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ORIGINAL ARTICLE

A new method for solving the mobile payment scheduling problem using harris hawks optimization algorithm during the COVID-19 pandemic

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Abstract

The Coronavirus Disease 2019 (COVID-19) epidemic is causing once-in-a-century upheavals in global civilization. Payment systems have advanced lately, from simple cash or credit card transactions to various forms of mobile payment systems. This transformation is occurred due to COVID 19 and shifts in the economy, the growth of social networks, technical advancements on the Internet, and the increased usage of mobile devices. Throughout COVID19, this article offers a unique approach to the payment scheduling issue, which seeks out a timetable that enhances the project's stakeholders' benefit. Both the sponsor and the contractor in a project want to have a strong payment plan on their own. To create an equal schedule between the sponsor and the development team, the timing of payments and the completion periods of project activities are decided concurrently. The Harris hawks optimization method is designed to tackle the problem because of its high NP-hardness. Harris hawks optimization is a novel meta-heuristic nature-inspired optimizer inspired by how Harris hawks hunt food in nature. By comparing the suggested Harris hawks optimization optimizer to existing nature-inspired methods, the efficacy of the suggested Harris hawks optimization optimizer is determined. The Harris hawks optimization algorithm appears to be highly promising based on the statistical findings and comparisons. The MATLAB simulator's simulation findings confirm the algorithm's superiority over earlier efforts regarding energy, cost, delay time, and net value.

Keywords Mobile Payment Scheduling · Harris Hawks Optimization · Algorithm · COVID-19 Pandemic

Wen Sun, Yi-Peng Xu and Chen She have contributed equal to their work.

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1 Introduction

Every day, more electronic gadgets are developed in response to the rising community and ever-expanding technology (Shokouhyar et al. 2021). Any financial transaction via the Internet is referred to as e-commerce (Zhao et al. 2021a). The payer utilizes his credit card to complete the transaction in most cases. For safe transaction completion, an e-commerce transaction requires the buyer or cardholder, the buyer's credit card issuer (bank), the merchant, the certifying authority, and the merchant's acquirer (bank). For creating a secure link among the engaged parties, the majority of these protocols use a key agreement mechanism (Vahidalizadehdizaj and Leider 2017). Mobile smart devices (like laptops or smartphones) are commonly utilized in routine life due to the advancement and pervasiveness of mobile communication technology (Afroz et al. 2020). As a result, there is a growing need for diverse Internet services (Chen et al. 2019). Currently, mobile payment is an extensively employed technique for businesses and financial institutions to deliver payment services through mobile devices like smartphones and iPads (Liao et al. 2018). Any transaction carried out through mobile devices, including the direct or indirect exchange of financial values among parties, is called mobile payment. The fact that a mobile phone may be utilized as a payment device in diverse scenarios is an intriguing element of mobile payment. Optimists predict that mobile devices will shift from a basic communication device to a payment techniques in the future world economy (Dizaj et al. 2011). Due to a considerable drop in the physical use of credit cards, cash, and debit cards throughout the COVID-19 epidemic, an increasing percentage of mobile payments are used (Cao 2021; Vahdat 2021).

According to a recent study, privacy, security, and ease of use are the three criteria for mobile payment subscribers, making mobile payment security an inescapable challenge in the growth of mobile payment businesses (Zhang et al. 2016). The Project Payment Scheduling Problem (PPSP), which is a novel branch of the Max-net Present Value (NPV) project scheduling issue, is concerned with how to plan progress payments to increase the contractor's or client's NPV (He et al. 2014). A schedule is a plan for conducting a method or operation that includes a list of the activities and times. Scheduling problems in project management, which is considered one of the most important and challenging aspects, have caught much of the attention of theoreticians and practitioners in the research community. It is a generic name given to a whole class of issues. The allocation of the project resources, optimizing the project duration, and estimated costs are necessary (Trinh et al. 2019). Because of the restrictions inherent in the project, project scheduling entails establishing the start time of each project activity and developing a timing sequence to conduct a set of relevant tasks in order of their priority (He, Liu et al. 2009). Hence, there is a balance between project completion time and overall cost, and one or more aims are met. The alternatives are evaluated in order to fulfill these goals, and then the best option is chosen (Hegazy and Petzold 2003). There are priority restrictions among tasks in all projects, but additional limitations, such as resource restrictions, exist. Resources are allocated according to the requirements of the operations, the time it takes to complete them, and the financial flows employed in the building process (Seyfi Sariqaya et al. 2019; Zhao et al. 2021a, b).

