ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

METHODS AND SOFTWARE FOR SIMULATION OF OPTIMAL RENEWAL OF CAPITAL ASSETS

[1]ASKAR BORANBAYEV, [2]SEILKHAN BORANBAYEV, [3]YURI YATSENKO, [2]YERSULTAN TULEBAYEV

[1]Nazarbayev University, Nur-Sultan, Kazakhstan

[2]L.N.Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan

[3]Houston Baptist University, Houston, USA

E-mail: [1]aboranbayev@nu.edu.kz, [2]sboranba@yandex.kz

ABSTRACT

This article surveys recent developments in the optimal renovation of capital assets and introduces new asset replacement algorithms under limited forecast about changing uncertain costs. The costs include operating costs of the current asset in use and the replacement cost (price of new assets). The evolution of those costs depends on external technological, economic, and environmental factors. The open innovation increases the importance and complexity of technological change. We study new modifications of the classic Economic Life replacement method for uncertain costs. The analyzed algorithms work well for arbitrary age-distribution of deterministic or stochastic operating cost. We demonstrate their superior performance in various scenarios of improving technology reflected in decreasing operating and new asset costs. Numeric experiments are provided, and managerial implications of the obtained outcomes are discussed.

Keywords: *Improving Technology, Capital Asset, Renovation, Modeling, Optimization.*

1. INTRODUCTION

This article provides a theoretical analysis of asset replacement methods in the context of an imperfect and uncertain technological forecast. On the basis of the developed methods, a software system was created for modeling the optimal renewal of capital assets. Serious research has been devoted to the problem of asset replacement, in particular, works [1-29]. It is known that the Infinite-Horizon (IH) method with perfect technological forecast is the ideal benchmark for asset replacement.

There are various methods for replacing assets, but most of them are not applied in practice. This is due to lack of data, time and other constraints. Therefore, the Economic Life (EL) method is recommended in the engineering economics literature (7, 21, 22). It is considered a simple and reliable method for practical application and allows you to find the optimal solution to replace a single asset.

On the other hand, it is known that if the cost of maintaining assets grows, then the Economic Life method yields different results from replacing Infinite-Horizon. Therefore, with the improvement of technology, the solution obtained by the Economic Life method may not be optimal.

To eliminate this disadvantage, the authors of [10] modified the classic Economic Life method - they introduced a corrected capital return ratio. It is shown in [10] that if exponential technological changes equally affect the operating costs and the value of new assets, then the modified Economic Life method and the Infinite-Horizon replacement produce the same replacement policy with an equal lifespan.

Further, in [12], this result was extended for the problem of asset replacement at stochastic costs.

At present, two alternative methods are used to analyze the replacement of a single asset at uncertain costs - minimizing costs on an infinite horizon and the problem of optimal stopping.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

In this article, to account for the uncertain operating costs, a stochastic modification of the Economic Life method is proposed. An algorithm is constructed that is convenient to use in practice.

2. METHODS: ASSET RENOVATION UNDER IMPROVING TECHNOLOGY

Let us consider a firm that needs to periodically replace a single asset with new assets that perform identical operations but have better replacement costs because of open innovation. We will describe this replacement process in the continuous time $0 \leq t < \infty$. The changing technological and economic environment is represented by the following functions:

(1) the *cost* $P(t)$ (the purchase price and installation cost) *of a new asse*t at time t (of vintage t);

(2) the *operating and maintenance (operating) cost* $A(t,u)$ for the asset bought at time t;

(3) the *salvage value* $S(t,u)$ at time u of the asset bought at time t, $0 \leq S(t,u) < P(t)$.

Then, the variable $a = u-t$ is the age of the asset, $0 \leq a \leq M$, where M is the maximal physical service life of assets.

The improving technology leads to the availability of newer assets that require less maintenance and/or are less expensive, so $P(t)$ and $A(t,u)$ decrease in t. This phenomenon is known as the technological *change* (*TC*). The operating cost $A(t,u)$ usually increases in the asset age $u-t$ (as the asset becomes older) because of physical deterioration, however, it can also decrease because of learning. In general, the function $A(t,u)$ can describe various hypotheses of deterioration and learning.

To calculate actual replacement costs over a finite horizon, the replacement theory commonly uses the *capital recovery factor* $R(r,T)$ that converts the present value of a certain cost over a specified future interval into the sequence of the *equivalent annual costs*. Under the assumption of continuous compounding, the *annual* capital recovery factor over the interval $[0,T]$ is

$$R(r,T) = \frac{r}{1-e^{-rT}}, \quad (1)$$

where $r > 0$ is the industry-wide *discount rate*.

To describe the sequential replacement of a single asset with new asset, we introduce the endogenous lifetime L_k of the k-th asset, k=1,2,…. Then, the time τ_k of the replacement of the k-th asset with the (k+1)-th asset is

$$\tau_k = \tau_{k-1} + L_k = \sum_{j=1}^{k} L_j, \quad (2)$$

For clarity, we assume that the first asset is purchased at time $t = 0$ and will be replaced at the end of its lifecycle, then $\tau_0 = 0$ and $\tau_1 = L_1$.

The asset replacement cost: The present value of the total replacement cost of the k-th asset, k=1,2,…, over its future lifetime L_k is calculated at a given industry-wide discount rate r>0 as

$$PW_k(L_k,\tau_k) = e^{-r(\tau_k+L_k)}\left[P(\tau_k+L_k) - S(\tau_k,\tau_k+L_k)\right] + \int_{\tau_k}^{\tau_k+L_k} e^{-ru}A(\tau_{k-1},u)du, \quad (3)$$

[7] The first term of (3) represents the discounted cost of the new asset minus the discounted salvage value of the current asset, and the integral is the discounted operating costs over the future lifetime of the current asset.

The goal is to construct replacement methods that use a limited technological forecast data but delivers the same results (at least, the time of first replacement) as for a perfect technological forecast. Correspondingly, our ideal (benchmark) problem is the infinite-horizon optimization. Next, we provide mathematical formulations of the replacement methods under study.

2.1 Infinite-Horizon (IH) Replacement

The IH replacement method [23, 24] assumes the external technological parameters P, A, and S to be known on the infinite horizon $[0,\infty)$ and determines the infinite optimal sequence of consecutive asset lifetimes L_k, k=1,2,…, that minimizes the present value of the total replacement cost over $[0,\infty)$:

$$PW_\infty(L_1^*, L_2^*, \ldots) = \min_{L_k, k=1,\ldots;\ 0<L_k\leq M} PW_\infty(L_1, L_2, \ldots), \quad (4)$$

$$PW_\infty(L_1, L_2, \ldots) = \sum_{k=1}^{\infty} PW_k(L_k, \tau_k), \quad (5)$$

where PW_k is given by (3) and τ_k is determined from (2).

