Risk Analysis of the Company's Activities by Means of Simulation

Elena M. Kuzmina[1][0000-0002-0061-9933], Oksana Klochko[3][0000-0002-6505-9455],

Nataliia B. Savina[2][0000-0001-8339-1219], Svetlana A. Yaremko[1][0000-0002-0605-9324],

Roman B. Akselrod[4][0000-0001-7643-7194], Christine Strauss[5][0000-0003-0276-3610]

[1]Vinnitsa Institute of Trade and Economics Kiev National Trade and Economic University, Vinnytsia, Street Soborna 87, Ukraine
lenakuzmina@ukr.ner, svitlana_yaremko@ukr.net
[2]The National University of Water and Environmental, Rivne, Ukraine
n.b.savina@nuwm.edu.ua
[3]Vinnytsia State Pedagogical University named after Mykhailo Kotsiubynsky, Vinnytsia, Ostrozkoho Street 32, Ukraine
klochkoob@gmail.com
[4]Kyiv National University of Construction and Architecture, Kyiv, Ukraine
akselrod.knuba@ukr.net
[5]University of Vienna, Vienna, Austria
christine.strauss@univie.ac.at

Abstract. The use of simulation methods and modern information technologies increases competitiveness, management efficiency and eliminates possible risks in the company's activities. The use of the Monte-Carlo method is promising in simulation. The basis of the classical Monte-Carlo method is to obtain a large number of implementations of a random process, which is formed so that the probabilistic characteristics (mathematical expectations, probability of some events, probability of the trajectory in a certain area, etc.) are equal to the predetermined value of the problem. Construction of the model using this method should be based on the distribution of random variables in the studied process. The set of implementations can be used as some artificially obtained statistical material processed by methods of mathematical statistics. The author's development was the application in the classical Monte-Carlo method of generating samples of random variables with uniform and triangular distribution, as well as risk analysis of the company and forecasting for the future with greater probability using modern means of automating complex calculations based on high-level programming languages. The software implementation of the advanced Monte-Carlo method is performed using high-level object-oriented Python language tools that allow you to automate all stages of application of the Monte-Carlo method and store the results in a database. Strategic planning support tools based on computer simulation provide an opportunity to reflect complex nonlinear interactions in the business, assess the consequences of the implementation of various scenarios or predict further developments in the company.

Keywords:information technologies, simulation, Monte Carlo method, probabilistic characteristics, risks.

1 Introduction

At the present stage of economic development, information technology (IT) can be considered an attribute of a successful company. Creating an effective IT application system in a company is one of the aspects of ensuring its competitiveness and avoiding risk. Modern simulation technologies, including economic systems, are needed to understand the causal relationships in economics, planning, forecasting, decision making, and more. With the help of simulation, you can answer various questions that arise when deciding on changes in the processes occurring in the business: how to change the profitability of the business; what changes that have already taken place will affect the productivity of technological equipment and personnel; what additional investments the company needs to make; what will be the payback period of the investment. Simulation allows you to test different ideas by reproducing them in a computer model, which is much cheaper than conducting many tests and bug fixes on real processes [2,3,4].

Today, simulation is a powerful analytical tool based on modern information technology, including object-oriented programming, Internet solutions, powerful graphical shells for modeling and interpretation of initial simulation results, multimedia tools, etc. [1,2]. Today, simulation is seen as a mandatory step in making important management decisions in companies that are actively implementing modern IT in their activities, and this contributes to the adoption of sound strategic management decisions. Strategic planning tools based on computer simulation provide an opportunity to reflect complex nonlinear interactions in the business, assess the consequences of various scenarios or predict the further development of the company [5,6,7].

2 Initial prerequisites and problem statement

One of the most powerful methods of analyzing economic systems is simulation, which is the process of conducting experiments with mathematical models of complex real-world systems using information technology. Computer simulation involves building a model using specialized software. Computer experiments with a certain degree of probability describe the patterns of functioning of real systems and objects. To apply this method to research, create a simulation system that includes a simulation model, as well as internal and external mathematical software. Then enter the required input data and observe the changes in indicators, which in the process of modeling can be analyzed and subjected to statistical processing. The range of applications of computer simulation is extremely wide - from specific forms of business to the simulation of the economy as a whole [8,9,10].