COVID-19's outbreak and subsequent management measures have resulted in a worldwide medical disaster that has impacted all facets of life. Policymakers and directors of companies or organizations that employ mobile payments should begin strategizing to resolve the COVID-19 epidemic's future challenges. Because the mobile payment-scheduling issue is NP-hard, numerous meta-heuristic and heuristic processes have been constructed to tackle it throughout the COVID-19 epidemic. Earlier research has employed Harris' Hawks Optimization (HHO) approach to handle various issues and demonstrated that it outperforms other newly invented and popular optimization techniques (Elgamal et al. 2020). We were inspired to use HHO to solve challenges with mobile payment scheduling. As far as we know, investigating the HHO for solving this issue was not done, especially in COVID 19 era; therefore, this is the main innovation of the article. HHO is based on the coordinated behavior and chase method of Harris' hawks in nature, known as surprise pounce. Multiple hawks work together to attack a victim from various directions to catch it off guard. According to the dynamic nature of circumstances and the prey's fleeing tactics, Harris hawks can exhibit diverse pursuing patterns (Heidari et al. 2019). This investigation statistically models such dynamic behaviors and patterns to develop an optimization strategy. We are trying to solve the related problems as follows:

RQ1: Has the HHO algorithm minimized delay time in mobile payment scheduling during the COVID-19 epidemic?
RQ2: Has the HHO algorithm minimized energy utilization in mobile payment scheduling during the COVID-19 epidemic?
RQ3: Has the HHO algorithm minimized the cost of mobile payment scheduling during the COVID-19 epidemic?
RQ4: Has the HHO algorithm maximized the NPV of the mobile payment schedule during the COVID-19 epidemic?

There are five sections to this study. The first section introduces mobile payment and its issues. A variety of strategies are explored and contrasted in Sect. 2. The approach proposed in this study is then explained in Sect. 3. Section 4 contains information on the recommended technique's simulation, data sets, and assessment criteria, among other things. Section 5 describes the limitation, implications, and future work. The paper's accomplishments and potential study topics are presented in Sect. 6. Finally, Appendix A contains a list of notations utilized in this study (Table).

2 Related work

Because of improvements in digital technology, m-payment mechanisms have gotten a lot of focus in the last ten years. These procedures can greatly enhance the quality of online services if they are used in the internet industry (Thammarat and

Techapanupreeda 2021). A summary of some optimization algorithms employed in mobile payment problems is presented below.

Mukhopadhyay and Upadhyay (2022) examined how organizational involvement and platform competition affected platform-based payment service uptake and retention intentions. The study was backed by a small number of conversations and is dependent on archive data. The findings revealed that organizational interventions (in various ways) boosted people's willingness to adopt m-payment. Furthermore, competition among numerous payment systems had a beneficial influence on customers' intentions to continue using m-payments.

Dhamija and Dhamija (2022) proposed architecture and presented a security approach for mobile payments systems. The proposed architecture defined the role and responsibilities of each participating entity and took care of all the concerning issues in the mobile payment system. A multi-factor authorization security approach based on hashing and cryptography had been adopted, adding an extra security layer before the transaction got executed, generating a unique OTP. The results showed that the proposed approach is implemented as a Web application and validated through experimentation.

Chen et al. (2021) suggested an antagonistic network for bias correction. They employed a limited collection of unbiased data collected by a full-randomized assignment approach to developing an unbiased framework, which they then utilized to remove bias using adversarial learning. According to the findings, their solution beats state-of-the-art alternatives and increases the performance of the resultant allotment policy in a real-time marketing campaign.

Zhang et al. (2020) looked at the Payment Scheduling Negotiation Problem (PSNP), which is a realistic expansion of the Resource-Constrained Project Scheduling Problem (RCPSP). It takes into account both the contractor's and the customer's needs. These two parties negotiated to develop an activity schedule and a payment project plan to enhance NPVs on both sides and create a win–win outcome. They presented a strategy that included the following aspects. First, the issue was recast as a preference-based bi-objective optimization issue. Second, a multilayer area interest method was given to handle the customer and contractor's differing priorities. Third, to address the PSNP effectively, this method was integrated into the Nondominated Sorting Genetic Algorithm II (NSGA-II). According to the observations, the suggested approach could search the Region of Interest (ROI) and provide more pleasing results.

Also, Vahdani and Shams (2020) looked at a multi-mode capital-restricted PPSP with a bonus-penalty structure applied at the project's deadline. They created a mathematical model of the issue based on the project's event-based description. They ran a computing trial to see how well our technique fared against the Simulated Annealing (SA) algorithm and two heuristic methods, Random Sampling (RS) and Multi-Start Iterative Improvement (MSII). The findings revealed that Tabu Search (TS) is a significantly more powerful solution approach, particularly for big issue cases. They also looked at the impact of important issue factors on the contractor's NPV. They discovered that the number of payments, the contractor's initial capital liquidity, and the awarding ratio of the bonus-penalty construction are positively related to the NPV.

Furthermore, Gholizadeh (2018) studied the multi-mode project scheduling issue aiming to plan payments considering limited resources. This model tried to propose a possibly close to reality schedule by taking realistic assumptions into account. Renewable resources (such as machinery, workforce, and equipment) and non-renewable ones (such as money and consumption) were considered in this model. Then, the issues of scheduling and planning the project payment were examined using the objectives of increasing the NPV of the project and decreasing the project's completion time. They subsequently recommended the NSGA-II method to deal with the issue in huge dimensions. The observations demonstrated that the recommended technique outperformed other approaches.