In contrast, the below replacement methods work in the case of a limited technological forecast. Namely, we assume that the technological parameters $P(t)$, $A(t,u)$, and $S(t,u)$ are known for $0 \le t \le u \le T < \infty$ on some finite future interval [0, T], where the value T should not be less than the future unknown lifetime L_1 of the current asset. For example, T may be the maximum physical lifetime M of assets.

2.2 Economic Life (EL) Replacement Method

The EL method determines the lifetime L_1 that minimizes the *equivalent annual cost (EAC)* of the first asset replacement [21]

$$C_1(L_1) = R(r, L_1) PW_1(L_1, 0), \qquad (6)$$

where $R(r, L_1)$ is defined by (1) and PW_1 is given by (3). By the EL method, the first optimal lifetime EL_1 is determined as

$$EL_1 = \arg\min_{0<L\le M} C_1(L). \qquad (7)$$

To find the first optimal lifetime EL_1, it is enough to know the cost $P(t)$ and the sequences $S(0,t)$ and $A(0,t)$ over the future interval [1, EL_1] only.

In the general case, the EL method produces different optimal lifetimes EL_1, EL_2,…, for sequentially replacements k=1,2,3,… of the asset. In engineering practice, finding the first optimal lifetime EL_1 is the most relevant task.

A common consensus in the replacement theory is that the EL method does not take technological change into account. This is true only partially. Indeed, the above version (6) of the EL method assumes replacement at the end of the current asset lifecycle and so, in fact, considers possible technological improvement as the change of the new asset cost $P(\tau_k + L_k)$. At the same time, the EL method (6)-(7) does not consider improvements in the operating cost at all. Next, we describe a modified method that addresses this drawback.

2.3 Modified EL Method

To address continuous technological change, we introduce the *efficient* capital recovery factor

$$\hat{R}(r, c, L) = R(r + c, L), \qquad (8)$$

where c is an *aggregate TC rate*. The choice of the rate c for various types of TC should be provided based on the comparison of the factual and desired properties of the replacement methods. Specifically, using $\hat{R}(r,c,L)$ instead of $R(r,L)$ in the EL algorithm significantly improves its efficiency.

The *modified EL method* determines the lifetime L_1 that minimizes the corrected *EAC* of the first asset replacement

$$L_1 = \arg\min_{0<L\le M} \hat{C}_1(L),$$
$$\hat{C}_1(L) = R(r + c, L) PW_1(L, 0), \qquad (9)$$

in which $\hat{R}(r,c,L)$ is used instead of $R(r,L)$ as in (6).

3. RESUTLS: COMPARATIVE ANALYSIS OF ALGORITHMS

All above replacement methods are equivalent in the *stationary environment with no technological improvement* when the asset costs do not depend on the current time. The optimal replacement policy in this case is known as the *like-with-like replacement* and does not depend on time as well. Namely, under stationary asset costs and an arbitrary age-dependent deterioration, the IH, EL, and modified EL algorithms produce the same first asset lifetime L. In the IH method, all lifetimes are the same: $L_k = L$ for $k = 2,3,…$.

Next, let the salvage cost $S(t,u)$ be negligible, and the purchase cost $P(t)$ and the operating cost $A(t,u)$ follow the *exponential technological change (TC)* with different rates c_p and c_q:

$$P(t) = \overline{P} e^{-c_p t}, \qquad A(t,u) = f(u-t) e^{-c_q t},$$
$$S(t,u) = 0, \qquad 0 \le t \le u \le T, \qquad (10)$$

where the function $f(u–t) = f(a)$ describes an *arbitrary deterioration profile* of the asset with its age $a = u–t$. The exponential TC (10) with the same rates $c_p = c_q$ is referred to as *proportional*, then technological improvement affects both asset costs equally. Otherwise, TC is called *non-proportional* (at $c_p \ne c_q$), see [10, 13, 25].

Let us consider the case of the proportional exponential TC: $c_p= c_q= c > 0$. Then, both the IH and modified EL algorithms produce the same first asset lifetime L^*, found from the nonlinear equation

$$\frac{1-e^{-(r+c)L}}{r+c} f(L) - e^{-cL}\int_0^L e^{-ru} f(u)du = Pe^{-cL}. \quad (11)$$

The optimal lifetimes of the consecutively replaced asset in the IH replacement (4)-(5) are equal: $L_k=L^*$, $k=1,2,\ldots$,

This result has essential practical implications. If the observed technological improvement follows the proportional rule, then the modified EL method delivers exactly the same optimal asset lifetime over the infinite horizon *for arbitrary age-dependent deterioration profile* $f(u)$ of the operating cost.

4. METHODS: ASSET RENOVATION UNDER COST UNCERTAINTY

Another important issue in the asset replacement theory and practice is the uncertainty of asset costs [17, 18, 20]. When a firm uses many identical assets that vary in operating costs, it naturally creates the uncertainty in future operating cost for a specific asset in use.

Here we offer a practical replacement technique based on the classic EL method (6)-(7) to take the uncertainty of operating cost into account. The suggested algorithm calculates the optimal asset lifetime for any age-dependent distribution of stochastic operating cost. Methodologically, our paper expands [19] who introduces and analyzes a deterministic approximation of the random time of asset replacement under uncertain cost using real option approach.

4.1 Results

In this section, we consider a stationary environment when the asset costs do not depend on current time: $P(t) = P$, $A(t,u) = f(u-t) = f(a)$, $S(t,u) = 0$. We assume that the operating cost $f(a)$ stochastically increases in its age a as the asset becomes older. To describe the cost uncertainty, we introduce the *continuous probability distribution* $fs(a)$ of the operating cost for the assets of age $a\in[0, M]$, with the mean $\mu(a)$ and standard deviation $\sigma(a)$.

4.2 Stochastic EL algorithm

In the case of uncertain cost C in (1), a simple and natural *stochastic* generalization of the EL replacement method is to minimize the *expected* annual replacement cost

$$L = \arg\min_{1\le L\le M} E[PW(L)], \quad (12)$$

where $E[\ldots]$ is the *expectation operator*. Following [2], we refer to the optimal L in (12) as the *proxy replacement time*.

Substituting (12) into (3) and using standard properties of the expectation operator, we obtain the final version of the *stochastic EL algorithm*: Find a real number $0 < L \le M$, such that

$$L = \operatorname{argmin} F(L), \quad \text{where}$$
$$F(L) = \frac{r}{1-e^{-rL}}\left[\int_0^L e^{-ru} E[fs(u)]du + e^{-rL}P\right]. \quad (13)$$

4.3 Analysis

In the case of deterministic cost $f(a)$, the technique for solving the problem (13) is the standard EL method, which minimizes the asset's total *equivalent annual cost* (7) of the asset replacement.

