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Building an E-Learning System Calculating Pension Funds Using the Cox Ingersoll Ross Interest Rate Model

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Abstract: Pension funds play a crucial role in ensuring financial security in retirement, yet many individuals struggle with understanding and accurately calculating their future pension benefits. This research aims to provide an interactive learning platform that allows users to understand and calculate pension fund projections more accurately, by integrating the Cox Ingersoll Ross (CIR) interest rate model into the e-learning system, so as to improve users' financial literacy, especially in retirement planning. This study uses a Research and Development (R&D) approach with the ADDIE method, data through research instruments such as pre-test and post-test questionnaires, system usability assessment forms, semi-structured interview guides, and system usage observation sheets, which are then analyzed using descriptive and inferential statistical methods for quantitative data and thematic analysis for qualitative data. The results show the creation of an effective and user-friendly e-learning system for calculating pension funds, with the successful implementation of the Cox Ingersoll Ross interest rate model into the system, which resulted in a significant increase in user understanding of the concept of pension funds and the use of the CIR model. The developed e-learning system has proven effective in improving user understanding of pension fund calculations, with the use of the Cox Ingersoll Ross interest rate model providing more accurate and realistic projections, thus contributing significantly to improving user financial literacy, especially in the aspect of retirement planning.

Keywords: Cox-Ingersoll-Ross Model; E-Learning; Finance; Interest Rate; Pension Fund

Introduction

Pension funds play a crucial role in ensuring financial security in retirement and supporting broader economic stability. Despite significant challenges, the industry continues to adapt by adopting innovative strategies and cutting-edge technologies to improve effectiveness and sustainability. Building an e-learning system (Al-Fraihat et al., 2020) to calculate pension funds using the Cox Ingersoll Ross (CIR) interest rate model involves a variety of technical, content development, user experience, validation, and security challenges.

With the right approach and focused solutions, the challenges faced in developing an e-learning system (Pham et al., 2019) for calculating pension funds (Ferreira Morici & Vigna, 2024) using the Cox Ingersoll Ross (CIR) interest rate model (Coffie et al., 2024) can be effectively addressed (Ra, 2024). These include the use of accurate discretization methods, efficient parameter optimization and calibration, and the development of comprehensive and personalized learning content according to user needs. In addition, an intuitive and user-friendly interface design (Ali et al., 2024), accompanied by clear and informative real-time feedback, will enhance the learning experience and understanding of users. Extensive simulation result validation and comprehensive learning effectiveness evaluation will ensure that the system is not only academically valid, but also practical and useful in real-world contexts (Alghabban & Hendley, 2024). By paying attention to the security and privacy of user data and compliance with applicable regulations, the system can be a reliable and trusted tool to improve financial literacy and help individuals plan their retirement better

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(Bhaskaran et al., 2021). The successful implementation of an e-learning system (Almaiah et al., 2020) for calculating retirement funds using the Cox Ingersoll Ross (CIR) interest rate model will have a significant impact on improving financial literacy in the community (Broeders et al., 2021). With access to sophisticated and interactive simulation tools, individuals will be able to understand the concept of retirement planning more deeply and accurately.

The system not only provides theoretical information, but also allows users to perform calculations and projections of retirement funds (Maurer et al., 2016) based on various interest rate scenarios, so that they can make more informed and timely decisions regarding their investments and retirement strategies. In addition, the personalization features and real-time feedback provided by the system will help users assess and adjust their retirement plans according to changing financial and economic conditions. Thus, the implementation of this system will provide a valuable tool for individuals to manage their finances more effectively, reduce the risk of insufficient retirement funds (Łyskawa & Bielawska, 2024), and ensure long-term financial security. The Cox Ingersoll Ross (CIR) model is a powerful model for capturing interest rate dynamics with its mean-reverting property and ensuring non-negativity of interest rates.

However, this model has limitations in capturing more complex market dynamics and structural changes occurring in the economy because the CIR model assumes that interest rate volatility depends only on the level of the interest rate itself. Calibration of the CIR model requires extensive and high-quality historical interest rate data, but obtaining sufficient data for accurate calibration can be challenging, especially in less liquid markets or in emerging economies. Although e-learning systems (Alhabeeb & Rowley, 2018) provide interactive simulation tools, not all users may have sufficient technical skills or knowledge to make full use of these features. Challenges in designing intuitive and user-friendly user interfaces often arise, especially in explaining complex concepts such as the CIR model to non-technical users.

In addition, e-learning systems (Lwoga & Komba, 2015) must be able to provide a personalized experience based on the specific needs and situations of users, but developing adaptive and relevant content for different user profiles can be a major challenge. The expectation to be achieved from "Building an E-Learning System to Calculate Pension Funds Using the Cox Ingersoll Ross Interest Rate Model" is to significantly improve public financial literacy, especially in the context of smarter and more informed retirement planning.