The main areas of use of simulation in economic objects are:

– forecasting the development of national economies;

- development and implementation of information systems for various purposes;
- training and personnel management.

The methods of computer simulation play an extremely important role in the introduction of information technology in the management of companies, in the creation of information systems of economic and organizational management. The strategy for the development of modern information systems in companies, in particular decision support systems, should provide analysis of the formulation and solution of this class of problems [1,3, 11]:

- analytical - calculation of the necessary indicators and statistical characteristics of business activity on the basis of retrospective (turned back) information from databases;
- data visualization - visual graphical and tabular display of available information;
- acquisition of knowledge - determining the relationships and interdependencies of business processes based on existing information;
- simulation - conducting computer experiments with mathematical models that describe the behavior of complex systems. Tasks of this class are used to analyze the possible consequences of a decision (analysis such as "What if? ...");
- management synthesis - determination of permissible control actions that ensure the achievement of goals;
- optimization - based on the integration of simulation, management, optimization and statistical methods of modeling and forecasting.

Today, computer simulation plays an important role in the process of automation of the company as a whole. This work involves the following steps:

1. Engineering - building a model of the company;
2. Stage of reengineering - implementation of analysis and improvement of the model;
3. Management stage - monitoring the company's work within the created model.

At the same time, various methods of analysis are used, in particular, such as functional-cost analysis, simulation modeling.

All over the world, simulation has become widespread in the study of complex systems and objects due to important advantages [1,3]:

1. It is possible to answer many questions that arise in the early stages of design and pre-design of systems, avoiding the use of trial and error, which involves significant costs [11].
2. The method makes it possible to study the peculiarities of the functioning of the system under any conditions, including those that are not implemented in field experiments. The parameters of the system and the environment can be varied within extremely wide limits, reproducing an arbitrary situation.
3. It becomes possible to predict the behavior of the system in the near and distant future, extrapolating to the model the results of industrial tests. In this case, the data obtained earlier are supplemented through the application of a statistical approach.

4. Simulation models of technical and technological systems and devices make it possible to reduce their testing time many times over.
5. Using the method of simulation, you can artificially quickly and in large quantities to obtain the necessary information that reflects the course of real processes, avoiding expensive and often impossible field tests of these processes.
6. The simulation model is an extremely flexible cognitive tool capable of reproducing arbitrary both real and hypothetical situations.
7. Implementing simulations on a computer is often the only real way to solve such problems.

However, it should be noted that the method of computer simulation, despite all its advantages and versatility, is not always acceptable, because the calculations on simulation models require significant money and time. Computer simulation as a method of solving complex problems should be used under the following conditions:

- unsuitability or lack of analytical methods for solving problems;
- complete confidence in the successful creation of a simulation model that adequately describes the studied system (process), in particular that it will be possible to collect all the necessary information about the simulated system (process), providing a reliable simulation of real situations on a computer;
- the ability to use the process of building a simulation model for a preliminary study of the system being modeled, in order to develop recommendations for improving the conditions of its operation.

Creating a simulation model designed to study the problems of organizational management, includes: study of the existing functional system, analysis of a hypothetical functional system, design of an advanced system. However, the successful solution of these problems of simulation is possible only on adequate models. Therefore, when studying complex economic systems on simulation models, the adequacy of the model to real objects should be established first. In case of inadequacy of the model, the results are unreliable, and the decisions made on their basis are erroneous. Adequate simulation model mathematically and logically with a certain degree of approximation reflects the studied system. The logical elements of the model correspond to the operations performed in reality, and the mathematical description determines the functions implemented in the real system. Probabilistic operators of an adequate simulation model reflect the random nature of the events of the real system. Endogenous parameters of the model with the appropriate input factors should be informative, ie to give credible messages about the system [15,16].

The future is questionable and therefore risky from a business point of view. When making business decisions, these risks must be assessed. In other words, there is a problem of decision-making under conditions of risk, when the parameters and variables are random variables (eg, cost of production, market share, total sales in future periods can not be determined accurately). If so, will the risky measure be profitable? There are several ways to explore aspects of risk (uncertainty).

The first way is to use the analytical capabilities of the what if scenario approach, which allows you to explore alternative situations by modifying the model and identifying the effects of change. Although this approach is suitable for studying the effects

of changes in one or two variables or obtaining a specific response based on the assumptions of the company's management, it is not the most effective for risk analysis.