Similarly to [13], we prove that the deterministic optimization problem (13) at a strictly increasing *expected cost* $E[fs(u)]$, $u\in[0,\infty)$, has a unique solution L determined from the nonlinear equation

$$\frac{1-e^{-rL}}{r}E[fs(L)] - \int_0^L e^{-ru}E[fs(u)]du = P. \quad (14)$$

The special case [19]. Let the operating cost $fs(t)$ be *lognormally distributed*:

$$fs(t) = f_0 e^{X(t)}, \qquad t \in [0, \infty), \quad (15)$$

and the mean of the lognormal distribution (15) is

$$E[fs(t)] = f_0 e^{\left(\mu+\frac{\sigma^2}{2}\right)t} = f_0 e^{bt}. \quad (16)$$

Then the relative rate $X(t) = \ln fs(t)$ of the operating cost $fs(t)$ at each instant t is *normally distributed* with the mean $\mu = b-\sigma^2/2$ and standard deviation σ, i.e., $X(t) \sim \mathcal{N}(\mu, \sigma^2)$.

In (16), we use the notation $b = \mu + \sigma^2/2$. Here $\mu > 0$ is the deterministic relative rate of the operating cost and σ describes its associated volatility. In the stochastic case, the rate $b = \mu + \sigma^2/2$ is larger than the trend relative rate μ because of (16).

Substituting the expected value (16) into the objective function (13), we obtain

$$F(L) = \frac{r}{1-e^{-rL}}\left[f_0 \int_0^L e^{(b-r)u} du + e^{-rL} P \right]. \quad (17)$$

The function (17) has a minimum at $0 < L < \infty$ only if $b > 0$. At $b = 0$, the function $F(L) = f_0 + P\frac{r}{e^{rL}-1}$ monotonically decreases in L on $[0,\infty)$. It is easy to show that the function (17) has a minimum when L satisfies the nonlinear equation

$$e^{(b-r)L} = \left(1-\frac{r}{b}\right)e^{bL} + \frac{r}{b} + \frac{r}{b}(b-r)\frac{P}{f_0} \quad \text{at} \quad b \neq r. \quad (18)$$

This equation has a unique solution $L > 0$ that describes the recommended optimal lifetime of the asset in exploitation.

5. SOFTWARE SYSTEM FOR MODELING ASSET REPLACEMENT

The software system calculates the effective equivalent annual cost for each asset life for the economic life method and the modified economic life method. The program sets the optimal year for asset replacement.

In the development of software systems, the level of its reliability and safety plays an important role. It is impossible to achieve uninterrupted and trouble-free operation of the control system without ensuring the reliability and safety of automated information systems [30-56]. When developing a software system for modeling the rational renewal of assets, technologies and methods were used that ensure an increase in the level of their reliability and safety.

When developing this program, the following were used: Delphi software system, ADO technology, MS SQL Server database management system.

5.1 Description of the program and interface

First, you need to create a database (Capital) in the SQL Server DBMS (Figure 1). To do this, click on the Databases tab in the Object Explorer window and select New Database.

To create a table, select the Tables tab, right-click, select New Table. The Capital database consists of three tables depicted in the diagram (Figure 2).

To connect the Delphi program and SQL Server DBMS, ADO components are used: ADOTable, ADOQuery.

The tables that are in the Sql Server database can be extracted into a Delphi application. To do this, insert the AdoTable component onto the form in Delphi. Click on the component, select the ConnectionString property in the Object Inspector window. Next, click on the Build button (Figure 3).

Figure 4 shows the main window of the program, where the choice of a method for replacing one asset is provided.

This form uses 3 components: Label1, Button1, Button2. When you press the "Method of Economic Life EL" button, the program switches to the corresponding window for calculations by the method of economic life. Similarly, when you click the "Modified method of economic life MEL" button, the program goes to the window for calculations by the modified method of economic life.

Events and actions in this form:

procedure TForm2.Button2Click(Sender: TObject);
begin
Form1.Showmodal; - when the button is pressed, it switches to the first form
end;

procedure TForm2.Button1Click(Sender: TObject);
begin
Form3.Showmodal; - when the button is pressed, it switches to the third form
end;

When you press the button "Method of Economic Life EL", we switch to the calculation by the method of economic life (Figure 5).

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

This form uses the following components: AdoTable, AdoQuery, DataSource, DBGrid, DBNavigator, Button, Edit, Label.

In the first table, we use ready-made data or manually enter data using the DBNavigator component. The data in this table will be used for calculations in the program. The second table calculates the effective equivalent cost for each year.

In component Edit1, the value of the annual discount rate d is entered, in component Edit2, the value of the cost of replacing new equipment R is entered. Parameters a and q are not taken into account, since the calculation is carried out according to the method of economic life.

The calculation was made according to the following formula:

$$EAC(L)=\frac{d(1+d)^L}{(1+d)^L-1^L}\left[\frac{P(\tau_0)}{(1+d)^{L-\tau_0}}+\sum_{j=1}^{L}\frac{A(\tau_0,j)}{(1+d)^{j-\tau_0}}\right].$$

Clicking the Calculate Metrics button displays the effective equivalent cost for each period.

Event and action that is responsible for the calculation:

```
procedure TForm3.Button2Click(Sender: TObject);
begin
LAbel6.Caption:= FloatToStr(
(exp(AdoTable1.FieldByName('Age').AsInteger )*
StrToInt(Edit3.Text)+(exp(AdoTable1.FieldByName('Age').AsInteger
)*AdoTable1.FieldByName('Cost').AsFloat))/

(exp(AdoTable1.FieldByName('Age').AsInteger *
ln(1+StrToFloat(Edit1.Text)))-
1)*exp(AdoTable1.FieldByName('Age').AsInteger *
ln(1+StrToFloat(Edit1.Text)))*StrToFloat(Edit1.Text)) ;
AdoQuery1.Edit;
AdoQuery1.FieldByName('EAC(L)').AsFloat:=
( (exp(AdoTable1.FieldByName('Age').AsInteger
)*
StrToInt(Edit3.Text)+(exp(AdoTable1.FieldByName('Age').AsInteger
)*AdoTable1.FieldByName('Cost').AsFloat))/

(exp(AdoTable1.FieldByName('Age').AsInteger *
ln(1+StrToFloat(Edit1.Text)))-
1)*exp(AdoTable1.FieldByName('Age').AsInteger *
ln(1+StrToFloat(Edit1.Text)))*StrToFloat(Edit1.Text)) ;
end;
```

By pressing the button "Modified method of economic life MEL", we go to the next window (Figure 6).

In the first table, we use ready-made data or manually enter data using the DBNavigator component. The data in this table will be used for calculations in the program. The second table calculates the effective equivalent cost for each year.