Moreover, Li et al. (2017) used the NPV of discounted cash flows to assess the potential value of multi-mode and resource constraints (MRCPSNP). They used a co-evolution method to mimic the negotiation procedure, in which the two sides negotiate to maximize their respective NPV. A Multi-swarm Particle Swarm Optimization (MPSO) technique combines the co-evolution approach and the multi-level region of interest methodology into a PSO algorithm. The recommended technique was extremely successful and promising compared to the outcomes of 30 project examples.

Finally, Mortazavi Nejad et al. (2017) tackled a project payment schedule where a project deadline was set and operations were permitted to be compressed to maximize the contractor's NPV. The volume of work completed at so-called review points was determined using two distinct techniques in this article. Only completed actions were evaluated in the first method. In the second method, any parts of the actions carried out were taken into account. The contractor might opt to crash some operations to maximize the volume of work completed at the review points, potentially increasing his NPV. A solution must have been reached because crashing action costs the contractor money. Two mathematical models were created to investigate each technique, assisting the contractor in making the best option possible. These models provided a method of determining if it is appropriate to halt particular activities and were useful. Even when the contractor paid for the activity crashing expenses, the contractor's NPV might be increased.

Table 1 examines and contrasts the available approaches for the issue of m-payment scheduling and the benefits and drawbacks of each solution. To solve these problems, the mobile payment scheduling problem using Harris hawks optimization algorithm during the COVID-19 is proposed, followed by the decreased cost, energy, delay time, and improved net present value.

3 Harris Hawks meta-heuristic optimization algorithm

The HHO algorithm is a population-based meta-heuristic method. It is inspired by the life of hawks in nature and the way they hunt (Kolli and Tatavarthi 2020). This algorithm was introduced by Heidari et al. (2019) Harris hawks seek prey by working together in the wild. Their predation is mostly based on unexpected attacks. In addition, the hawks can employ diverse pursuing techniques in response to the changing features of the environment and prey escape tendencies. Exploitation, exploration, and

Table 1 Comparison of available methods

Article	Purpose	Method	Outputs	Weaknesses
Mukhopadhyay and Upadhyay (2022)	Examining the impact of institutional intervention and platform competition on the initial adoption and continuance intention of platform-based payment services	Drawing insights from the institutional theory and theories on the multisided platform Using archival data and a limited number of interviews	Understanding of the technology adoption challenges Highlighting the relative success of technology adoption Improving the continuance intention of users to use mobile payments	Using the limited data
Dhamija and Dhamija (2022)	Defining the role and responsibilities of each participating entity and taking care of all the concerning issues in the mobile payment system	Preparing architecture and presenting a security approach for mobile payments systems	Increasing security Improving network availability and bandwidth	Not considering cost
Chen et al. (2021)	Introducing the mechanism of adversarial learning to build an unbiased response model	Presenting an adversarial learning method for incentive optimization in mobile payment marketing	Improving allocation	Reducing accuracy Not considering energy consumption
Zhang et al. (2020)	Looking at the PSNP, which is a realistic expansion of the RCPSP	Proposing a multi-level ROI strategy to deal with the complicated preferences in the PSNP	Controlling the tolerance degree of the preferences Improving NPVs	Not considering user preferences
Gholizadeh and AFSHAR (2018)	Studying the multi-mode project scheduling issue aiming to plan payments	Proposing the NSGA-II algorithm	Increasing the NPV of the project Decreasing the completion time of the project	Considering limited resources
Li et al. (2017)	Providing MRCPSNP for the practical extension to the RCPSP	Forming an MPSO approach	Increasing the NPV of the project	Not considering delay time

Table 1 (continued)

Article	Purpose	Method	Outputs	Weaknesses
Mortazavi Nejad et al. (2017)	Payment scheduling under project crashing based on project progress	Using two different approaches to determine the volume of work performed (review points) Developing two mathematical models	Increasing the NPV Improving activity crashing costs	Not considering energy consumption Increasing complexity

the change of those two states will be used to define the algorithm in HHO. Figure 1 illustrates the fundamental logic of HHO.

Three stages make up the HHO algorithm: 1. Exploration phase, 2.1 The transition from exploration to exploitation (extraction), 3. Exploitation phase (extraction): soft siege and hard siege.

3.1 Exploration phase

Hawks can detect prey with their keen eyes without being seen by prey. For successful hunting, they spend several hours monitoring their prey and attacking at the right time. In this algorithm, the answer candidates are hawks, and the best hawk (answer) is introduced as a hunting candidate (leader); it may be the main optimal answer in its neighborhood. The placement of the hawks in the exploration phase is done in two strategies.

Strategy 1: They choose their posture depending on the positions of other individuals of their family and prey ($q<0.5$).

Strategy 2: Hawks are randomly scattered in random positions within the search space ($q \leq 0.5$).

