Feasibility study of using meta-heuristic algorithms on optimizing of the integrated risk in banking system

Eskandar Vaziri
Responsible author,phd candidate, accounting and management faculty,Islamic azad university of shahrood,iran
svaziri2010@hotmail.com

Farhad Dehdar
Assistant professor, accounting and management faculty , Islamic azad university of shahrood,iran
f.dehdar1970@yahoo.com

Mohammad Reza Abdoli
Associateprofesso, accounting and management faculty, Islamic azad university of shahrood,iran
mra830@yahoo.com

Submit: 05/11/2021 Accept: 14/12/2021

ABSTRACT

The aim of this study was to evaluate the integrated risk of the banking system through the meta-heuristic algorithms of gray wolf, genetics and particle swarming. This research is applied research in terms of purpose and correlational in nature and method. Data collection has been done through library studies, articles and sites in deductive form and data collection to refute and confirm hypotheses inductively. The statistical population of this research is the banking system and the sample includes banks listed on the Tehran Stock Exchange during the fiscal years 1392 to 1397. In order to collect the required data, the financial database of the Ministry of Economic Affairs and Finance, codal website, etc. have been used. After extracting the information, and adjusting them in the form of an integrated risk model, the objective function and constraints are entered in MATLAB software and the variables of risk (market risk, operational risk, liquidity risk and credit risk) and return (profit and loss on assets and Debts were obtained using particle swarm algorithms, genetics, and gray wolves, and we compared their results using SPSS 16 software. After that, first the descriptive statistics were analyzed and then inferential statistics were performed. The results of descriptive statistics showed that the average of total assets in 1397 is 670744505 million Rials and the average of total debts during the years 1392 to 1397 is 182372564 million Rials. 81.79% of assets have risk weights that the average liquidity risk is credit. And the operation of the banking system during the years under review are 0.12, 0.16 and 0.0051, respectively. In the inferential statistics section, after reviewing the results of comparing the evaluation indicators of algorithms (Pareto number response index, quality index, average distance index from ideal point index, distance index, diversity index and algorithm execution time index), it was determined that the gray wolf algorithm is efficient. Provides better goal function optimization (maximizing returns and minimizing risk). Also, by examining the research hypotheses, it was found that particle swarm algorithms and genetics have the same efficiency for assessing the integrated risk of the banking system. Provides better problem solving

Keywords:

Risk, Risk Assessment, Gray Wolf Algorithm, Genetic Algorithm, Particle Swarm Algorithm

1. Introduction

Due to the constant changes in environmental factors and economic systems, different risks affect the financial structure of banks every day. Meanwhile, the banking system, considering its special features, faces risks that are very important to identify and manage, so that it can design methods, standards, training and systems to control, reduce and prevent adverse events that have a devastating effect on the lives of banks. Therefore, the present study tries to make a comparative study and finally conclude on the usefulness of each of these algorithms in comparison with each other in terms of new techniques that result from the use of meta-heuristic algorithms in the financial field. Pay bank risk optimization.

2. Literature and theoretical foundations of research

Concept of risk: Risk is an unforeseen event with financial consequences that causes a loss or a decrease in profitability. In simpler terms, risk means the probability of loss. Most economists attribute the risk to a lack of complete information. Many economists have equated investment risk with the dispersion of returns. Keynes defines investment risk as the probability of deviating from the average return. Hicks, like Keynes, defines risk as the variance of returns; Dumar defines investment risk as the probability of incurring losses. (Raei 2009)

Market risk: One of the risks that banks face is related to the losses that occur in the items above and below the balance sheet line and are due to fluctuations in market prices. A certain part of market risk is exchange rate risk. Banks act as "market makers" by offering rates to their customers or by opening foreign currency accounts. During periods when the exchange rate is not stable enough, the risks that form an integral part of the foreign exchange trade increase. (Khosh Sima 1391)

Operational risk: The most important types of operational risk include deficiencies in internal controls and corporate governance. Such breaches may result in financial losses through error, fraud or failure to comply with the obligations in a timely manner, or in any other way, to the detriment of the Bank's interests. Other operational risk situations include major defects in IT systems, events such as large-scale fires, or other disasters. Operational risk includes human resource risks of the organization, business processes, information technology, business continuity, effective distribution channels, customer satisfaction, safety and health of employees and the workplace, organizational culture, failure to produce or provide service, efficiency, capacity Production and market risk. (Khosh Sima 1391)

Liquidity risk: Liquidity risk arises from a bank's inability to reduce debt or raise funds to increase assets. When a bank does not have enough liquidity, it will not be able to raise sufficient funds quickly and at a reasonable cost by increasing debt or converting assets, and this will affect profitability. In acute situations, insufficient liquidity may lead to the bankruptcy of a bank. (Raei 1384)

Credit risk: Lending is the main activity of most banks. Lending requires banks to comment on the ability of loan applicants to repay. As a result, one of the major risks that banks face is the credit risk or the inability of the other party to enforce the provisions of the contract. This risk includes not only types of loans but also other amounts at risk that are at the top and bottom of the balance sheet, including guarantees, acceptances and investments in securities.

Risk management

Risk management is a process that is performed by the board of directors and other employees of the company and is used in formulating the strategy and all activities of the company. The process is designed to identify those potential events that could affect the company's goals and to control the risks within the company's risk range to provide reasonable assurance that its goals will be achieved. (Saeedi 1388) The main steps in this process are: risk identification, risk analysis and assessment, risk response, based on this, the objectives of integrated risk management (ERM) are: to create appropriate preparedness for future threats and Effective use of opportunities ahead; Improving a reasonable level of confidence in achieving the company's goals; Promoting the stability of decisions and facilitating decision-making and decision-making at various levels of the company and creating stability in the growth of equity and other stakeholders of the company.

Risk assessment: Risk assessment of all financial and non-financial aspects of the business is an integral part of the successful management of the organization in business environments full of lack of confidence. By assessing risk, businesses anticipate what threats they face in achieving their goals in order to prepare for an active response. There are various quantitative and qualitative methods for risk assessment. According to its needs and goals, each organization can choose the best framework for managing the risks it is exposed to.

Integrated risk assessment: Risk identification should be comprehensive. This assessment should include all interactions between goods, services and internal information within an organization and between the organization and other relevant external entities and entities. In addition, the organization must consider the risks posed by external factors such as new legislation by the authorities, environmental issues, potential natural disasters, and so on. Risk identification is an interactive process and is often closely related to the planning process.

Genetic Algorithm (GA)

Genetic Algorithm (GA) is an optimization and search algorithm based on the principles of genetics and natural selection. In a genetic algorithm, a group of individuals emerges and develops in a situation where the overall goal is to maximize the merits of the entire population or to minimize a cost associated with the population. In this algorithm, past information is extracted due to heredity and used in the search process. In other words, genetic algorithms are random search techniques that operate based on natural selection and natural genealogy. (Afshar et al. 2008) These algorithms have fundamental differences with conventional search and optimization methods, which Goldberg summarizes as follows: The genetic algorithm works with sets of encoded solutions, not With them; The genetic algorithm starts the search process with a set of answers, not just one; The genetic algorithm uses fitting function information, not derivatives or other auxiliary methods, and the genetic algorithm uses probabilistic rules, not definite rules (Keller 1998).

