of Armenia. The software system can be adapted for other countries and regional ecological-economics systems if the datasets required are available. The feature of the system we created is the developed agent-based simulation implemented with the AnyLogic platform and integrated with the suggested genetic algorithm, data warehouse, and a geographical map like Google Map to visualize the evolutionary dynamics of agent-enterprises. The results obtained confirm the existence of optimal scenarios for ecological modernization that significantly reduce the level of total emissions into the atmosphere while safeguarding positive dynamics of industrial production. ∎

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Система управления динамикой экологической модернизации предприятий (на примере Республики Армения)[1]

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Аннотация

Статья посвящена системе управления динамикой экологической модернизации предприятий, разработанной с использованием методов имитационного моделирования и реализованной на примере Республики Армения (РА). Система предназначена для обеспечения поддержки принятия стратегических решений по модернизации предприятий РА с целью их трансформации из исходного неэкологического состояния в направлении экологически чистого (малоотходного) производства.

Особенностью разработанного программного комплекса является, прежде всего, оригинальная агентная модель, описывающая динамику эколого-экономической системы, реализованная с использованием

платформы AnyLogic. Данная модель интегрирована с многомерным информационным хранилищем, генетическим оптимизационным алгоритмом (модифицированным для задачи бикритериальной оптимизации эколого-экономической системы), подсистемой визуализации результатов моделирования (графики, карты Google Maps) и другими программными модулями, спроектированными с использованием технологий Java.

Впервые сформулирована и решена бикритериальная оптимизационная задача эколого-экономической системы, функционалами которой являются минимизируемый интегрированный (накопленный) объем совокупных выбросов вредных веществ в атмосферу и максимизируемый интегрированный (усредненный) индекс физического объема выпуска (популяции предприятий). При этом значения целевых функционалов вычисляются с помощью разработанной имитационной модели как результат деятельности всей популяции агентов-предприятий, с учетом их внутреннего взаимодействия. Для исследования были отобраны 270 предприятий РА, являющихся основными стационарными источниками выбросов вредных веществ. В модели имеется обобщенный агент-потребитель, а также агент-государство, реализующий экологическое регулирование через механизмы штрафов, субсидий и ставок платежей за выбросы. Ядром модели является разработанный алгоритм поведения каждого агента-предприятия, обеспечивающий механизм перехода агента из исходного неэкологического состояния к другим возможным состояниям. При этом управление эволюционной динамикой агентов осуществляется с использованием предложенного генетического алгоритма. В результате разработанная система позволяет осуществлять поиск оптимальных по Парето решений для бикритериальной оптимизационной задачи рассматриваемой эколого-экономической системы агентного типа.

Ключевые слова: агентное моделирование, имитационное моделирование, эколого-экономическая система, генетические алгоритмы, многокритериальная оптимизация.

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✦ The abstract should be informative (no general words), original, relevant (reflects your paper's key content and research findings); structured (follows the logics of results' presentation in the paper)

✦ The recommended structure: purpose (mandatory), design / methodology / approach (mandatory), findings (mandatory), research limitations / implications (if applicable), practical implications (if applicable), originality / value (mandatory).

✦ It is appropriate to describe the research methods/methodology if they are original or of interest for this particular research. For papers concerned with experimental work the data sources and data procession technique should be described.

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✦ Conclusions may be associated with recommendations, estimates, suggestions, hypotheses described in the paper.

✦ Information contained in the title should not be duplicated in the abstract. Authors should try to avoid unnecessary introductory phrases (e.g. «the author of the paper considers...»).

✦ Authors should use the language typical of research and technical documents to compile your abstract and avoid complex grammatical constructions.

✦ The text of the abstract should include key words of the paper.

KEYWORDS are presented in native language and English. The number of key words / words combinations are from 6 to 10 (separated by semicolons).

FORMULAE should be prepared using Math Type or MS Equation tool.

FIG.S should be of high quality, black and white, legible and numbered consecutively with Arabic numerals. All Fig.s (charts, diagrams, etc.) should be submitted in electronic form (photo images − in TIF, PSD or JPEG formats, minimum resolution 300 dpi). Appropriate references in the text are required.

REFERENCES should be presented in Harvard style and carefully checked for completeness, accuracy and consistency.

The publication is free of charge.

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ШРИФТ, ФОРМАТИРОВАНИЕ, НУМЕРАЦИЯ СТРАНИЦ

ШРИФТ – Times New Roman, кегль набора – 12 пунктов, полуторный интервал, форматирование по ширине. Нумерация страниц – вверху по центру, поля: левое – 2,5 см, верхнее, нижнее и правое – по 1,5 см.

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СВЕДЕНИЯ ОБ АВТОРАХ приводятся на русском и английском языках и включают следующие элементы:

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✦ должность, звание, ученая степень каждого автора

✦ полное название организации – места работы каждого автора в именительном падеже, полный почтовый адрес каждой организации (включая почтовый индекс)

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✦ Объем – 200-300 слов.

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