The second way is to evaluate the best and worst cases. Under this approach, estimates are created taking into account the most favorable and unfavorable conditions that each input variable could have. Optimistic values are set for the best case and pessimistic values for the worst. In the real world, not all variables acquire their best values at the same time as their worst. Although the study of critical situations is very useful, but this approach does not lead to a set of situations that can really be expected.

The third way is to use Monte-Carlo simulation. The Monte-Carlo method is one of the powerful tools for analyzing real economic systems. The basis of this method, including stochastic simulation, is the synthesis, as well as methods of sensitivity analysis and scenarios. The Monte-Carlo method is a numerical method based on obtaining the number of implementations of a random process, which is formed so that the probabilistic characteristics (mathematical expectations, the probability of some events, the probability of the process trajectory in some area, etc.) are equal to certain values of the problem. The Monte-Carlo method is based on the simulation of a mass process by subtracting its course, in which random oscillations are determined by drawing lots or a table of random numbers. Economic experiment can be replaced by statistical tests of the economic process model. The construction of this model can be based on the distribution of random variables in the studied process.

The Monte-Carlo method is based on the method of statistical tests. Its essence is that the test result depends on the value of some random variable distributed according to a given law. Therefore, the result of each individual test is random. A fundamental feature of the method is that it guarantees high quality statistical estimates only with a very large number of tests that cannot be performed without the help of a computer.

3 Presentation of the main results of the research

The key words in the concept of simulation are "selective experiments". A large number of tests are created in a sample experiment. Due to the uncertainty, the result of each test may differ from the results of other tests. In simulations, sample experiments are performed on a computer model, thus allowing many tests to be performed with little material cost (as opposed to field experiments).

When solving a problem that contains one or more random variables, you must have a rule for deciding what values each random variable will take. The most effective way to do this is to assign values according to the probability distribution and consider them as values that actually took place. Because the simulation is a sample experiment, this process is repeated many times (for example, 1000 times). Each time we refer to a random variable, we select a value from the probability distribution and use it to determine the result, ie we choose the value of the random variable so that the frequency of occurrence of individual values is related to the probability distribution.

The simulation procedure in summary consists of the following steps:

1. construction of a simulation model that determines uncertainty and risks;
2. performing experiments on a computer, repeating them according to the model many times. Each time getting one possible scenario;
3. conducting statistical analysis of experimental data;
4. interpretation of the obtained statistical results for making the optimal decision.

The software implementation of the Monte-Carlo method solves the model problem many times with different combinations of values of values, each time selected from the corresponding probability distributions, which were previously specified. The results of these experiments are statistically analyzed and the output is statistical results. These results can be interpreted as risks included in the decision. For example, you can find that there is a 10% chance that the internal rate of return will exceed 25%, or with a probability of 0.9 you can be sure that it will exceed 14%.

The computer implementation of the simulation model involves its repeated application, using different combinations of randomly selected values using probability distributions. The aim is to obtain information not only on the average expected value, but also on the distribution of probabilities of possible outcomes (to know the risks).

The computer implementation of the Monte-Carlo method involves the user specifying the number of iterations to be performed or the number of default iterations to be performed (for example, 100 iterations). Once the system has entered the simulation mode, you need to select and enter into the system:

- variables to be analyzed;
- data output format (eg histogram, frequency distribution);
- periods for which you want to get printed results.

As a rule, if an error is made when entering the parameters of the Monte Carlo model into the system, the system provides certain options for its correction.

Typically, simulations end with one or more probability distributions for each variable and certain columns. The output of the Monte-Carlo method is organized in the following sequence: table of normal approximation, frequency table, descriptive statistics (mean value, standard deviation, asymmetry, steepness, etc.), histogram.

The essence of the Monte-Carlo method is as follows [4]:

For the desired value of m we find such a random variable X, the mathematical expectation of which is equal to m, $M(X)=m$.

For this purpose, we calculate n independent values of m_1, m_2,…, m_n of the random variable m; evaluate the mathematical expectation as $M(X) \approx \frac{m_1+m_2+\ldots+m_n}{n}$.

Since the sequence of equally distributed random variables in which there are mathematical expectations obeys the law of large numbers, then for $n \to \infty$ the arithmetic mean of these quantities coincides in probability to the mathematical expectation, ie, for large n quantities $M(X) \approx m$.