PSO algorithm

The idea of PSO was first mooted by Kennedy and Eberhart in 1995. The particle swarm algorithm is an evolutionary computational algorithm inspired by nature and based on iteration. The source of inspiration for this algorithm was the social behavior of animals, such as the mass movement of birds and fish. Because the particle swarm algorithm also starts with an initial random population matrix, it is similar to many other evolutionary algorithms such as the continuous genetic algorithm and the colonial competition algorithm. (Mir Jalili 2010) It does not have the same as mutation and marriage. Therefore, it can be said that the colonial competition algorithm is more similar to particle swarm. Each element of a population is called a particle. In fact, the particle swarm algorithm consists of a specific number of particles that are randomly assigned the initial value. For each particle, two values of position and velocity are defined, which are modeled with a location vector and a velocity vector, respectively. These particles move repeatedly in the n-dimensional space of the problem to search for possible new options by calculating the optimization value as a measurement criterion. The problem space dimension is equal to the number of parameters in the function to be optimized. One memory is dedicated to storing the best position of each particle in the past, and one memory is devoted to storing the best position among all particles. (Jim 2002) With the experience gained from these memories, the particles decide how to move next. Each time it is repeated, all the particles move in the next n-space of the problem until the general optimal point i s finally found.

Gray Wolf Algorithm (GWO)

This algorithm is one of the best algebraic and swarm intelligence algorithms that, with the idea of how to hunt gray wolves, searches the problem space well and quickly approaches the optimal point. The above algorithm is based on the hunting of wolves and their hierarchy. In this algorithm, the optimal point location is calculated based on the location of the three points alpha, beta and delta (the best points in each iteration). Is a population that simulates the social life of wolves in hierarchical groups. (Zare 1394) Social structure and hierarchy of gray wolves: Gray wolves are one of nature's best predators. These animals live in groups, each group consisting of an average of 5 to 12 gray wolves, and all members adhere to a hierarchical dictatorship. Each group includes alpha, beta, delta and gamma wolves. Level 1 wolves are alpha wolves that can be male or female and are the leader of the team. In the group of wolves, the strongest wolf is not always the leader, but the wolf that can better lead the team is chosen as the alpha wolf. The second level wolves are the beta wolves that act as the alpha wolves and help them in decisions. They can be male or female. Third-level wolves, delta wolves, are wolves that are not on the level of alpha and beta wolves and are usually considered as subordinates. They execute alpha and beta wolves and command omega-level wolves. The fourth level wolves are called omega-level wolves, which have no special function for the team and are mostly used as prey. Mir Jalili 2010) In the gray wolves algorithm, we consider the target function based on the behavior of alpha, beta and delta wolves, respectively, and the rest of the solutions are considered omega wolves. In this algorithm, the attack is managed by alpha, beta and delta wolves. Omega wolves follow the behavior of three upstream levels.

Evaluation indicators of MOPSO, GWA and GA meta-heuristic algorithms

Given that meta-heuristic methods are estimated algorithms for solving optimization problems and are random in nature; Solving a problem through different methods may lead to different answers, so evaluating algorithms and selecting the appropriate algorithm with the help of various indicators has been considered by researchers in different sciences; But convergence in Pareto responses and providing density and variability among the set of responses are two separate and somewhat contradictory goals in multi-objective evolutionary algorithms, so there is no absolute criterion that can decide the performance of algorithms. Finally, after reviewing the literature, the following six indicators have been identified and introduced as performance evaluation indicators of algorithms in this research.

Pareto response number index (NPS): This index indicates the number of Pareto responses found through the algorithm and the higher the number, the better the performance of the algorithm (Ardaneh, 1394).

Quality Index (QM): This index indicates the share of the algorithm in the set of Pareto responses resulting from the combination of Pareto responses presented through all the comparable algorithms. (Mohammadi et al., 2011) The higher the value of this index, the better the performance of the algorithm.

Mean Distance from Ideal Point (MID): This indicator shows the average distance of Pareto points from the ideal answer. The ideal value is equal to the best possible value for each of the objective functions used in all algorithms (Zeizag and Jaskiewicz, 1998). A lower value of this index means better performance of the algorithm.

Distance Index (SM): This index indicates the standard deviation of the distance of unsuccessful responses. In other words, it calculates the relative distance of Pareto consecutive responses. (Chambery et al., 2012) The higher the value of this index, the better the performance of the algorithm.

Diversity Index (DM): This index shows the Euclidean distance between the initial and final answers of the Pareto response set (Zeitler and Siele, 1998). . The larger the value of this index, the higher the performance of the algorithm.

Algorithm execution time index (Time): This index emphasizes the algorithm execution time and is one of the most important indicators in comparing different algorithms and the lower the value (if other indicators are equal), the algorithm will be more efficient (Ardaneh, 1394).

3. Research methodology

Research variables: Research variables include integrated risk that we seek to minimize (objective function) and another variable is the return that we seek to maximize. Multiple linear programming model is used to perform the tests. In this study, considering that banks are always looking for low risk and high profit, using data sources and multiple programming methods to support decisions. The optimal level of fragmentation will be presented, which solves many problems. The aim of this study is to create an integrated linear model of risk that minimizes the overall risk of assets against a certain level of risk, although in general there are simple differences between them. There is variance and covariance. Therefore, adding a simple linear model will reflect risk changes. Therefore, we consider the following model to express integrated risk:

$$Risk (x) = \Sigma R\_i (x)$$

Where x = (x1, x2,…, xn) represents the portfolio of assets and liabilities and (x) R_i expresses the i risk. For the specified risk (x) R_i, consider the following linear relation to express the portfolio:

$$R\_i (x) = \sum\_rijx\_ij$$

Where rij is the risk i of asset j, and here specifically var, which we consider for the risk of each unit of asset, and xaj expresses the size of asset j. Therefore, we measure the total risk by the gross variance of the total assets. In addition, the profit function is expressed as the difference between the profit and loss of assets and liabilities:

ret (x) = ∑x_aj.p_aj-∑x_dj.p_dj

Where p_aj and p_dj are the profit and loss of my assets or liabilities.

Research Limitations

1) Capital Adequacy Rate (CBRC) Limit: This constraint requires that each bank or group of banks must maintain a legal capital ratio at risk weighted assets of more than 12%. Therefore, we have the following equation:

CaRital / RWA≥12% . RWA is a weighted asset risk.

2) Legal deposit rate limit: According to the rules of the Central Bank, banks must deposit a certain percentage of their deposits with the Central Bank. This amount is known as the deposit reserve rate. According to the laws of our country, the deposit reserve rate is less than 13%. We have:

x_C≥13% × 〖〖xd_j〗 . X_C is the legal reserve of the central bank ∑〖xd_j〗 is the total deposit of banks (debts).

3) Restrictions on customer deposits: Most of the banks' resources are deposits attracted by them. Banks provide more facilities by attracting more deposits. In accordance with the real conditions, these are high limits. Therefore: a≤∑ 〖d_j≤b〗 . Where b, a indicate the deposit boundary.