In the following stage, the hawks' position vector will be computed as follows:

$$X(t+1) = \begin{cases} X_{rand}(t) - r_1\left|X_{rand}(t) - 2r_2X(t)\right| & q \geq 0.5 \\ \left(X_{rabit}(t) - X_m(t)\right) - r_3\left(L_B + r_4\left(V_B - L_B\right)\right) q < & 0.5 \end{cases} \quad (1)$$

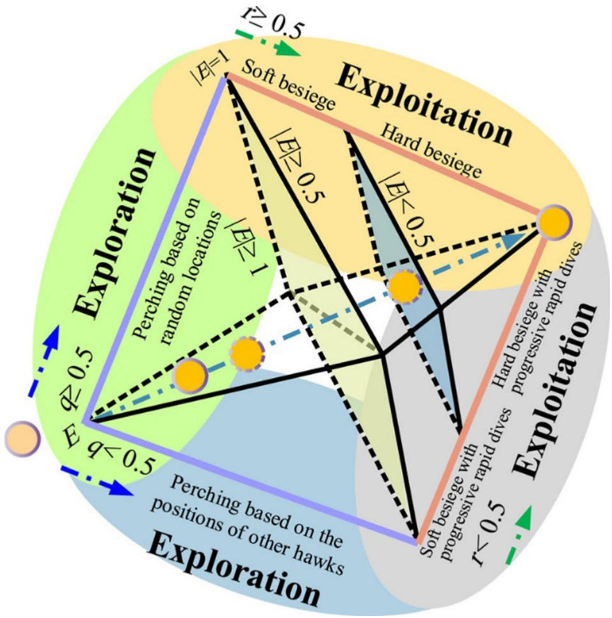

Fig. 1 The logic of HHO (Jiao et al. 2020)

where, $X_{rand}(t)$, $X_{rabit}(t)$, $X_m(t)$, L_B, and V_B indicate the random selection of hawks in the community, the mean location of the present community of hawks, the hunting location (rabbit), the vector position of the current position of hawks, the lower limit, and the upper limit, respectively. Parameters r_1, r_2, r_3, r_4, and q are randomly selected numbers between (0, 1) intervals, updated at each step. The preceding formula is used to calculate the estimates of the mean location of the present group of hawks in this formula:

$$X_m(t) = \frac{1}{N}\sum_{i=1}^{N} X_i(t) \tag{2}$$

In this regard, N and $X_i(t)$ represent the population of hawks and the position of each hawk in stage t.

Transitioning from the exploration stage to the extraction stage: This algorithm is capable of transitioning from exploring to extracting. It may adjust its behavior depending on how much energy the victim has left. Throughout the run, the energy of the prey is depleted. Equation 3 is used to calculate the energy of the prey:

$$E = 2E_0\left(1 - \frac{t}{T}\right) \tag{3}$$

where, E_0 and T represent the initial energy and the highest number of steps, two states can occur here:

1) $|E| \geq 1$: In this case, the hawks are looking for different areas to find the hunting place, so the exploration phase must be updated and re-executed.
2) $|E| < 1$: In this case, the algorithm tries to find the best answer to check in its neighborhood so that the algorithm will move to the extraction phase.

3.2 Extraction phase

Here, the hawks should perform the sudden attack stage by the candidate prey appointed in the previous stage. As stated, this phase has two modes of soft and hard siege. Parameter E, or hunting escape energy, determines which state we are in.

A. Soft siege: When the prey has enough energy to escape, the hawks gently surround it to deplete its energy ($|E| \geq 0.5$).

The accompanying formula can be used to update the hawks' location at this point:

$$X(t+1) = \Delta X(t) - E\left|JX_{rabit}(t) - X(t)\right| \tag{4}$$

where,

$$\Delta X(t) = X_{rabit}(t) - X(t) \tag{5}$$

$$J = 2\left(1 - r_5\right) \tag{6}$$

Here, the variation across the position vector of food and the present location is represented by $\Delta X(t)$, J, r_5, a random value between 1 and 0, imitating the hunting motion. When the rabbit has sufficient strength to flee throughout the soft siege, the hawks make multiple fast team dives around the victim. They attempt to slowly alter their position and course in response to the prey's deceptive moves. The accompanying formula can be used to provide an update on the location of the hawks:

$$X(t+1) = \begin{cases} Y & if \quad F(Y) < F(X(t)) \\ Z & if \quad F(Z) < F(X(t)) \end{cases} \tag{7}$$

where

$$Y = X_{rabbit}(t) - E\left|X_{rabbit}(t) - X(t)\right| \tag{8}$$

$$Z = Y + S * LF(D) \tag{9}$$

$$LF(D) = 0.01 * \frac{u * \sigma}{|\vartheta|^{\frac{1}{\beta}}} \tag{10}$$

$$\sigma = \left(\frac{r(1+\beta) * \sin\left(\frac{\pi\beta}{2}\right)}{r\left(1 + \frac{\beta}{2}\right) * \beta * 2^{\left(\beta - \frac{1}{2}\right)}} \right)^{\frac{1}{\beta}} \tag{11}$$

where, u, S, D, ϑ, and β represent the random value between 1 and 1, the random vector with $1*D$ size, the dimensions of the problem, the random value between 1 and 0, and the constant parameter with the value of 1.5, respectively. *LF(D)* is defined to simulate the deceptive movements of prey during the escape phase. Hawks are constantly changing positions to deal with all kinds of deceptive movements of prey. Therefore, according to these behaviors, they can choose the best way to reach the prey.