In component Edit1, the value of the annual discount rate d is entered, in component Edit3, the value of the cost of replacing new equipment R is entered. Parameters a and q are not taken into account, they are entered in the components Edit2 and Edit4.

The calculation was made according to the following formula:

$$EEAC(L)=\frac{d(1+d)^L}{(1+d)^L-q^L}\left[\frac{P(\tau_0)a^{L-\tau_0}}{(1+d)^{L-\tau_0}}-\frac{S(\tau_0,L)}{(1+d)^{L-\tau_0}}+\sum_{j=1}^{L}\frac{A(\tau_0,j)}{(1+d)^{j-\tau_0}}\right].$$

Event and action that is responsible for the calculation:

```
procedure TForm1.Button2Click(Sender: TObject);
begin
LAbel6.Caption:= FloatToStr(
(exp(AdoTable1.FieldByName('Age').AsInteger *
ln(StrToFloat(Edit2.Text)))*
StrToInt(Edit3.Text)*(exp(AdoTable1.FieldByName('Age').AsInteger*ln(StrToFloat(Edit4.Text))))+(exp(AdoTable1.FieldByName('Age').AsInteger *
ln(StrToFloat(Edit2.Text)))*AdoTable1.FieldByName('Cost').AsFloat))/

(exp(AdoTable1.FieldByName('Age').AsInteger *
ln(1+StrToFloat(Edit1.Text)))-
1)*exp(AdoTable1.FieldByName('Age').AsInteger *
ln(1+StrToFloat(Edit1.Text)))*StrToFloat(Edit1.Text)) ;
AdoQuery2.Edit;
AdoQuery2.FieldByName('EACL2').AsFloat:=
( (exp(AdoTable1.FieldByName('Age').AsInteger
* ln(StrToFloat(Edit2.Text)))*
StrToInt(Edit3.Text)*(exp(AdoTable1.FieldByName('Age').AsInteger*ln(StrToFloat(Edit4.Text))))+(exp(AdoTable1.FieldByName('Age').AsInteger *
ln(StrToFloat(Edit2.Text)))*AdoTable1.FieldByName('Cost').AsFloat))
(exp(AdoTable1.FieldByName('Age').AsInteger *
ln(1+StrToFloat(Edit1.Text)))-
1)*exp(AdoTable1.FieldByName('Age').AsInteger *
```

*ln(1+StrToFloat(Edit1.Text)))*StrToFloat(Edit1.Text)) ;*
end;

Obtained results, parameters and their values:
d = 0.05; q = 0.9524; R = 45000; a = 0.95.

Figure 7 shows the calculations for the modified method of economic life. Figure 8 shows the calculations using the economic life method.

Figure 7 shows that in the case of applying the modified model of economic life, the effective equivalent annual cost decreased until 2020. This means that the asset must be replaced in 2020. Figure 8 shows that in the case of a model of economic life, the effective equivalent annual cost increases every year without taking into account the parameters a and q. Accordingly, it is difficult to figure out when to replace an asset.

6. CONCLUSIONS

The major advantage of the proposed stochastic EL algorithm is that it works equally well for *any distribution of age-dependent* stochastic operating cost. In contrast, real-option-based stopping problems [12, 19, 20] have been offered only for the linearly and exponentially increasing stochastic cost (formally described as arithmetic and geometric Brownian motions). Such theoretic cost distributions are convenient for analysis, but real applications rarely follow them. Essential task remains to analyze the efficiency of those methods when the future dynamics of maintenance costs is not exponential or is not completely known even on a limited horizon.

The decision-making practice is characterized by discrete time, information gaps, and measurement errors [8, 26, 27, 28, 29]. The related important issues are the suitability of a replacement model to business practice, clarity and logical simplicity of the model, applicability to common standards and time periods for recording data, reasonable requirements to input data, and other practical matters. Practical recommendations for choosing an efficient replacement algorithm depend on and data availability and the observed dynamics of technological improvement.

7. ACKNOWLEDGEMENT

The authors acknowledge financial support of the Ministry of Education and Science of Kazakhstan under Grant № AP05131784.

REFERENCES

[1] P. Grinyer, The effects of technological change on the economic life of capital equipment, AIIE Transactions, 1973, 5, pp. 203-213.
[2] E. J. Elton, M. J. Gruber, On the optimality of an equal life policy for equipment subject to technological improvement, Operational Research Quarterly, 1976, 27, pp. 93-99.
[3] S. Sethi, S. Chand, Planning horizon procedures in machine replacement models, Management Sciences, 1979, 25, pp. 140-151.
[4] J. Bean, J. Lohmann, J. Smith, Equipment replacement under technological change, Naval Research Logistics, 1994, 41, pp. 117-128.
[5] G. Bethuyne, Optimal replacement under variable intensity of utilization and technological progress, The Engineering Economist, 1998, 43, pp. 85-106.
[6] E. Regnier, G. Sharp, C. Tovey, Replacement under ongoing technological progress, IIE Transactions, 2004, 36, pp. 497-508.
[7] Hartman, J. Engineering Economy and the Decision-Making Process, Upper Saddle River, New Jersey: Pearson Prentice Hall, 2007.
[8] P.A. Scarf, R. Dwight, A. McCusker, A. Chan, Asset replacement for an urban railway using a modified two-cycle replacement model, Journal of the Operational Research Society, 2007, 58, pp. 1123-1137.
[9] R. Goetz, N. Hritonenko, Y. Yatsenko, The optimal economic lifetime of vintage capital in the presence of operating cost, technological progress, and learning, Journal of Economic Dynamics and Control, 2008, 32, pp. 3032-3053.
[10.] Yatsenko, Y., Hritonenko, N. Economic life replacement under improving technology, International Journal of Production Economics, 2011, 133, pp. 596-602.
[11] Yatsenko, Y., Hritonenko, N. Asset replacement under improving operating and capital costs: a practical approach, International Journal of Production Research, 2016, 54, pp. 2922-2933.
[12] Yatsenko, Y., Hritonenko, N. Machine replacement under evolving deterministic and stochastic costs, International Journal of

Production Economics, 2017, 193, pp. 491-501.

[13] Yatsenko, Y., Hritonenko, N. Discrete-continuous analysis of optimal equipment replacement, International Transactions in Operational Research, 2010, 17, pp. 577-593.

[14] P.A. Scarf, M. Hashem, On the application of an economic life model with a fixed planning horizon, International Transactions of Operational Research, 1997, 4, pp. 139-150.

[15] J. Rogers, J. Hartman, Equipment replacement under continuous and discontinuous technological change, IMA Journal of Management Mathematics, 2005, 16, pp. 23-36.

[16] Yatsenko, Y., Hritonenko, N. Technological breakthroughs and asset replacement, The Engineering Economist, 2009, 54, pp. 81-100.