4) Limitation of facilities: According to the relevant laws, banks are not allowed to grant facilities more than 75% of deposits. This limitation means that the limitation of the deposit leads to the limitation and granting of facilities, therefore C≤∑〖x_ij≤d〗. Where d, c indicate the facility boundary.

5) Limitation of money scale: In order to meet the essential needs of customers and their perceptions, the following equation is considered. a_1≤xaj≤xcasL≤a_2≤xij. Where x_casL represents the amount of cash, ∑x_aj represents the sum of assets a_1 and a_2 represents the corresponding rate. It should be noted that the above restrictions are only part of the realities of banking operations and more restrictions can be added to it.

Multiple planning model Max:

$$\textbf{Max:}\begin{cases} ret(x) = \sum x_{aj}.p_{aj} - \sum x_{dj}.p_{dj} \\ -Risk(x) = -\sum\sum r_{ij}x_{aj} \end{cases}$$

$$\textbf{S.T.}\begin{cases} \frac{\text{CaRital}}{\text{RWA}} \geq 12\% \\ x_C \geq 13\% \times \sum xd_j \\ C \leq \sum x_{ij} \leq d \\ a \leq \sum d_j \leq b \\ a_1 \leq \sum x_{aj} \leq x_{casL} \leq a_2 \leq x_{ij} \end{cases}$$

Research Hypotheses

Hypothesis 1: Particle mass optimization algorithm is not as efficient as the gray wolf algorithm for assessing the integrated risk of the banking system.

H_0 = EH (MPSO) = EH (GWO) H_1 ≠ EH (MPSO) ≠ EH (GWO)

Hypothesis 2: Particle mass optimization algorithm is not as efficient as the genetic algorithm for assessing the integrated risk of the banking system.

H_0 = EH (MPSO) = EH (GA) H_2 ≠ EH (MPSO) ≠ EH (GA)

Hypothesis 3: The gray wolf hyper-optimization algorithm is not as efficient as the genetic algorithm for assessing the integrated risk of the banking system.

H_0 = EH (GWO) = EH (GA) H_3 ≠ EH (GWO) ≠ EH (GA)

Hypothesis 4: Particle mass optimization algorithm, gray wolf and genetics for assessing the integrated risk of the banking system do not have the same efficiency.

H_0 = EH (MPSO) = EH (GWO) = EH (GA) H_1 ≠ EH (MPSO) ≠ EH (GWO) ≠ EH (GA)

Research purposes

The process of identifying, evaluating, managing and controlling potential events or situations to reasonably ensure the achievement of the organization's goals is called integrated risk management. Banks face various uncertain conditions for planning future activities. These conditions potentially affect the realization of management plans and goals, and today the challenge for decision makers is to determine the acceptable level of uncertainty on the basis of which the value of the firm can be maintained for stakeholders and try to increase it. To properly, regularly and methodically face this challenge, the implementation of an integrated risk management process is very necessary and vital. Risk management enables the organization to identify and manage a wide range of risks and all managers at different levels to better understand and manage Risk helps. This is achieved through accepting risk responsibility, support from the board of directors and executives, improving results, increasing accountability and stewardship capacity, and so on. Also, the results of the present study can benefit the money and capital market activists and all stakeholders in the financial markets and all members of society in general due to daily relations with banks and financial institutions.

Statistical Society:

The statistical population of the present study includes all public, semi-public and private banks in the banking system of the country. The period of the present study also includes the financial statements for the years 1392 to 1397.

Research Methods

A) Type of research method: The research is of the applied purpose type and in terms of nature and method is of the correlation type. Metaphorical algorithms have been used to test the hypotheses and prove the research model. The research is conducted as deductive and inductive reasoning; This means that the theoretical foundations and research background are done through library studies of articles and sites in the form of deductive and information collection to reject or confirm hypotheses through induction. The following statistical methods have been used to test the research hypotheses: **First to Third Hypotheses:** Wilcoxon statistical test is used to test hypotheses one to three, which examine the performance of each of the algorithms in a comparative and two-by-two manner. When in a research the goal is to compare two variables and if the sample is not assumed to be normal, non-parametric tests such as the above test can be used to compare the two groups.

Hypothesis 4: To test the fourth hypothesis, Kruskal-Wallis statistical test, which is a non-parametric test and is considered as a series of analysis of variance tests, has been used. This method tests the hypothesis that k sample groups from a common statistical population or similar statistical population extracted with respect to the averages to determine the performance of each algorithm.

B) Data collection method: Using information obtained from published financial statements, the website of the Central Bank of the Islamic Republic of Iran, the Statistics Center of Iran, the website of the Stock Exchange and affiliated sites of the Ministry of Economic Affairs and Finance such as the financial and economic database.

C) Data collection tools: To prepare the desired information, the website of the Central Bank of the Islamic Republic of Iran and the economic and financial database of the Ministry of Economic Affairs and Finance and the Cadal site have been used.

D) Information analysis method: using multi-purpose optimization algorithms and meta-heuristic techniques including MOPSO, GWO and GA.Test model research process A three-step process including basic information and model input for integrated risk optimization (first step), information processing The input is based on the above mentioned algorithms (second stage) and the analysis and achievement of the research model outputs is based on the set objectives (third stage). Also, MATLAB software has been used to perform operations related to data analysis and model output, which is the efficiency of each algorithm.

Multi-objective research optimization model:

$$\min:\begin{cases} -\mathrm{ret}(x) = -(\%0.207x_2 + \%0.0789x_3 + \%0.0217x_4 \\ +\%2.33x_5 + \%0.049x_6 + \%0.13x_7 + \%0.077x_8 \\ +\%0.445x_9 + \%0.112x_{10} - \%0.108y_1 - \%0.284y_2 \\ -\%0.256y_3 - \%0.006y_4 - \%0.001y_5 - \%0.003y_6) \\ \mathrm{Risk}(X) = 0.00122x_2 + (0.000251+0.00511 + 0.12)x_3 \\ +(0.000148 + 0.00511 + 0.12)x_4 \\ +(0.01087 + 0.00511 + 012 + 0.1609)x_5 \\ +(0.0000282 + 0.00511 + 0.12)x_6 \\ +(0.000343 + 0.00511 + 0.12)x_7 \\ +(0.000057 + 0.00511 + 0.12)x_8 \\ +(0.000343 + 0.00511 + 0.12)x_9 \\ +(0.000924 + 0.00511 + 0.12)x_{10} \\ = 0.000122x_2 + 0.125697x_3 + 0.125593x_4 + 0.297223x_5 \\ +0.125473x_6 + 0.125789x_7 + 0.125502x_8 + 0.125789x_9 + 0.126369x_{10} \end{cases}$$

$$s.t.\begin{cases} 44.2 \times \dfrac{0.8179}{0.2x_9 + 0.5x_5 + 0.5x_6 + x_3 + x_4 + x_7 + x_8 + x_{10}} \geq 12\% \\ x_2 \geq 13\%(y_1 + y_2 + y_3 + y_4 + y_5 + y_6) \\ 17.95 \leq (y_1 + y_2 + y_3) \leq 4.42 \times 17.95 = 79.339 \\ 44.67 \leq x_5 \leq 197.46 \\ x_1 \leq 0.15(x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10}) \\ x_1 \geq 0.05(x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10}) \end{cases}$$