The error of the Monte-Carlo method is estimated as $O(1/\sqrt{n})$, decreases slowly, depends on the variance and does not depend on the dimension of the problem.

The application of the Monte-Carlo method is carried out by generating a sample of a uniformly distributed random variable, as well as generating a sample of a quantity having a triangular distribution [4,5].

The uniform law of distribution of a continuous quantity X on the segment [a, b] is characterized by a constant probability density on this segment and is equal to zero outside it. For a uniform distribution law, the probability density has the form [4, 5]:

$$\varphi(x) = \begin{cases} 0, if\ x < a; \\ \frac{1}{b-a}, if\ a \le x \le b; \\ 0, if\ x > b. \end{cases}$$

Mathematical expectation and variance of a random variable *X* are calculated by the formulas, respectively: $M(X) = \frac{a+b}{2}$, $D(X) = \frac{(b-a)^2}{12}$.

For a uniform distribution law, the function of a random variable X has the form:

$$F(x) = \begin{cases} 0, if\ x < a; \\ \frac{x-a}{b-a}, if\ a \le x \le b; \\ 1, if\ x > b. \end{cases}$$

According to the research task, we also chose a triangular distribution (Simpson distribution). Because, it is used in cases of lack or limited amount of data, as well as to build complex distribution laws. This distribution does not provide the opportunity to independently vary the numerical characteristics of the distribution - mode, median, mathematical expectation. This distribution is used when adding or subtracting two random variables that are evenly distributed.

That is, if X1 and X2 are independent random variables having a uniform distribution law in the interval [a / 2, b / 2], then the random variable X=X1+X2 has a triangular distribution in the interval [a, b].

For the triangular distribution law, the probability density has the form [4, 5]:

$$\varphi(x) = \begin{cases} 0, if\ x < a; \\ \frac{4(x-a)}{(b-a)^2}, if\ \frac{a+b}{2} \le x \le b; \\ 0, if\ x > b. \end{cases}$$

Mathematical expectation and variance of a random variable X, distributed by a triangular law, are calculated by the formulas, respectively:

$$M(X) = \frac{a+b}{2}, D(X) = \frac{(b-a)^2}{24}.$$

For the triangular distribution law, the distribution function of a random variable X has the form:

$$F(x) = \begin{cases} 0, if\ x < a; \\ \frac{2(x-a)^2}{(b-a)^2}, if\ \frac{a+b}{2} \le x \le b; \\ 1, if\ x > b. \end{cases}$$

Thus, taking into account the peculiarities of the distribution of the studied indicators, the authors chose uniform and triangular laws of distribution of random variables for simulation of a particular enterprise using modern tools to automate all stages of calculations.

The action of the proposed method will be considered by example. The initial data are as follows: the industrial holding company wants to invest 10 million dollars. into the parent enterprise improvement program, hoping that this program will have a life cycle of 10 years. The company's management has determined that the key factors for analyzing the profitability of this proposed investment are: Market size; Selling price; The company’s market share; Total investment; Salvage value of the investment; Operating costs; Fixed costs.

All of these metrics are related to the uncertainty that is modeled by the probability distributions that can be specified. In formulating a forecast, the company knows that it intends to close the facility if the selling price is lower than the variable cost per unit of output. In this case, it is necessary to take into account fixed costs.