[17] S.Mercier, Optimal replacement policy for obsolete components with general failure rates. Applied Stochastic Models in Business and Industry, 2008, 24(3), pp. 221-235.

[18] T. Nguyen, T. Yeung, B. Castanier, Optimal maintenance and replacement decisions under technological change with consideration of spare parts inventories, International Journal of Production Economics, 2013, 143, pp. 472-477.

[19] Dobbs, I. Replacement investment: optimal economic life under uncertainty. Journal of Business Finance & Accounting, 2004, 31, pp. 729–57.

[20] S. Richardson, A. Kefford, M. Hodkiewicz, Optimised asset replacement strategy in the presence of lead time uncertainty, International Journal of Production Economics, 2013, 141, pp. 659–667

[21] Thuesen, G., Fabrycky, W. Engineering Economy, 8th ed., Englewood Cliffs, New Jersey: Prentice Hall, 1993.

[22] Newman, D., Eschenbach, T., Lavelle, J. Engineering Economic Analysis, 9th ed., New York: Oxford University Press, 2004.

[23] Hartman, J., Tan, C. H. Equipment replacement analysis: a literature review and directions for future research, The Engineering Economist, 2014, 59, pp. 136-153.

[24] Hritonenko, N. Yatsenko, Y. Optimal equipment replacement without paradoxes: a continuous analysis, Operations Research Letters, 2007, 35, pp. 245-250.

[25] Yatsenko, Y., Hritonenko, N. Algorithms for asset replacement under limited technological forecast, International Journal of Production Economics, 2015, 160, pp. 26-33.

[26] Al-Chalabi, H., Lundberg, J., Ahmadi, A., Jonsson, A. Case study: Model for economic lifetime of drilling machines in the Swedish mining industry, The Engineering Economist, 2015, 60, pp. 38-154.

[27] Yatsenko, Y., Hritonenko, N., Boranbayev, S. Non-equal-life asset replacement under evolving technology: A multi-cycle approach. Engineering Economist, 2020.

[28] Hritonenko, N., Yatsenko, Y., Boranbayev, S. Environmentally sustainable industrial modernization and resource consumption: Is the Hotelling's rule too steep? Applied Mathematical Modelling, 2015, Volume 39, Issue 15, pp. 4365-4377.

[29] Boranbayev, S.N., Nurbekov, A.B. Construction of an optimal mathematical model of functioning of the manufacturing industry of the Republic of Kazakhstan. Journal of Theoretical and Applied Information Technology, 2015, 80 (1), pp. 61-74.

[30] Boranbayev, A., Boranbayev, S., Nurusheva, A., Yersakhanov, K. Development of a software system to ensure the reliability and fault tolerance in information systems. Journal of Engineering and Applied Sciences. – 2018, 13 (23), pp. 10080-10085.

[31] Boranbayev, S., Goranin, N., Nurusheva, A. The methods and technologies of reliability and security of information systems and information and communication infrastructures. Journal of Theoretical and Applied Information Technology. -2018, 96 (18), pp. 6172-6188.

[32] Boranbayev, A., Boranbayev, S., Nurusheva, A. Development of a software system to ensure the reliability and fault tolerance in information systems based on expert estimates. -2018, Advances in Intelligent Systems and Computing, Vol. 869, pp. 924-935.

[33] Boranbayev, A., Boranbayev, S., Yersakhanov, K., Nurusheva, A., Taberkhan, R. Methods of Ensuring the Reliability and Fault Tolerance of Information Systems. Advances in Intelligent Systems and Computing. -2018, Vol. 738, pp. 729-730.

[34] Boranbayev, S., Altayev, S., Boranbayev, A. Applying the method of diverse redundancy in cloud based systems for increasing reliability. The 12th International Conference on Information Technology: New Generations

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

(ITNG 2015). April 13-15, 2015, Las Vegas, Nevada, USA, pp. 796-799.

[35] Turskis, Z., Goranin, N., Nurusheva, A., Boranbayev, S. A fuzzy WASPAS-based approach to determine critical information infrastructures of EU sustainable development. -2019, Sustainability (Switzerland), Volume 11, Issue 2, 424.

[36] Turskis, Z., Goranin, N., Nurusheva, A., Boranbayev, S. Information security risk assessment in critical infrastructure: A hybrid MCDM approach. -2019, Informatica (Netherlands), Volume 30, Issue 1, pp. 187-211.

[37] Boranbayev, A. S., Boranbayev, S. N., Nurusheva, A. M., Yersakhanov, K. B., Seitkulov, Y. N. Development of web application for detection and mitigation of risks of information and automated systems. Eurasian Journal of Mathematical and Computer Applications. -2019, Volume 7, Issue 1, pp. 4-22.

[38] Boranbayev, A.S., Boranbayev, S.N., Nurusheva, A.M., Seitkulov, Y.N., Sissenov, N.M. A method to determine the level of the information system fault-tolerance. Eurasian Journal of Mathematical and Computer Applications. -2019, Volume 7, Issue 3, pp. 13-32.

[39] Boranbayev Askar, Boranbayev Seilkhan, Nurbekov Askar, Taberkhan Roman. The Development of a Software System for Solving the Problem of Data Classification and Data Processing. 16th International Conference on Information Technology - New Generations (ITNG 2019). -2019, Volume 800, pp. 621-623.

[40] Boranbayev Askar, Boranbayev Seilkhan, Nurusheva Assel, Yersakhanov Kuanysh, Seitkulov Yerzhan. A software system for risk management of information systems. Proceedings of the 2018 IEEE 12th International Conference on Application of Information and Communication Technologies (AICT 2018), 17-19 Oct. 2018, Almaty, Kazakhstan, pp. 284-289.

[41] Boranbayev Seilkhan, Boranbayev Askar, Altayev Sanzhar, Nurbekov Askar. Mathematical model for optimal designing of reliable information systems. Proceedings of the 2014 IEEE 8th International Conference on Application of Information and Communication Technologies (AICT 2014), Astana, Kazakhstan, October 15-17, 2014, pp. 123-127.

[42] Boranbayev Seilkhan, Altayev Sanzhar, Boranbayev Askar, Seitkulov Yerzhan. Application of diversity method for reliability of cloud computing. Proceedings of the 2014 IEEE 8th International Conference on Application of Information and Communication Technologies (AICT 2014), Astana, Kazakhstan, October 15-17, 2014, pp.244-248.

[43] Boranbayev Seilkhan. Mathematical Model for the Development and Performance of Sustainable Economic Programs. International Journal of Ecology & Development. -2007, Volume 6, Issue 1, pp. 15-20.

[44] Boranbayev A., Boranbayev S., Nurusheva A. Analyzing methods of recognition, classification and development of a software system. Advances in Intelligent Systems and Computing. –2018, Vol. 869, pp. 690-702.