4. Analysis of findings

Descriptive index of research variables: The average initial values of assets, liabilities, rate of return and interest rates of the sample member banks in the years 1392 to 1397 are as follows:

Table 1. Initial amount of assets and liabilities, rate of return and interest rate of sample banks

Rate of return	value	symbol	Assets
	٦٦٤٩٠٩٢٣	x_1	cash
% ٠,٢٠٧	٥٨٠٣٧٤١٤	x_2	Legal deposit
% ٠,٠٧٨٩	١٠٧٣٣٣٩٨	x_3	Tangible assets
% ٠,٠٢١٧	٦٧٢٥٧٦١	x_4	Intangible assets
% ٢,٣٣	٤٤٦٧٤٤٢٥٩	x_5	Loans of non-govermental
% ٠,٠٤٩	٦٥٧١٢٥٣	x_6	Account reseivable(internal)
% ٠,١٣	١٦٤٨٥٧٨٣	x_7	investments
% ٠,٠٧٧	٥٦٩٤٩٨٣	x_8	Other resievables
% ٠,٤٤٥	٣٠٧٣١٠٠١	x_9	Trade reseivables
% ٠,١١٢	٣٥٥١٤٠١١	x_{10}	Other assets
Rate of return	value	symbol	debts
% ٠,١٠٨	٢٩٨٤٥٣٠٥	y_1	Trade debts
% ٠,٢٨٤	٧٨٨١٠٠٩٠	y_2	deposits
% ٠,٢٥٦	٧٠٩٠٣٩٤٠	y_3	Other debts
% ٠,٠٠٦	١٦٨٧٩٢٥	y_4	Tax payable
% ٠,٠٠١	٣٢٤١٠٢	y_5	Earning share payable
% ٠,٠٠٣	٨٠١٢٠٢	y_6	Retirement of personnel

The total amount of assets is 670744505 million and the total amount of liabilities is 182372564 million

Adjusting research parameters: In this research, 4 types of risks are considered for banks, which include: market risk, operational risk, liquidity risk and credit risk. Market risk by assets is presented in Table 2:

Table 2. Market risk of each asset of banks

Market risk	symbol	Assets
	x_1	cash
% ٠,١٢٢	x_2	Legal deposit
% ٠,٠٢٥١	x_3	Tangible assets
% ٠,٠١٤٧	x_4	Intangible assets
% ١,٠٨٧	x_5	Loans of non-govermental
% ٠,٠٠٢٨٢	x_6	Account reseivable(internal)
% ٠,٠٣٤٣	x_7	investments
% ٠,٠٠٥٧	x_8	Other resievables
% ٠,٠٣٤٣	x_9	Trade debts
% ٠,٠٩٢٤	x_{10}	Other assets

Optimization results of MOPSO, GWO and GA algorithms: In this section, the optimization results for each of the PSO, GWO and GA algorithms are given. The best answer of each algorithm is obtained through 5 repetitions of program execution.

Results of MOPSO algorithm: In MOPSO algorithm, a concept called archive or repository has been added to PSO algorithm, which is also known as Hall of Fame. (Chang 2008) Choosing the best overall answer and the best personal memory for each particle is an important and fundamental step in this algorithm. (Mir Jalili 2010) When particles want to make a move, they choose a member of the tank as a leader. This leader must be a member of the tank and undefeated. The results of solving the problem model using the MOPSO algorithm are shown below:

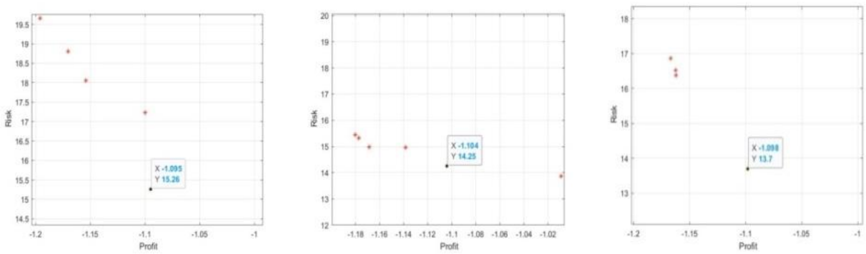

figure 1. Objective function changes in the worst, meanest and best execution in the MOPSO method

Table 3. Results of the implementation of MOPSO algorithm in solving the research pro

repeat	implementation									
	١		٢		٣		٤		٥	
	Ret	Risk	Ret	Risk	Ret	Risk	Ret	Risk	Ret	Risk
١٠٠	١,١٠٣	١٤,٨٧	١,٠١٦	١٢,٣٢	١,٠٧٢	١٤,٣٥	١,٠٢٧	١٤,٣٥	١,٠٢٧	١٤,٣٩
٢٠٠	١,٠٨	١٤,٧٢	١,٠٩٣	١٣,٥٧	٠,٩٩٩	١٣,٣٤	١,٢٣٤	١٤,٨٧	١,١٠٩	١٤,٩
٣٠٠	١,٠١٩	١٣,٠٣	١,٠٠٤	١٢,٠٩	١,٠٨٢	١٤,٣٢	١,٠٣٧	١٣,٦٢	١,٠٣	١٤,٨٣
٤٠٠	١,٠٦١	١٥,٢١	١,٠٣٩	١٣,٩٧	١,٠٩٨	١٣,٧٠	١,٠٥	١٤,٥٧	١,٠٥٩	١٤,٣
٥٠٠	١,٠٨٤	١٣,٥٤	١,٠٨	١٤,٠٧	١,٠٧	١٣,٧٥	١,٠٨٨	١٣,٩١	١,٠٤٧	١٣,٧٤

Table 4. Statistical parameters of objective function in MOPSO method

parametr	maximum	minimum	average	Standard deviation	Coefficient of change
Ret	١,١٦٦٩	١,٠٩٨	١,١٤٧٤	٠,٠٣٢٩	٠,٠٢٨٧
Risk	١٦,٩٩٢	١٣,١٤٧٣	١٥,٢٩٨٨	١,٧٥٠٩	٠,١١٤٤