B. Hard siege: When the prey loses its energy, the hawks tighten the siege. The hawks' new location is calculated using the corresponding formula:

$$X(t+1) = X_{rabbit}(t) - E|\Delta X(t)| \tag{12}$$

When the siege is challenging and the victim lacks the strength to run, the hawks strive to shorten the gap between themselves and the running prey. The accompanying formula is used to compute the new location of the hawks in this scenario (Wang et al. 2021):

$$X(t+1) = \begin{cases} Y & if \quad F(Y) < F(X(t)) \\ Z & if \quad F(Z) < F(X(t)) \end{cases} \tag{13}$$

$$Y = X_{rabbit}(t) - E\left|JX_{rabit}(t) - X_m(t)\right| \tag{14}$$

$$Z = Y + S * LF(D) \tag{15}$$

The flowchart of HHO is displayed in Fig. 2.

The pseudo-code for the algorithm is given below (Milenković 2021):

4 Results

Math Works, Inc. of Natick, Massachusetts, is very economical and designed, which also provides support. MATLAB is an efficient programming platform for meta-heuristic algorithms like HHO, and it offers several benefits over other platforms, including:

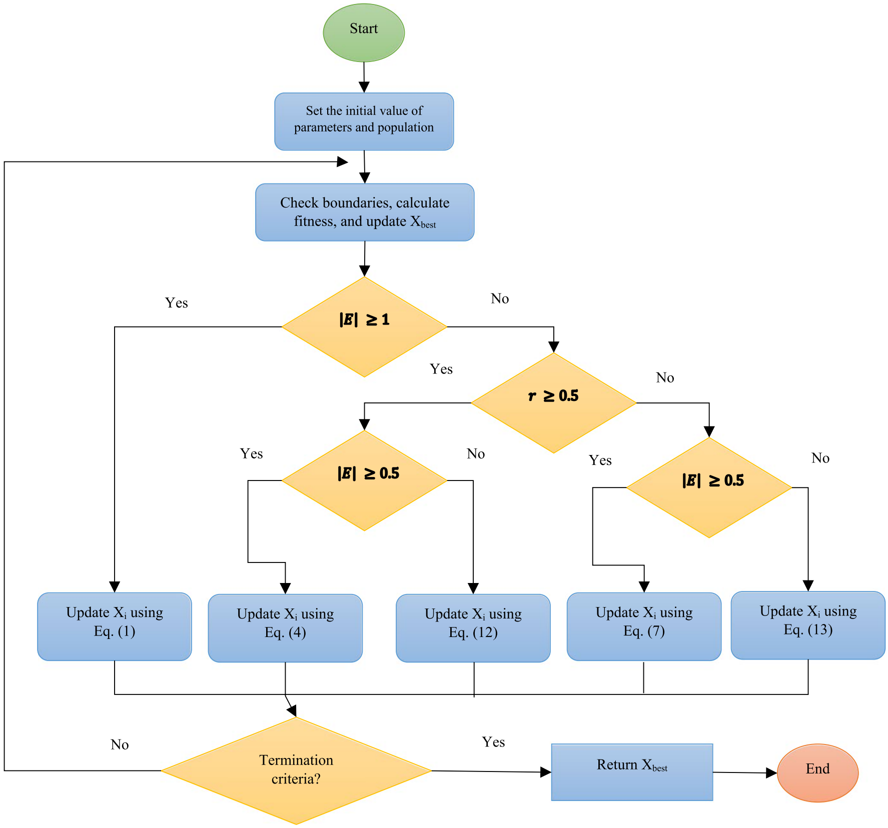

Fig. 2 HHO algorithm flowchart

- Its major data component is the matrix;
- It has a strong capacity to study the impact of various physical layer factors on the device;
- It enables graphical outputting for generating data with a variety of techniques and capabilities;
- It has node creation freedom.

Investigators may do sophisticated calculations and simulations with the help of MATLAB, and formerly accessible methods can be utilized as a novel toolbox (Sadrishojaei et al. 2021). MATLAB allows investigators to concentrate on their inventions instead of seeking the necessary computational resources. Thus, MATLAB is used to analyze the suggested approach. The suggested aggregation approach was simulated and evaluated using MATLAB software. A computer with Windows 7, an Intel Core i5 – 2.5 GHz processor, and 4 GB RAM is used for all the tests. Table 2 also includes the values of the technique's crucial parameters.

The objective function is displayed in the studied iterations to investigate the suggested algorithm's convergence. The outcomes reveal that the recommended method outperforms the GA (Seyfi Sariqaya et al. 2019) and Ant Colony Optimization (ACO) algorithm in terms of fitness. In 100 replications, the suggested strategy is compared against the GA and ACO to evaluate its convergence (Fig. 3).