[45] Boranbayev, A.S., Boranbayev, S.N. Development and optimization of information systems for health insurance billing. ITNG2010 - 7th International Conference on Information Technology: New Generations. –2010, pp. 1282-1284.

[46] Akhmetova, Z., Zhuzbayev, S., Boranbayev, S., Sarsenov, B. Development of the system with component for the numerical calculation and visualization of non-stationary waves propagation in solids. Frontiers in Artificial Intelligence and Applications. -2016, Vol. 293, pp. 353-359.

[47] Boranbayev, S.N., Nurbekov, A.B. Development of the methods and technologies for the information system designing and implementation. Journal of Theoretical and Applied Information Technology. -2015, 82 (2), pp. 212-220.

[48] Boranbayev, A., Shuitenov, G., Boranbayev, S. The method of data analysis from social networks using apache hadoop. Advances in Intelligent Systems and Computing. -2018, Vol. 558, pp. 281-288.

[49] Boranbayev, S., Nurkas, A., Tulebayev, Y., Tashtai, B. Method of Processing Big Data. Advances in Intelligent Systems and Computing. -2018, Vol. 738, pp. 757-758.

[50] Boranbayev, A., Boranbayev, S., Nurbekov, A. Estimation of the Degree of Reliability and Safety of Software Systems. Advances in Intelligent Systems and Computing. -2020, Vol. 1129, AISC, pp. 743-755.

[51] Boranbayev, A., Boranbayev, S., Nurbekov, A. Development of the Technique for the Identification, Assessment and Neutralization

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

of Risks in Information Systems. Advances in Intelligent Systems and Computing. -2020, Vol. 1129, AISC, pp. 733-742.

[52] Boranbayev, A., Boranbayev, S., Nurusheva, A., Seitkulov, Y., Nurbekov, A. Multi Criteria Method for Determining the Failure Resistance of Information System Components. Advances in Intelligent Systems and Computing. -2020, Vol. 1070, pp. 324-337.

[53] Boranbayev, A., Boranbayev, S., Nurbekov, A., Taberkhan, R. The Software System for Solving the Problem of Recognition and Classification. Advances in Intelligent Systems and Computing. -2019, Vol. 997, pp. 1063-1074.

[54] Akhmetova, Z., Boranbayev, S., Zhuzbayev, S. The visual representation of numerical solution for a non-stationary deformation in a solid body. Advances in Intelligent Systems and Computing. -2016, Vol. 448, pp. 473-482.

[55] Boranbayev, A., Boranbayev, S., Nurbekov, A. Evaluating and Applying Risk Remission Strategy Approaches to Prevent Prospective Failures in Information Systems. Advances in Intelligent Systems and Computing. -2020, Vol. 1134, pp. 647-651.

[56] Boranbayev, A., Boranbayev, S., Nurbekov, A. A Proposed Software Developed for Identifying and Reducing Risks at Early Stages of Implementation to Improve the Dependability of Information Systems. Advances in Intelligent Systems and Computing. -2020, Vol. 1134, pp. 163-168.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