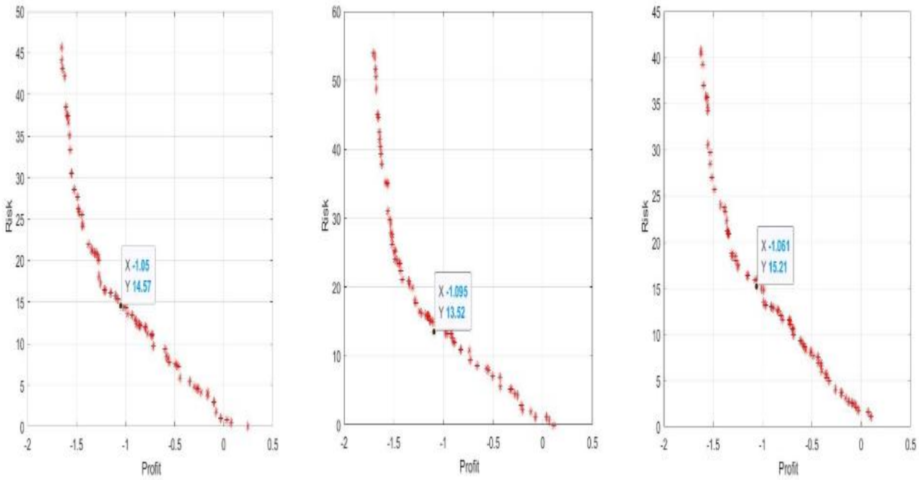

figure 2. Objective function changes in the worst, meanest and best execution in the MOPSO method

Results of GA algorithm: Objective value values for different parameters of genetic algorithm in 5 times of program execution are given in the table below. According to the results, the minimum values for the objective function of return and risk are 1.011 and 16.823, respectively, which is calculated for 500 generations and two-point displacement. The statistical parameters of the best solution as well as the change curves of the worst, average and best performance are presented in the table and figure below, respectively.

Table 5. Objective value values in 5 program execution times for GA method

repeat		execution									
		١		٢		٣		٤		٥	
		Ret	Risk	Ret	Risk	Ret	Risk	Ret	Risk	Ret	Risk
١٠٠	Single point	١,٠٨	١٤,١٩	١,٠٧٧	١٤,١٨	١,٠٦٦	١٣,٩٦	١,١١٥	١٤,٤٤	١,١١١	١٤,٤٤
	Dual point	١,٠٨	١٣,٩٨	١,٠٧٤	١٤,١١	١,٠٩	١٤,٢٥	١,٠٩٧	١٤,٢٢	١,٠٨٧	١٤,١٥
٢٠٠	Single point	١,٠٩٨	١٤,٢٤	١,٠٧٩	١٤,٠٢	١,٠٧٩	١٤,٠٢	١,٠٧٥	١٤,١	١,٠٩٦	١٣,٩
	Dual point	١,٠٨٩	١٤,٠٨	١,٠٦٨	١٤,٠٢	١,١٠٢	١٤,٢٧	١,١٠٨	١٤,٣٤	١,٠٩	١٤,١٨
٥٠٠	Single point	١,٠٦٨	١٤,٢١	١,٠٩	١٤,٠٨	١,٠٦٨	١٤,٣١	١,٠٦٣	١٤,٠٢٩	١,٠٨	١٤,٠٢
	Dual point	١,٠٧٤	١٤,٠٥	١,١٠٨	١٤,٠٦	١,٠٩	١٤,١	١,٠٩٤	١٤,٢٥	١,١	١٤

Table 6. Statistical parameters of the objective function in the GA method

parametr	maximum	minimum	average	Standard deviation	Coefficient of change
Ret	١,٢٠١	٠,٩٩٩٧	١,١١٤	٠,٠٥٥٥	٠,٠٤٩٨
Risk	١٦,٢٣	١٣,٢٨	١٤,٣٦	٠,٨٠٩	٠,٠٥٦٣

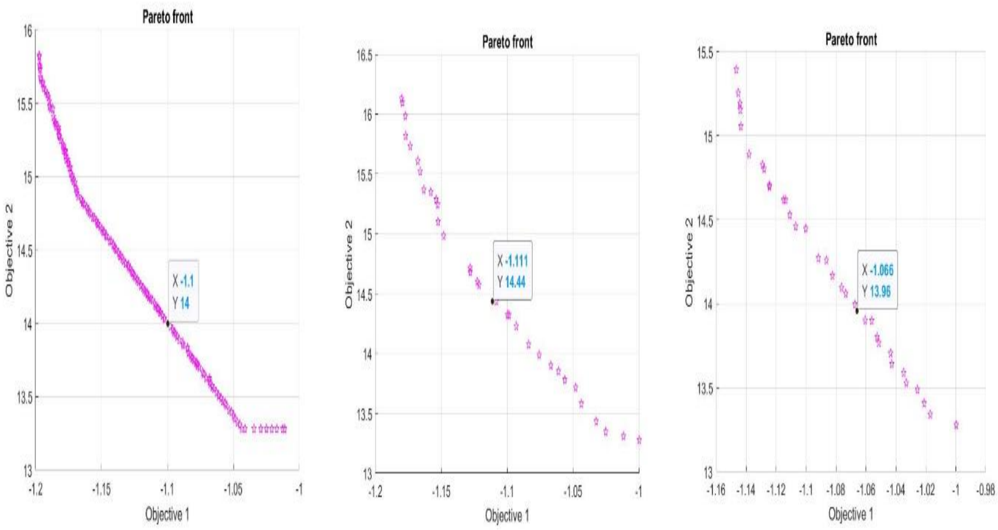

Figure 3. Changes in the objective function in the worst, middle and best execution of the GA method

GWO Algorithm Results: The GWO algorithm is executed 5 times on each benchmark function. The results of the gray wolf algorithm and statistical results (mean and standard deviation) are shown in the following tables and figures:

Table 7. Results of the implementation of the GWO algorithm in solving the research problem

repeat	implementation									
	١		٢		٣		٤		٥	
	Ret	Risk	Ret	Risk	Ret	Risk	Ret	Risk	Ret	Risk
١٠٠	١,٠٦	١٢,٥٥	١,١٥٤	١٣,٧٦	١,٠٨٩	١٣,٣٤	١,٠٨	١٢,٩٩	١,٠٨	١٣,١٢
٢٠٠	١,٠٨٩	١٣,٤٣	١,١	١٣,٧٧	١,١٢٩	١٣,٨٢	١,٠٥٩	١٢,٦٢	١,١٠٨	١٣,٥٧
٣٠٠	١,٠٨٧	١٢,٥٦	١,٠٤٩	١٢,٦١	١,١٠٧	١٣,٧٦	١,٠٥٨	١٢,٤٦	١,١١٦	١٣,٢
٤٠٠	١,٠٩٣	١٣,٨٥	١,١١٧	١٣,٨٨	١,١٢	١٣,٣٤	١,٠٥٧	١٢,٢٩	١,١٠٩	١٣,٤٤
٥٠٠	١,١٠٣	١٢,٨	١,٠٥٣	١٢,٤١	١,١٠٤	١٣,٦٧	١,٠٨١	١٢,٨٧	١,٠٩٢	١٣,٧١

Table 8. Statistical parameters of objective function in GWO method The coefficient of variation of the standard deviation of the mean minimum maximum maximum parameter

parametr	maximum	minimum	average	Standard deviation	Coefficient of change
Ret	١,١٩٦٨	١,٠٠٢٦	١,٠٩٩٢	٠,٠٥٢٨	٠,٠٤٨
Risk	١٤,٠٥٤٦	١١,٧١	١٢,٨٦٠٨	٠,٧١٩	٠,٠٥٥٩