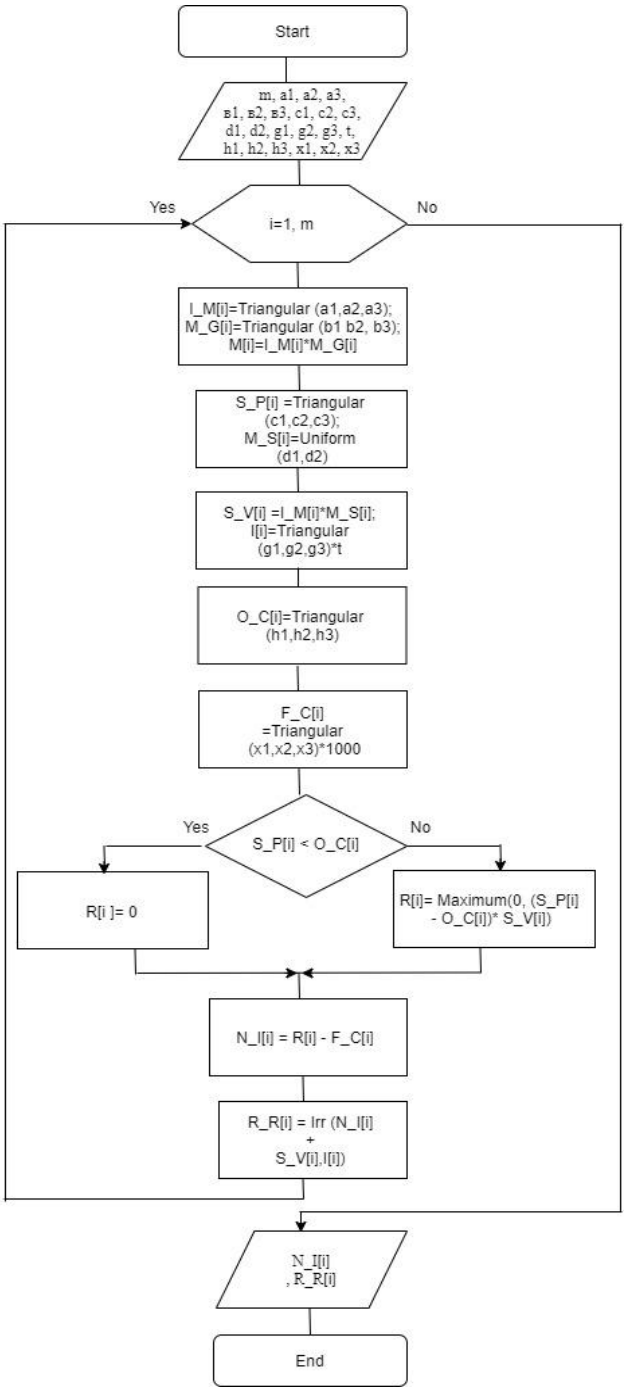

Fig.1. Algorithm for applying the Monte -Carlo method to predict the company's activities

A generalized algorithm for determining the company's income or the condition of cessation of production and payback ratio or profit margin is shown in Fig.1. The algorithm is based on a modification of the Monte-Carlo method of generating samples of random variables with uniform and triangular distribution.

For the convenience of description, the following notations were introduced in the algorithm: I_M - Initial Market, the input parameters of which are marked as (a1, a2, a3); M_G is the Market Growth, which can take values that aredenoted as (b1, b2, b3), M [m] is the product of I_M and M_G; S_P is the Selling Price, the input parameters of which are denoted, as (c1, c2, c3), M_S - Market Share, the value of which is marked as (d1, d2); I - investment, million dollars. (Investment), the input variables of which are denoted as (g1, g2, g3); t - the amount of investment; O_C - variable (operating) costs per unit of output (Operating Cost per unit), the parameters of which are marked as (u, v, w); F_C - fixed costs, $ thousand (Fixed Cost), whose values are marked as (x, y, z); R - Revenue income; N_I - net income Net Income; R_R - Net Income rate of return.

After creating the algorithm, the program code for implementing the Monte Carlo method was developed to predict the company's activities in the object-oriented high-level programming language Python [6,7]. A fragment of the listing which, where the calculation of key indicators is presented in Fig.2.

```
while i < m:
    M[i] = random.triangular(a1,a2,a3) * random.trian
gular(b1,b2,b3);
    S_P[i] = random.triangular(c1,c2,c3)
    M_S[i] = random.uniform(d1,d2)
    S_V[i] = M[i] * M_S[i]
    I[i] = random.triangular(g1,g2,g3)*t
    O_C[i] = random.triangular(h1,h2,h3)
    F_C[i] = random.triangular(x1,x2,x3) #* 1000
    if(S_P[i] < O_C[i]):
        R[i] = 0
    else:
        R[i] = max(0,(S_P[i] - O_C[i]) * S_V[i])
    N_I[i] = R[i] - F_C[i]
    R_R[i] = round(npf.irr((N_I + S_V) ), int(I[i]))
    table_data.append([probability[i],N_I[i],R_R[i]])
    i += 1
table = ax.table(cellText=table_data, loc='center')
table.set_fontsize(24)
table.scale(1,1)
ax.axis('off')
plt.show()
```

Fig. 2. A fragment of the listing of the program for the implementation of the Monte Carlo method

Termination conditions are also programmed. The condition of production shutdown is expressed by using the built-in Maximum function to determine income. If the selling price is lower than operating costs, the income is 0; if higher, the income is determined by multiplying the sales volume by the difference between the selling price and variable (operating) costs.