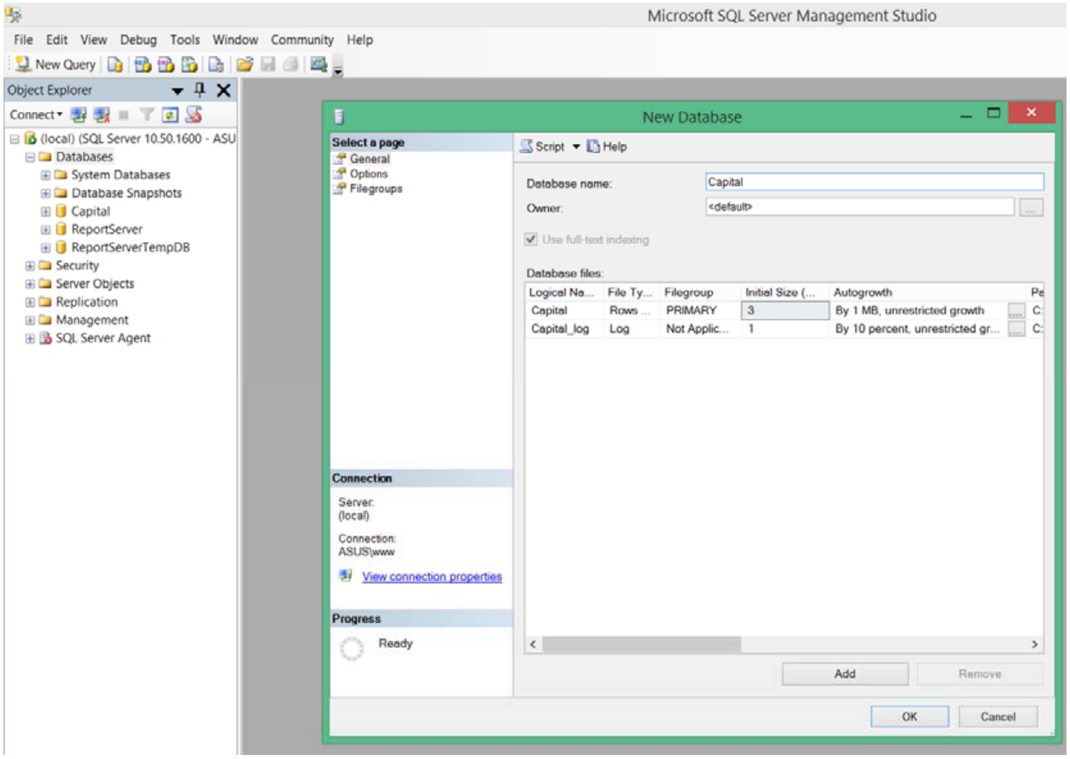

Figure 1. Creating a database

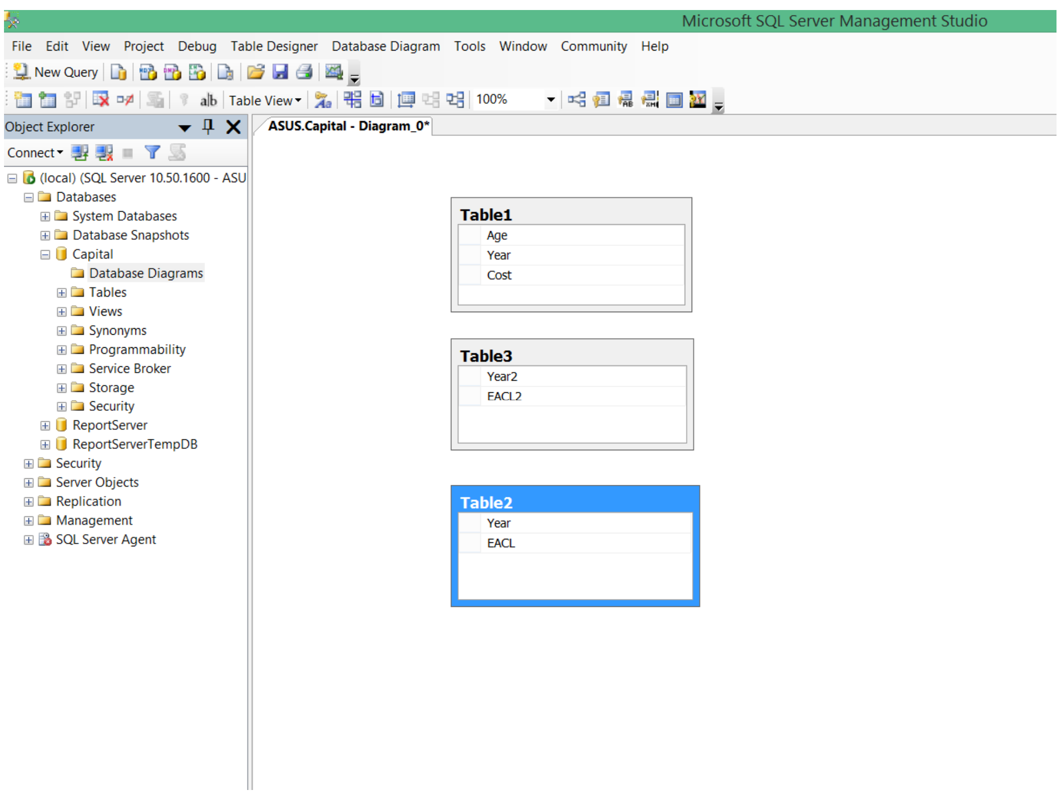

Figure 2. Creating tables

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

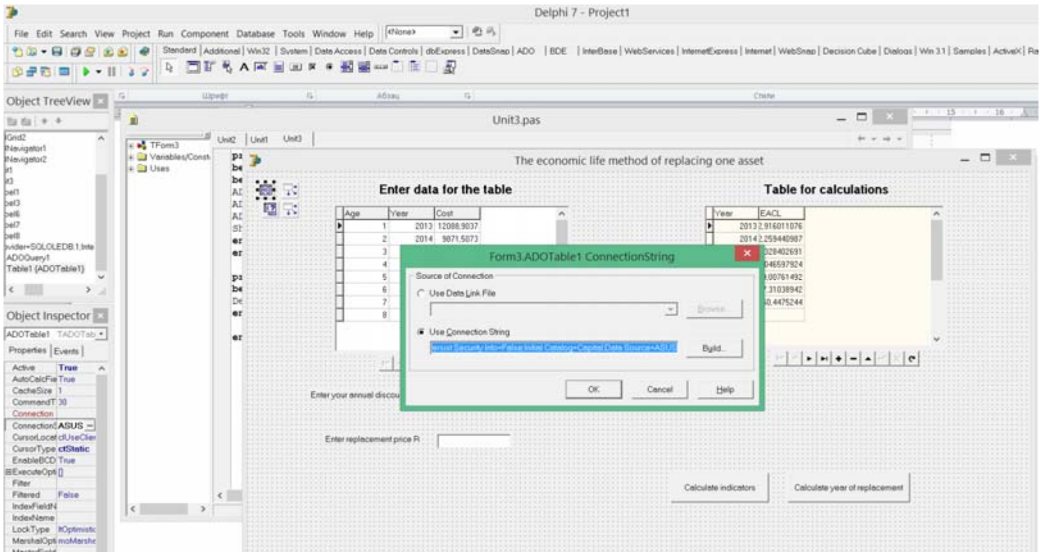

Figure 3. Establishing Communication Between Delphi Application and SQL Server

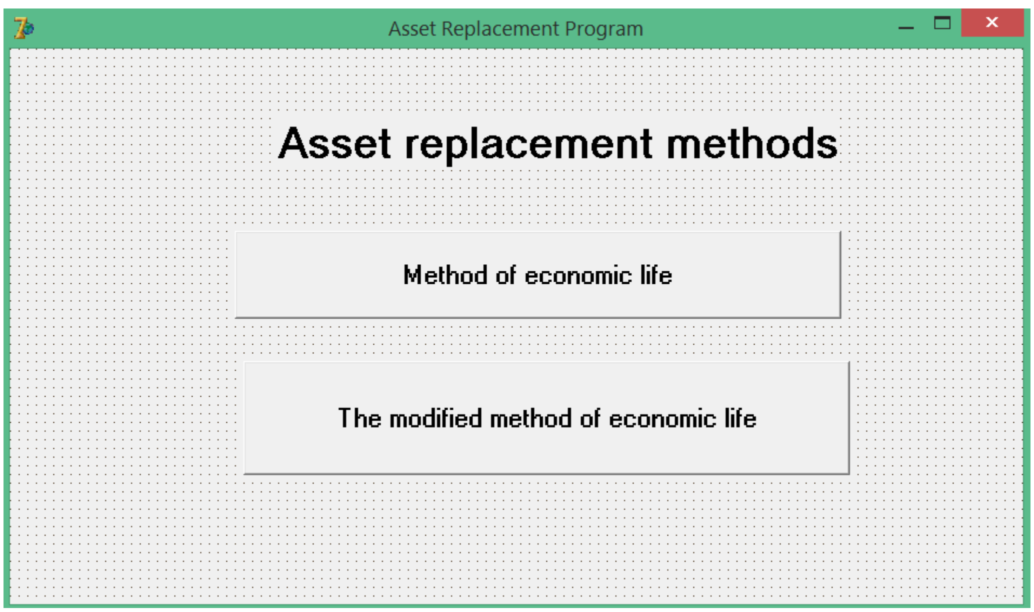

Figure 4. Main window

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