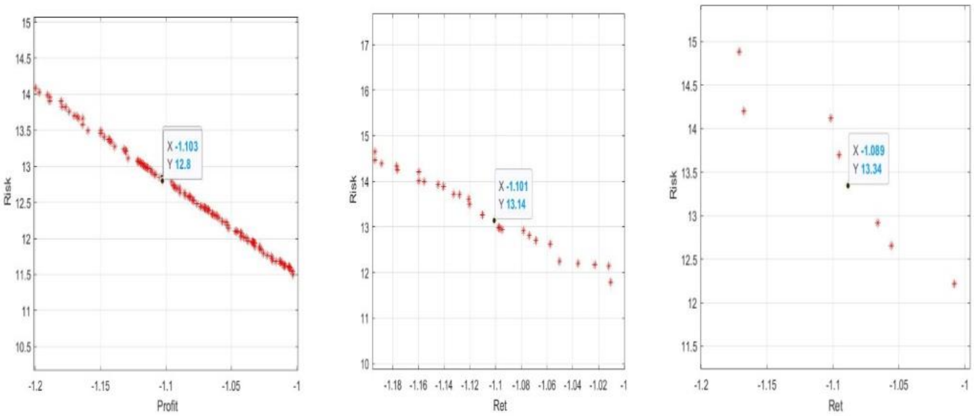

Figure 4. Target function changes in the worst, middle and best execution in the GWO method

Table 9. Results of evaluation of algorithms in six identified indicators

			C_1 NPS	C_2 QM	C_3 MID	C_4 SM	C_5 DM	C_6 TIME
A_1	MOPSO	Ret	٤	٠,٧	١,١٤٧٤	٠,٠٣٢٩	٠,٠٦٨٩	٠,١٤
		Risk			١٥,٢٩٨٨	١,٧٥٠٩	٣,٨٤٤٧	
A_2	GA	Ret	٢٢٠	٠,٧	١,١١٤	٠,٠٥٥٥	٠,٢٠١٣	١٥,٤٦
		Risk			١٤,٣٦	٠,٨٠٩	٢,٩٥	
A_3	GWO	Ret	١١٥	٠,٨	١,٠٩٩٢	٠,٠٥٢٨	٠,١٩٤٢	١٢,٣٩
		Risk			١٢,٨٦٠	٠,٧١٩	٢,٣٤٤٦	

Risk Inferential analysis (test of research hypotheses): Wilcoxon statistical test is used to compare data in two related groups. Therefore, in the following table, a comparison is made between MOPSO, GWO and GA algorithms in terms of the value of the objective function:

Table 10. Answer of the objective function of MOPSO, GWA and GA algorithms in consecutive iterations

تکرار	MOPSO		GA		GWO	
	RET	RISK	RET	RISK	RET	RISK
١	١,١٠٣	١٤,٨٧	١,٠٨	١٣,٩٨	١,٠٦	١٢,٥٥
٢	١,٠٨	١٤,٧٢	١,٠٩٨	١٤,٢٤	١,٠٨٩	١٣,٤٣
٣	١,٠١٩	١٣,٠٣	١,٠٨٩	١٤,٠٨	١,٠٨٧	١٢,٥٦
٤	١,٠٦١	١٥,٢١	١,٠٧٩	١٤,٢١	١,٠٩٣	١٣,٨٥
٥	١,٠٨٤	١٣,٥٤	١,٠٧٤	١٤,٠٥	١,٠٩٦	١٢,٨٢
٦	١,٠١٦	١٢,٣٢	١,٠٧٤	١٤,١١	١,١٥٤	١٣,٧٦
٧	١,٠٩٣	١٣,٥٧	١,٠٧٩	١٤,٠٢	١,١	١٣,٧٧
٨	١,٠٠٤	١٢,٠٩	١,٠٦٨	١٤,٠٢	١,٠٤٩	١٢,٦١
٩	١,٠٣٩	١٣,٩٧	١,١١٩	١٤,٠٦	١,١١٧	١٣,٨٨
١٠	١,٠٨	١٤,٠٧	١,١٠٨	١٤,٠٦	١,٠٥٣	١٢,٤١
١١	١,٠٧٢	١٤,٣٥	١,٠٩	١٤,٢٥	١,٠٩١	١٣,٥٢
١٢	٠,٩٩٩	١٣,٣٤	١,٠٧٩	١٤,٠٢	١,١٢٩	١٣,٨٢
١٣	١,٠٨٢	١٤,٣٢	١,١٠٢	١٤,٢٧	١,١٠٧	١٣,٧٦
١٤	١,٠٩٥	١٣,٥٢	١,٠٦٨	١٣,٨٧	١,١٢	١٣,٣٤
١٥	١,٠٧	١٣,٧٥	١,٠٩	١٤,١	١,١٠٤	١٣,٦٧
١٦	١,٠٢٧	١٤,٣٥	١,٠٩٧	١٤,٢٢	١,٠٨	١٢,٩٩
١٧	١,٢٣٤	١٤,٨٧	١,٠٧٥	١٤,١	١,٠٥٩	١٢,٦٢
١٨	١,٠٣٧	١٣,٦٢	١,٠٩٨	١٣,٧٠	١,٠٥٨	١٢,٤٦
١٩	١,٠٥	١٤,٥٧	١,٠٦٣	١٤,٠٢	١,٠٥٧	١٢,٢٩
٢٠	١,٠٨٨	١٣,٩١	١,٠٩٤	١٤,٢٥	١,٠٨١	١٢,٨٧
٢١	١,٠٢٧	١٤,٣٩	١,٠٨٧	١٤,١٥	١,٠٨	١٣,١٢
٢٢	١,١٠٩	١٤,٩	١,٠٩٦	١٣,٩	١,١٠٨	١٣,٥٧
٢٣	١,٠٣	١٤,٨٣	١,٠٩	١٤,١٨	١,١١٦	١٣,٢
٢٤	١,٠٥٩	١٤,٣	١,١٧	١٣,٨٩	١,١٠٩	١٣,٤٤
٢٥	١,٠٤٧	١٣,٧٤	١,١	١٤	١,١٠٣	١٢,٨

Hypothesis zero in this test indicates no difference and the opposite hypothesis indicates the existence of difference. Therefore, in this section, a comparison of the performance of portfolios obtained from genetic, particle aggregation and gray wolf algorithms in optimizing the risk model is presented.

Hypothesis number one: The meta-heuristic optimization algorithm of particle masses does not have the same efficiency compared to the gray wolf algorithm for assessing the integrated risk of the banking system.

H0: Particle mass meta-heuristic optimization algorithm has the same efficiency compared to the Gray Wolf algorithm for assessing the integrated risk of the banking system.

H1: Particle mass meta-heuristic optimization algorithm does not have the same efficiency compared to the Gray Wolf algorithm for assessing the integrated risk of the banking system.