- The delay time of mobile payment scheduling problem

One direction to reduce delay time is to use new methods such as deep algorithms (Lv et al. 2021, Zhong et al. 2021) and unsupervised domain adaptation (Fang et al. 2020). This paper proposed an HHO algorithm to minimize the delay time in the mobile payment schedule. In Fig. 4, the suggested approaches' delay times are compared to ACO and GA. The suggested technique's latency reduced as the number of tasks increased, demonstrating that the recommended approach outperformed the other two techniques.

- The energy utilization of mobile payment scheduling problem

Energy management is frequently considered a crucial aspect of developing nations' efforts to enhance their economic outlook (Ebrahimian et al. 2018). Numerous architectures and approaches for energy management systems are developed utilizing several optimization algorithms like the multi-objective PSO

Table 2 Values of parameters in HHO

q, r_1, r_2, r_3, r_4, r_5	U (0, 1)
μ	N (0, 1)
v	N (0, 1)
β	1.5
F	6
Q	5

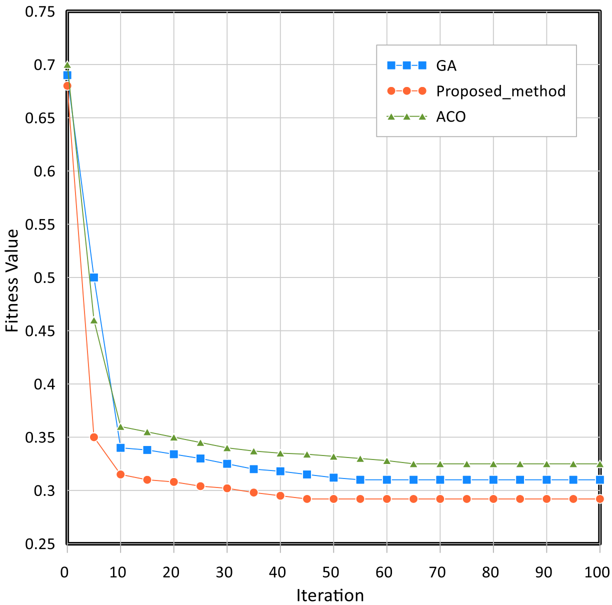

Fig. 3 Convergence diagram of three strategies in 100 iteration

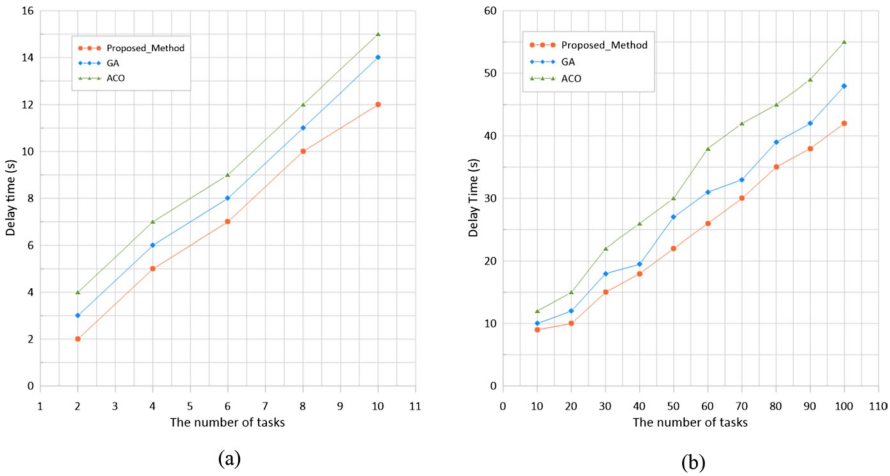

Fig. 4 Comparison of the delay time of the proposed method to GA and ACO algorithms: (**a**) with ten tasks and (**b**) with 100 tasks

algorithm (Aghajani and Ghadimi 2018), Sine–Cosine Algorithm (SCA), and Crow Search Algorithm (CSA) (Yang et al. 2021). In order to reduce power usage in m-payment schedules, this article presented an HHO algorithm. Compared to ACO and GA, Fig. 5 demonstrates how much energy the suggested technique uses. As the tasks grow, the recommended technique's energy usage decreases compared to the other two, demonstrating that it performs well.

- The cost of the mobile payment scheduling problem

Comparing the suggested method to ACO and GA, Fig. 6 displays the costs. Compared to the other two algorithms, the suggested technique's costs have dropped as the tasks have risen, indicating the recommended method's superior performance.