This system is expected to provide an interactive and accurate simulation tool, allowing users to understand and apply complex concepts such as the CIR model more easily and intuitively. In addition, with personalization features and real-time feedback, this system aims to provide a learning experience that is tailored to the needs and financial situation of each user, so that they can make better and more strategic decisions regarding investment and retirement planning (Njoku et al., 2019). This system is expected to help individuals achieve long-term financial security and make a positive contribution to improving (Lusardi & Messy, 2023) overall financial literacy in society.

The need for financial literacy in retirement planning is becoming increasingly urgent as individuals must make informed decisions about their financial future. Many people struggle to understand how interest rates affect pension fund projections, which can lead to suboptimal financial decisions. Traditional learning methods may not provide sufficient interactivity or personalized guidance to help users grasp these complex financial concepts. Therefore, developing an e-learning system that integrates the CIR model is essential to bridge this gap by providing an accessible, interactive, and effective tool for financial education.

This research aims to develop and evaluate an e-learning system that incorporates the CIR interest rate model for pension fund calculations. The goal is to enhance users' financial literacy and decision-making capabilities regarding retirement planning by offering accurate and user-friendly simulations. By integrating this model into an interactive platform, this study seeks to provide a practical solution that enables users to better understand the impact of interest rate fluctuations on their pension savings, ultimately empowering them to make more informed and strategic financial decisions.

Method

This study employs a Research and Development (R&D) approach aimed at developing and evaluating an e-learning system for pension fund calculations based on the Cox Ingersoll Ross (CIR) interest rate model. This approach is chosen because it allows for the development of an empirically-based system while also validating its effectiveness through user trials.

The study follows the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model as the primary research design. In the Analysis phase, user needs are identified through literature review and preliminary surveys. The Design phase focuses on structuring the e-learning system architecture and integrating the CIR model into pension fund calculation simulations. Once the design is finalized, the Development phase is carried out by building the software, developing simulation algorithms, and designing interactive learning content.

The next stage, Implementation, involves testing the developed system with users through a series of experiments and simulations. Data obtained from these trials are then analyzed in the Evaluation phase to assess the system's effectiveness in improving users' understanding of pension fund calculations using the CIR model.

To measure the system's effectiveness, various research instruments are utilized. Pre-test and post-test questionnaires are administered to users to evaluate their knowledge before and after using the system. Usability assessment forms are employed to gauge user experience, particularly regarding the system's ease of use and interactivity. Additionally, semi-structured interview guides help explore users' perceptions of the developed system in greater depth. System usage observation sheets are also used to record interaction patterns and challenges faced by users when navigating the platform.

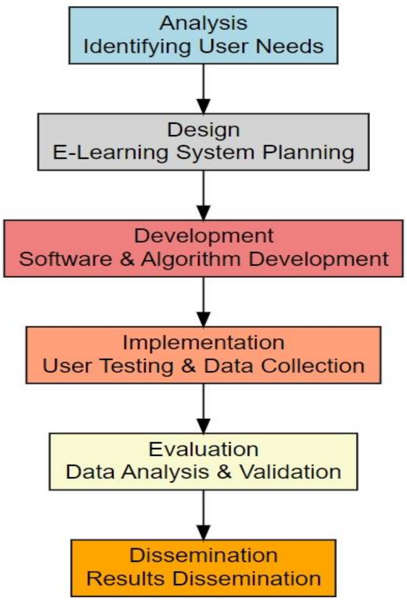

Figure 1. The stages of Research

Data collection is conducted through multiple methods, including survey questionnaires, interviews, direct observations, and system trials. The results of the survey questionnaires are analyzed quantitatively to assess changes in users' understanding, while interviews provide qualitative insights into their experiences. Direct observations help identify user interaction patterns, whereas data from system trials offer insights into the system's effectiveness and efficiency in real-world applications.

Data analysis is carried out using various approaches. Descriptive statistical analysis is employed to interpret data from pre-test and post-test questionnaires, identifying trends in users' learning progress. Inferential statistical analysis, such as t-tests or regression analysis, is applied to measure the impact of the system on users' learning outcomes. For qualitative data, thematic analysis is used to identify key themes and patterns from interviews. Additionally, usability analysis follows standard approaches such as the System Usability Scale (SUS) to evaluate how user-friendly the system is. The stages of this research procedure are presented in the following figure 1.

Result and Discussion

From 2010 to 2020, the interest rate data shows 132 observations with a mean of 5.99% and a standard deviation of 2.25%, indicating moderate variation in the data. Interest rates are recorded in the range of 2.04% as the minimum value and 9.91% as the maximum value. The distribution of the data also shows that the lowest 25% of the data is below 4.12%, while the highest 25% is above 7.58%, with a median value of 6.30%. This data depicts a relatively spread out distribution of interest rates with several peaks and valleys over the period.