Ranks		N	Mean Rank	Sum of Ranks
	Negative Ranks	21a	13.57	285.00
	Positive Ranks	4b	10.00	40.00
	Ties	0c		
	Total	25		
a. GWO.Risk < MPSO.RISK				
b. GWO.Risk > MPSO.RISK				

Ranks			N	Mean Rank	Sum of Ranks
	Negative Ranks		21a	13.57	285.00
	Positive Ranks		4b	10.00	40.00
		Ties	0c		
		Total	25		
a. GWO.Risk < MPSO.RISK					
c. GWO.Risk = MPSO.RIS					

Test Statistics[b]	
GWO.Risk - MPSO.RISK	
Z	-3.296a
Asymp. Sig. (2-tailed)	.001
a. Based on positive rank	
b.Wilcoxon Signed Rank Test	

Wilcoxon test results table for the first hypothesis: As can be seen from the Wilcoxon test results, the value of the significance number (Sig) is less than 0.05, so at the 95% confidence level we can claim that the null hypothesis is rejected and the hypothesis one is based on method efficiency inequality. The particle mass is verified in comparison with the gray algorithm.

Hypothesis 2: Particle mass optimization algorithm is not as efficient as the genetic algorithm for assessing the integrated risk of the banking system

H0: Particle mass meta-heuristic optimization algorithms have similar efficiency compared to genetic algorithms for integrated banking risk assessment.

H1: Particle mass meta-heuristic optimization algorithm is not as efficient as the genetic algorithm for assessing the integrated risk of the banking system.

	Ranks	N	Mean Rank	Sum of Ranks
MGA.RISK - MPSO.RISK	Negative Ranks	13a	11.23	146.00
	Positive Ranks	12b	14.92	179.00
	Ties	0c		
	Total	25		
a. MGA.RISK < MPSO.RISK				
b. MGA.RISK > MPSO.RISK				
c. MGA.RISK = MPSO.RISK				

Test Statistics[b]	
MGA.RISK - MPSO.RISK	
Z	-.444a
Asymp. Sig. (2-tailed)	.657
a. Based on negative ranks.	
b. Wilcoxon Signed Rank Test	

Wilcoxon test results table for the second hypothesis: As can be seen from the Wilcoxon test results, the value of the significance number (Sig) is greater than 0.05, so at the 95% confidence level we can claim that null hypothesis is confirmed and hypothesis one is based on the inequality of mass method efficiency. Particles are rejected compared to the gray algorithm. Therefore, particle mass optimization method and genetic method have the same efficiency in assessing the integrated risk of the banking system.

Hypothesis No. 3: The Gray Wolf meta-heuristic optimization algorithm is not as efficient as the genetic algorithm for assessing the integrated risk of the banking system.

H0: The gray wolf meta-heuristic optimization algorithm has the same efficiency compared to the genetic algorithm for assessing the integrated risk of the banking system.

H1: The Gray Wolf meta-heuristic optimization algorithm is not as efficient as the genetic algorithm for assessing the integrated risk of the banking system

.

Ranks				
		N	**Mean Rank**	**Sum of Ranks**
GWO.Risk - MGA.RISK	Negative Ranks	25a	13.00	325.00
	Positive Ranks	0b	.00	.00
	Ties	0c		
	Total	25		
a. GWO.Risk < MGA.RISK				
b. GWO.Risk > MGA.RISK				
c. GWO.Risk = MGA.RISK				

Test Statistics[b]	
	GWO.Risk - MGA.RISK
Z	-4.373a
Asymp. Sig. (2-tailed)	.000

a. Based on positive ranks
.b. Wilcoxon Signed Ranks Test

Wilcoxon test results for the third hypothesis: As can be seen from the Wilcoxon test results, the value of the significance number (Sig) is less than 0.05, so at the 95% confidence level we can claim that null hypothesis rejects and hypothesis one assumes a significant difference between risk assessment. There is a gray wolf algorithm optimization method compared to the genetic method. **Hypothesis 4:** Particle mass optimization algorithm, gray wolf and genetics to evaluate the integrated risk of the banking system do not have the same efficiency.

H0: Particle mass optimization algorithm, gray wolf and genetics are equally effective for assessing the integrated risk of the banking system.

H1: Particle mass optimization algorithm, gray wolf and genetics to evaluate the integrated risk of the banking system do not have the same efficiency.

To test the fourth hypothesis, Kruskal-Wallis test, which is a non-parametric test and a series of analysis of variance tests, was used. This hypothesis tests the k group of a sample of a common statistical population or a similar statistical population extracted with respect to the means to determine the performance of each algorithm.

Ranks			
		N	Mean Rank
Risk	1	25	45.34
	2	25	50.68
	3	25	17.98
	Total	75	

Test Statistics[a,b]

	Risk
Chi-Square	32.402
Df	2
Asymp. Sig .	0.000

a. Kruskal Wallis Test
b. Grouping Variable Method

Table of results of Kruskal-Wallis test for the fourth hypothesis: As can be seen from the results of Kruskal-Wallis test in the table above, the value of significant number (Sig) is less than 0.05, so at 95% confidence level, null hypothesis is rejected and hypothesis one is based on efficiency mismatch. The three methods of MOPSO, GA and GWO are approved in the integrated risk assessment of banks.

5. Conclusion

Results of descriptive statistics of research variables: The data used in this research are related to the fiscal years 1392 to 1397 of the banks listed on the Tehran Stock Exchange. Table 1 shows the average initial value of assets and their average rate of return, as well as the average initial value of liabilities and their average interest rate. The average of total assets in 1397 is 670744505 million Rials and the average of total debts in the years under review is 182372564 million Rials. In this study, 4 types of risks are considered for banks, which include: market risk, operational risk, liquidity risk and credit risk. Market risk by assets is presented in the table related to the fourth section of the research (research findings), the average liquidity, credit and operational risk are 0.12, 0.16 and 0.0051, respectively. 81.79% of assets have risk weights that are selected and finally, based on the collected data, the multi-objective optimization model is adjusted with two objective functions including maximizing returns and minimizing returns and setting 6 limits.

Results of comparing algorithm evaluation indices: After reviewing the literature and opinions of experts and experts, six indicators of Pareto number, quality index, average distance index from ideal point index, distance index, diversity index and algorithm execution time index as performance evaluation indices Algorithms have been identified and introduced in this research. After identifying the indicators, the values of each indicator in the algorithms were calculated and presented. Also, in the table related to the results of comparing the evaluation indicators of the algorithms, the desired values (final decision matrix) were shown in the findings analysis section (Section 4). Based on the results of the table of comparison of indicators in Section 4, it was found that the GWO method offers better efficiency in optimizing the objective function (maximizing returns and minimizing risk).

Results of inferential analysis (test of research hypotheses): In this study, to evaluate the integrated risk of the banking system, we examined the efficiency of three methods of particle mass algorithm, genetics and gray wolf to enumerate the possible benefits of the more efficient method. According to the obtained results, the efficiency of the gray wolf method is higher than the other two methods. The algorithms were evaluated in terms of six indicators of Pareto number of answers, quality index, mean distance index from ideal point index, distance index, diversity index and execution time index of the algorithm, which indicates better indicators of gray wolf algorithm in solving this problem. Wilcoxon statistical test also shows better performance of GWO method than other two methods.