- Maximizing NPV

When the financial analyst does not have total assurance in the values of cash flow characteristics, the choice will result in risk and uncertainty. In this scenario, the financial analysis must be based on the idea of "anticipated value". Rather than using an absolute number for the cash flow parameter, this approach uses a range of values depending on the pattern of previous data or potential volatility. Estimating the probability distribution of parameters and NPV and calculating the mean and variance of that distribution are effective in economic analysis. Risk is the result of variance in the value of variables that can be used to predict the behavior of changes in values using random numbers. The expected value (estimated) in year *K* (F_k) has the mathematical expectation of $E(F_k)$ and variance of $Var(F_k)$. Therefore, the mathematical expectation of the *E (NPV)* and its variance *(Var (NPV))* is calculated as follows:

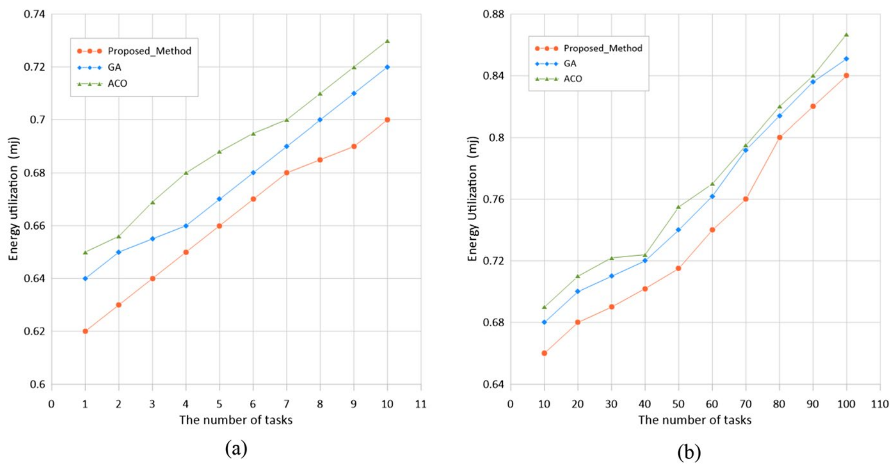

Fig. 5 Comparison of energy utilization of the proposed method to the GA and ACO algorithms: (**a**) with ten tasks and (**b**) with 100 tasks

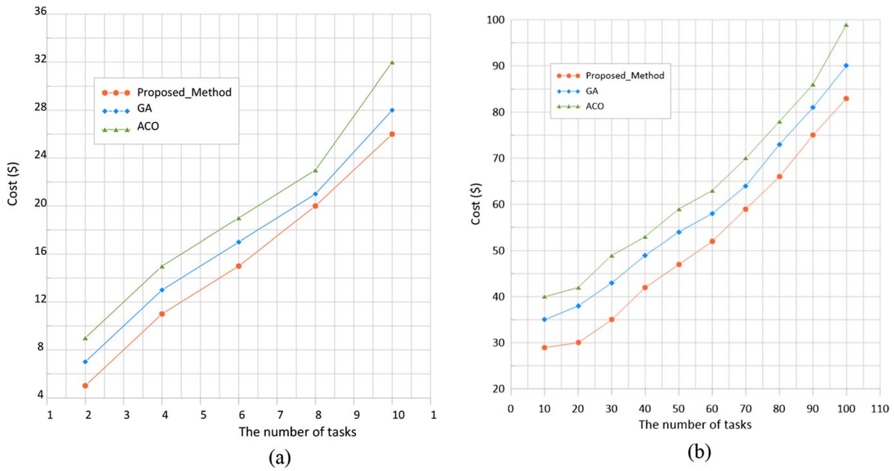

Fig. 6 Comparing the costs of the recommended technique to the GA and ACO algorithms: (**a**) with ten tasks and (**b**) with 100 tasks

$$E(NPV) = \sum_{K=0}^{K} \left({}^{P}/_{F},\ \ i\%,\ \ K \right) . E\left(F_k\right) \tag{16}$$

$$Var(NPV) = \sum_{K=0}^{K} \left({}^{P}/_{F},\ \ i\%,\ \ K \right)^2 . Var\left(F_k\right) \tag{17}$$

Volatility and uncertainty about the future cause the NPV or rate of return of a project to fluctuate widely. In such instances, the best socioeconomic choice is to approve a project with an average net present value (NPV) or a project with an average present value larger than 0 and above the average present value of other incompatible projects. Figure 7 shows the percentage change in NPV over time.

- **Statistical analysis**

Compared to the GA and ACO algorithms, an analytical method has been used to analyze the proposed method based on nonparametric statistical measures. Friedman is also utilized in several comparative investigations as a result of this characteristic. To conduct a quantitative analysis of the algorithms used to assess the investigation classifications, get the necessary post-hoc techniques, and calculate the regulated p values. For the randomly generalized implementation graphs, algorithms were statistically assessed.

H1: The efficiency of the proposed method appears to be distinct from the other algorithms.