After developing the program, the initial parameters of all variables were entered into the program, which for convenience of presentation were summarized in table 1.

Table 1. Functions of distribution of probabilities of expenses and receipts of the company

Index	Distribution	Parameter values
Initial Market	triangular	150 000, 300 000, 84 000
Market Growth	triangular	1.04, 1.07, 1.1
Selling Price	triangular	420, 570, 610
Market Share	homogeneous (uniform)	14 % to 19 %
Investment	triangular	8000, 10500, 12500
Operating Cost-perunit	triangular	390, 520, 565
Fixed Cost	triangular	300, 350, 410
Salvage Value	triangular	4.5, 5.5, 6

After entering the initial data and processing them by the program, indicators of simulation of net income and profit margins of the company during the forecast periods were obtained (Fig. 3).

Probability	Net Income	Rate of return
90	-344.26805701774424	0.7480120291709607
80	229471.28681890471	665.5483048703992
70	1797315.514072782	673.2907811520579
60	667870.7784141868	673.2949994337671
50	3169308.9177367706	673.2950291199065
40	747705.1326463063	673.2950291302925
30	618255.3618725382	673.2950291303054
20	2043440.1127934593	673.2950291302601
10	-331.6622795206445	673.2950291303046

Fig. 3. The results of simulation in the form of a table of frequencies

Analyzing the results of simulation, it can be noted that even in the 10th year, net income can fluctuate greatly (between losses of more than 300 thousand dollars and profits of more than 3 million dollars). In addition, the rate of return varies according to these investment indicators from 0.7 to 673,295.

The graph of the distribution of probabilities of net profit (Fig. 4) showed that the lowest (with negative values) profit may have a low or highest probability when there are significant risks of losing investment and when variable (operating) costs exceed the selling price.

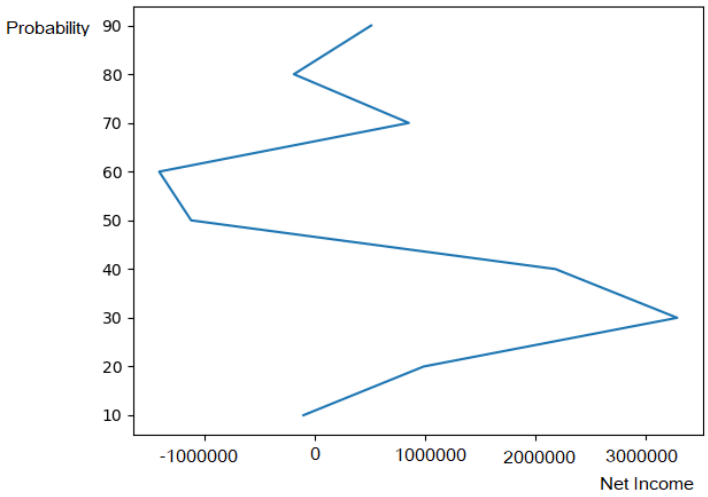

Fig. 4. Graph of the distribution of the probability of net profit

In general, it can be noted that the use of the Monte Carlo method and the triangular distribution allows you to predict the activities of the enterprisefor future periods with a certain probability of the ratio of profit and payback.

4 Conclusions

Based on computer simulation, as an effective method of analyzing economic systems, it is possible to ensure competitiveness and avoid risk in companies of any level and scale. Making management decisions at risk is always accompanied by subjective and objective difficulties that are associated with changes in business processes. Strategic planning support tools based on computer simulation provide an opportunity to reflect complex nonlinear interactions in the business, assess the consequences of the implementation of various scenarios or predict further developments in the company.

The synthesized new mathematical model and its software implementation describe the determination of the company's income or the condition of cessation of production and the rate of return or rate of return. The application in the classical Monte Carlo method of generating samples of random variables that have a uniform and triangular distribution, as well as risk analysis of the company's activities and forecasting for the future give a greater probability of a correct result. In addition, this approach is used in cases of lack or limited amount of data, which is also an advantage of using the proposed method.

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