Hypothesis.1: The meta-heuristic optimization algorithm of particle masses does not have the same efficiency compared to the gray wolf algorithm for assessing the integrated risk of the banking system. The results of the Wilcoxon test in the Analysis of Findings section (Section 4) indicate that the efficiency of the particle mass method and the gray wolf algorithm for assessing the integrated risk of the banking system is heterogeneous. The gray wolf algorithm provides better evaluation indicators in problem solving than the particle mass algorithm.

Hypothesis.2: Particle mass optimization algorithm has the same efficiency compared to the genetic algorithm for assessing the integrated risk of the banking system. The results of the Wilcoxon test in the analysis of the findings show that the efficiency of the particle mass method and the genetic algorithm for assessing the integrated risk of the banking system are similar. Genetic algorithm and particle mass algorithm provide homogeneity evaluation indicators in problem solving.

Hypothesis.3: The Gray Wolf meta-heuristic optimization algorithm is not as efficient as the genetic algorithm for assessing the integrated risk of the banking system. The results of the Wilcoxon test in the analysis of the findings show that the efficiency of the gray wolf method and the genetic algorithm for assessing the integrated risk of the banking system is heterogeneous. The gray wolf algorithm provides better evaluation indicators in problem solving than the genetic algorithm.

Hypothesis.4: Particle mass optimization algorithm, gray wolf and genetics to evaluate the integrated risk of the banking system do not have the same efficiency. The results of Kruskal-Wallis test in the analysis of findings (Section 4) show that the efficiency of particle mass method, gray wolf and genetic algorithm for assessing the integrated risk of the banking system is heterogeneous. Gray wolf algorithm has better stability and convergence and less execution time than particle mass and genetic algorithms and provides more appropriate evaluation indicators in problem solving.

Practical suggestions for research results:

*The present study, as a research in the theoretical and practical field, seeks to provide optimal solutions and sub-optimal solutions to minimize the risk of assets and liabilities and maximize the return on assets with the desired limitations.

* In the theoretical field of the present study, those interested in portfolio optimization topics, the possibility of using intelligent methods in obtaining optimal answers and optimal sub-answers.

* In the field of application, the present study, by positively evaluating the quality of the optimal sub-responses of the risk and return model, proposes the gray wolf algorithm method to the banks to calculate the optimal risk and return policy.

Recommendations for future researchers:

Recommended for future researchers: * Solve the model while adding other constraints of the model and compare the results. * Compare Iranian and foreign risk and returns by examining Iranian and foreign banks simultaneously. * Solve the problem in this research with other optimization methods of meta-heuristic algorithms and compare them. Research Limitations: Due to the selection of the period from 1392 to 1397 due to the availability of information required by banks listed on the stock exchange, there was no restriction in this area.

References

1) Ardaneh, Ali (1394). Optimizing the accessibility of series-parallel systems with repairable three-state components. Master Thesis, Raja Institute of Higher Education, Faculty of Engineering.
2) Khosh Sima R, Shahiki Tash M. (1391). The Impact of Credit, Operational and Liquidity Risks on the Efficiency of the Iranian Banking System, Quarterly Journal of Planning and Budget, 4: 16-11.
3) Reza., Saeedi, Ali., (2009) Fundamentals of Financial Engineering and Risk Management ", Samt Publications., Pp. 9-5-58,
4) Zare, Ehsan and Hamidi, Farhad and Rahati, Amin, 2015, Improved Gray Wolf Algorithm, Fourth Joint Congress of Iranian Fuzzy and Intelligent Systems (15th Fuzzy Systems Conference and 13th Intelligent Systems Conference)
5) Sarmad Z, Bazargan AS, Hejazi A. 2001. Research Methods in Behavioral Sciences. Fifth Edition. Tehran: Agah Publications.
6) Saeedi A., Mr. A. 1388. Prediction of financial distress of companies listed on the Tehran Stock Exchange using Bayesian networks of accounting and auditing studies, 56: 78-59.
7) , M. H. and R. Moeini. 2008. Partially and fully constrained ant algorithms for the optimal solution

of large scale reservoir operation problems. Water Resources Management, 22(12): 1835– 1857.

8) Afshar, M. H. and M. Shahidi. 2009. Optimal solution of large-scale reservoir-operation problems: Cellular-automata versus heuristic-search methods. Engineering Optimization, 41(3):275-293.
9) Angeline, P. J. 1998. Evolutionary optimization versus particle swarm optimization: Philosophy and performance differences. Evolutionary Programming VII, Lecture Notes in Computer Science, 1447: 601-611.
10) Fama E. F., (1970), "Efficient capital markets: A review of theory and empirical work", Journal of finance, 25:2, pp. 283-417 [10] Goldberg, D., (1989), "Genetic Algorithm in search, Optimization and machine Learning", Addison-Wesely
11) Huang, X., (2008), "Portfolio selection with new definition of risk", European journal of Operational research, 186, PP. 351-357
12) Keller, R. E., Banzhaf, W., Nordin, P., Francone, F.D., (1998), "Genetic Programming–An Introduction; On the Automatic Evolution of Computer Programs and its Applications" Morgan Kaufmann, dpunkt.verlag
13) Geem Z.W., Kim J-H, Loganathan GV. "Harmony search optimization: Application to pipe network design". Int J Modell Simulat;22(2):125 33, 2002.
14) Lin, Chang., Lin, Yi, Ting., (2008), "Genetic algorithm for portfolio selection problem with transaction lost", European journal of operational research., Vol. 185, ISSUE, 1, 16, PP. 393-401
15) Lin, Chi., Ming, Mitsuo, Gon., (2007), "An effective decision-based genetic algorithm approach to multi objective portfolio optimization problem", Applied mathematical science, Vol. 1, S, E, PP.1-21
16) Markowitz, H., M., (1952), "Portfolio Selection", The Journal of Finance, Vol. 7, 1, PP. 77-91
17) S. Mirjalili and S. Z. M Hashim, "A New Hybrid PSOGSA Algorithm for Function Optimization," International Conference on Computer and Information Application, pp.374-377, 2010
18) Muro. C r. R and Spector. L, Escobedo. R from emerge strategies hunting) lupus canis (pack-wolf Behavioural, simulations computational in rules simple .197-192(2011) 3(88)
19) S. Mirjalili and S. Z. M Hashim, "A New Hybrid PSOGSA Algorithm for Function Optimization," International Conference on Computer and Information Application, pp.374-377, 2010
20) Savic, D. A., Walters, G. A., "Genetic algorithms for least-cost design of water distribution networks". Journal of Water Resources Planning, Management, ASCE,, 123(2), 67-77, 1997.
21) Maier, H.R., Simpson, A.R., Zecchin, A.C., Foong, W.K., Phang, K.Y., Seah, H.Y., Tan, C.L. "Ant colony optimization for design of water distribution systems." J. Water Resour. Plng., Mgmt., 129(3), 200-209, 2003.
22) Zitler, E., & Thiele, L. (1998). Multiobjective optimization using evolutionary algorithms a comparative case study. In A.E. Eiben, T. Back, M. Schoenauer and H.P. Schwefel (Eds.), Fifth International Conference on Parallel Problem Solving from Nature (PPSN-V), Berlin, Germany, 292-301.