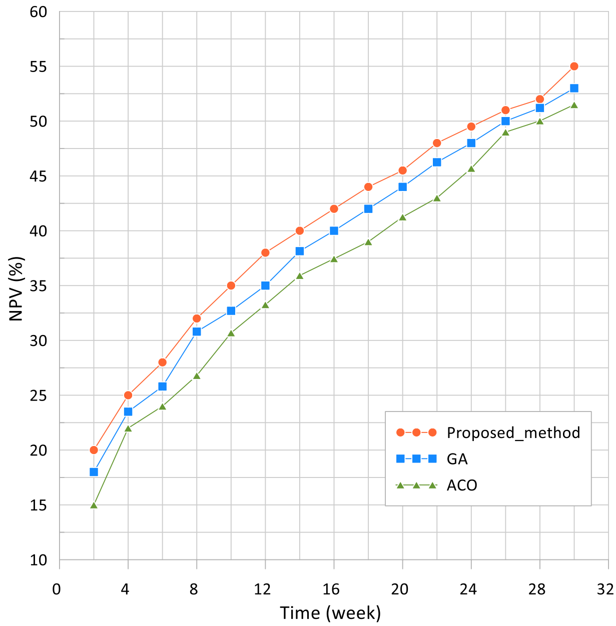

Fig. 7 Percentage of NPV changes over time

H0: The efficiency of the proposed method does not appear to vary from the other algorithms.

In terms of average ranks achieved by complete algorithms for 150 tasks, Tables 3 and 4 reflect Friedman's outcomes. We require to utilize the outcomes of Table 3 (Test statistics) to interpret the Friedman test outcomes to figure out if the discrepancy in the average success algorithms is important. According to the chi-square test (40.263), meaningful at an error rate of less than 0.01, the proposed method's result is analytically corrected with a 0.99 confidence level, as shown in this table. This result indicates that H0 is ruled out, and H1 is verified.

Table 3 Test statistics

Parameter	Value
N	200
Chi-square	40.263
df	2
Asymp. sig	0.000

a. Friedman Test

Table 4 Friedman test (Ranks)

	Mean rank
ACO	1.88
GA	1.96
Proposed method	2.04

We must now use the findings of Table 4 to determine which algorithm has the lowest and which method has the highest performance. According to this table, the average rankings of GA and ACO were 1.96 and 1.88, respectively. Nevertheless, the recommended technique's mean value is 2.04, indicating improved effectiveness.

5 Limitation, implications, and future work

The suggested approach, like other optimization methods, has some drawbacks. The main disadvantage is that it takes a long time to run compared to other algorithms. The mathematical complexity of the traditional HHO, not the recommended changes, explains the wasted time. Moreover, one of this method's limitations is considering four parameters in the mobile payment scheduling problem. In addition, HHO suffers from drawbacks of local optima and population diversity, so this method is other limitations. Utilizing the suggested strategy, the conclusions in this research will assist m-payment service suppliers in improving m-payment scheduling. Additionally, the outcomes of this article assist these suppliers in effectively globalizing by focusing on those precursors. We plan to verify the feasibility of the suggested solution to be actually tested as upcoming work. We suggest expanding the current multi-mode capital restricted project payment scheduling problem with the bonus-penalty construction to include resource restrictions in the decision model as a future research path. In addition, integrating the provided method with other techniques which were utilized to tackle several issues, like Convolutional Neural Networks (CNNs) (Dong et al. 2021) and clustered lifelong learning (BN 2021).

6 Conclusion

The outbreak of COVID-19 has caused many alternations in the societies (Vahdat et al. 2021a; Vahdat et al. 2021b). It is likely to have a substantial impact on the payment card industry. Contactless payment is touted as a more sanitary and secure method of payment. This problem encourages people to use their phones to pay for things. The COVID-19 encourages individuals to explore alternative payment methods when shopping to prevent touching cash and other items. Nevertheless, while the COVID-19 improves mobile payments, it is critical to keep digital and online transactions safe. Mobile payment service is also a key enabler for mobile commerce. It is a technology that enables the user to use the mobile phone and its applications to make requests to purchase a product, pay bills, bank bills, etc. In order for electronic payment systems to meet the user's needs properly, it is necessary to obtain user's satisfaction. Hence, reducing costs, time, and energy and improving NPV can be considered essential criteria for evaluating the success of mobile payment services. As a result, throughout the COVID-19 pandemic, a new approach is used to tackle mobile payment scheduling utilizing the HHO optimization algorithm. In this algorithm, some hawks attack a hunt to startle it (exploration phase). When escaping and fleeing the hunt, the hawks may conduct a series of rapid dives near the target to startle it and wear it out (exploitation phase). Depending on the fleeing potential of the victim, the algorithm may transition from exploring to exploiting and subsequently move among several exploitative modes. The simulation outcomes indicated that the proposed method could efficiently improve time, cost energy, and current net worth. Its performance is better than GA and outperforms ACO well.

Appendix

See Table 5

Table 5 List of notations

Project payment scheduling problem	PPSP
Max-net present value	NPV
Harris' hawks optimization	HHO
Payment scheduling negotiation problem	PSNP
Resource-constrained project scheduling problem	RCPSP
Nondominated sorting genetic algorithm II	NSGA-II
Region of interest	ROI
Simulated annealing	SA
Random sampling	RS
Multi-start iterative improvement	MSII
Tabu search	TS
Multi-swarm particle swarm optimization	MPSO
Ant colony optimization	ACO

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