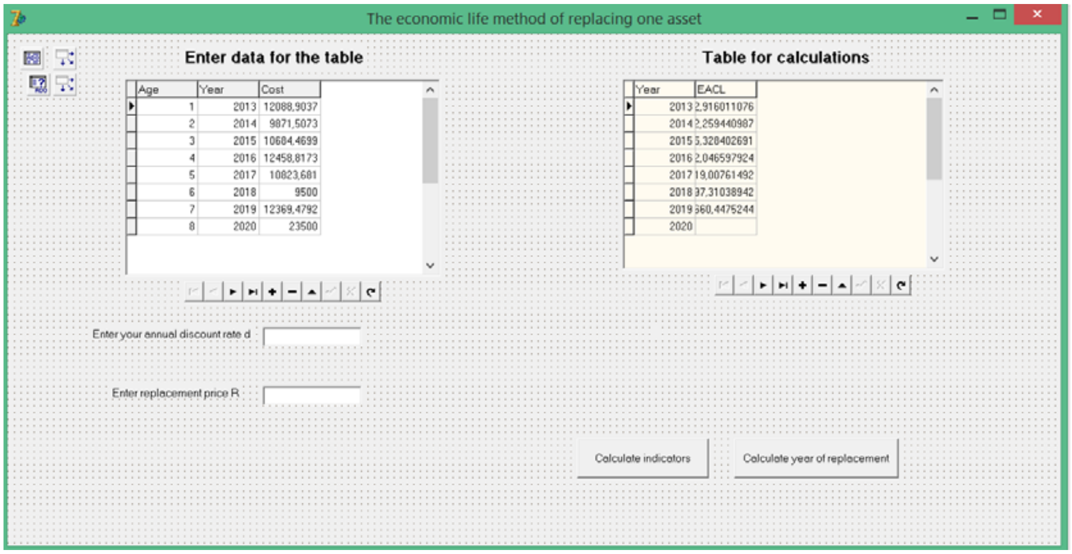

Figure 5. Window for calculations by the method of economic life

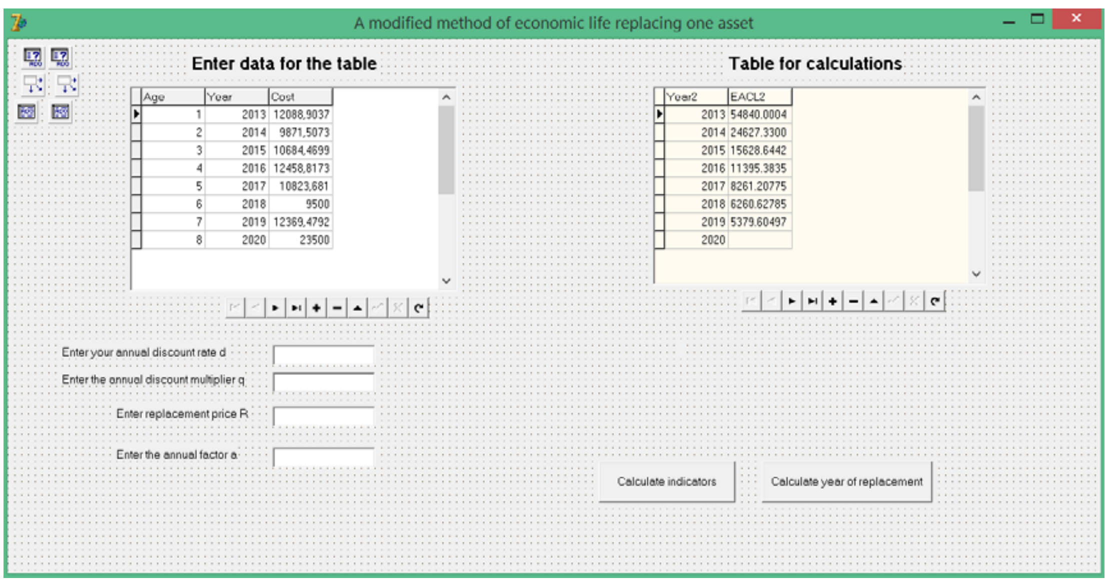

Figure 6. Window for calculations according to the modified method of economic life

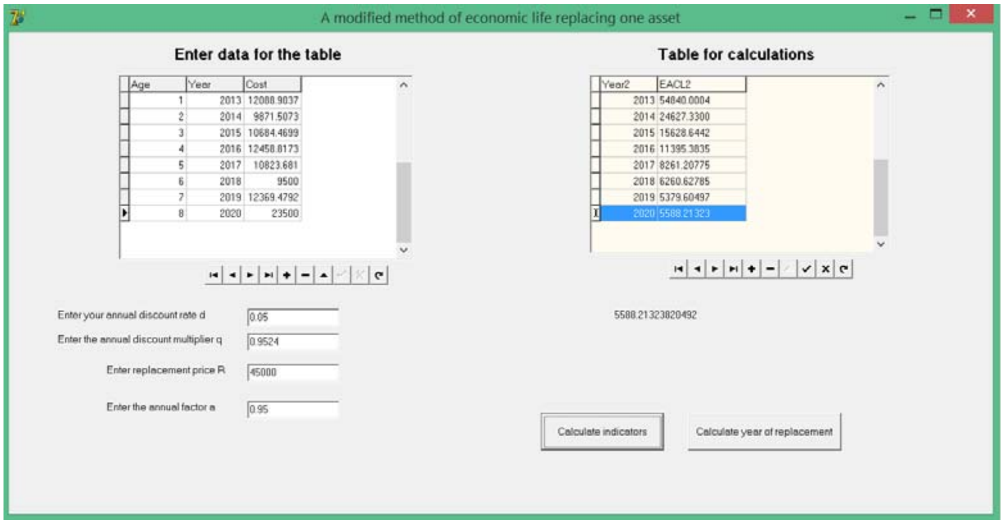

Figure 7. Calculations by the modified method of economic life

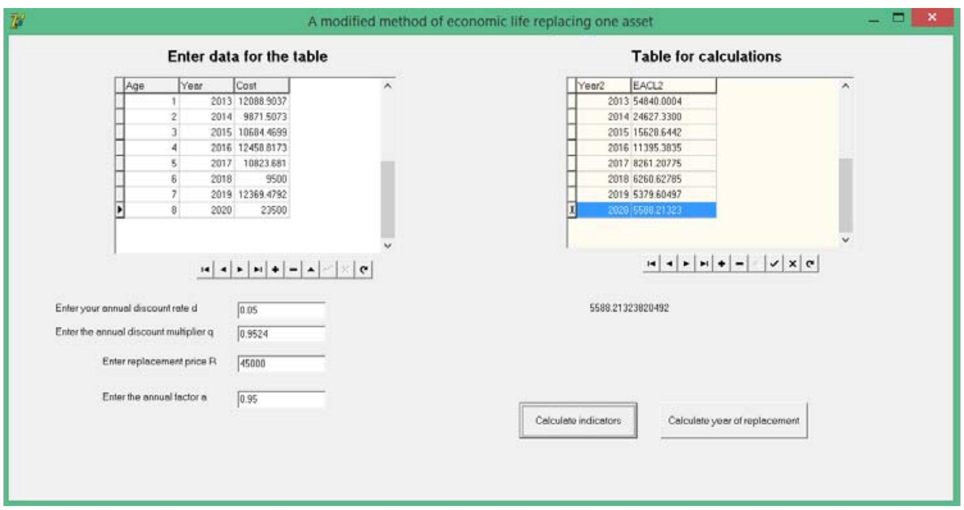

Figure 8. Calculations by the method of economic life