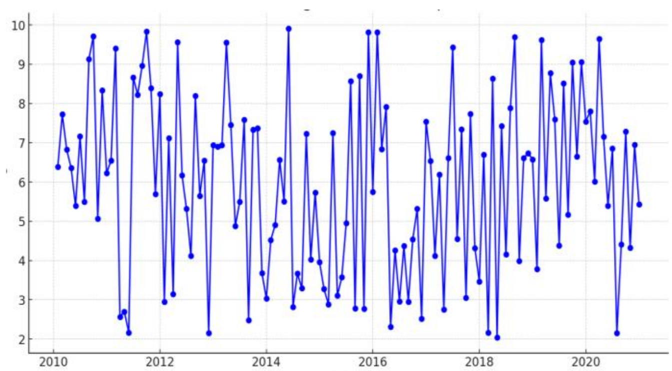

Figure 2. Interest Rate Trend from 2010 to 2020

The interest rate trend chart from 2010 to 2020 shows significant fluctuations with no consistent upward or downward trend. Interest rates ranged from 2% to nearly 10%, with periods of high fluctuations especially at the beginning of the decade, and were relatively stable between 2014 and 2016 before fluctuating again. These fluctuations are likely influenced by macroeconomic factors such as inflation, monetary policy, and global market conditions. To project future interest rates, stochastic models such as CIR can be used, with calibration against historical data to produce more accurate estimates.

The CIR interest rate model has three parameters and must be estimated, namely α, μ, and σ using the conditional least square estimation (CLSE) method as follows:

$$\alpha = \frac{B}{\Delta t}, \qquad \mu = \frac{A}{\alpha \Delta t}$$
$$\alpha = \sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(\frac{\Delta r_t - \alpha(\mu - r_t)\Delta t}{\sqrt{r_t}}\right)^2} \quad (1)$$

The results of the parameter estimation α=−6.05, μ=−77.37, σ=1.03. continued by carrying out the Milstein Method for the CIR model as follows:

$$r_{t+1} = r_t + k(\theta - r_t)dt + \sigma\sqrt{r_t dW_t} + \frac{1}{4}\sigma^2\left(\left(\sqrt{r_t dW_t}\right)^2 - dt\right) \quad (2)$$

where dWt is the Wiener change (Brownian motion) that follows a normal distribution with mean 0 and variance dt. The CIR model parameter estimation using the CLSE method with constraints produces Adjustment speed (α): 0.01, Long-term average interest rate (μ): 0.01, Volatility (σ): 1.03. The following are the results of the interest rate simulation using the CIR model with the Milstein method for the period 2010 to 2020.

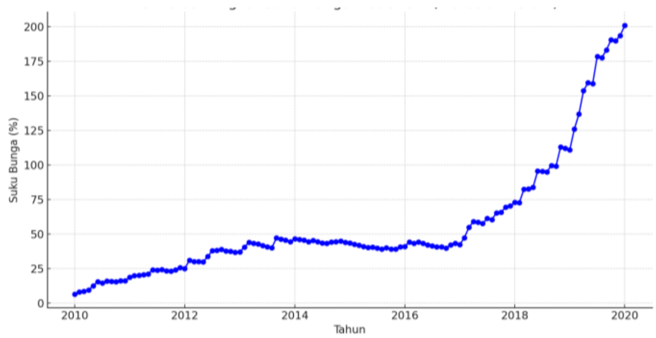

Figure 2. CIR Model Interest Rate Simulation

The graph of the results of the interest rate simulation using the CIR model with the Milstein method shows a very sharp upward trend, especially after 2017 to 2020, where interest rates increased drastically from around 50% to more than 200%. Previously, interest rates tended to be stable with a slight gradual increase from 2010 to 2016. This result reflects the sensitivity of the CIR model to the parameters used, which causes the accumulation of volatility effects and adjustments towards the average, eventually resulting in a significant spike in interest rates in the last years of the simulation.

The simulation results show that the resulting interest rate levels exhibit more realistic adjustments, with fluctuations reflecting volatility according to the parameter σ. In addition, a higher parameter α in the model indicates that adjustments towards the long-run average (μ) occur more quickly, indicating that the model is able to better capture the dynamics of the interest rate market.

Figure 3. CIR Model Interest Rate Simulation

The graph of the results of the interest rate simulation using the CIR model with the Milstein method and adjusted parameters shows a more realistic and controlled interest rate trend. Interest rates experienced a steady increase to a peak of around 11% in 2012, then decreased to a low of around 5% in 2016. After that, interest rates increased gradually again to approach 12% in 2020. This pattern reflects the natural fluctuations that occur in the interest rate market, with model adjustments successfully replicating market conditions that are more in line with historical reality.

Validating the model, the simulation results are compared with historical data using evaluation metrics such as Mean Squared Error (MSE) or Mean Absolute Error (MAE) to measure how close the simulation results are to the actual data. In addition, a comparison plot between historical data and simulation results is made to visualize how the model matches historical data with the results of Mean Squared Error (MSE): 28.37, Mean Absolute Error (MAE) with the graph showing the comparison between historical data and simulation results using the selected parameters α=0.3, μ=6.0, σ=0.7). The following are additional simulation results of interest rates using the CIR model with the Milstein method for several combinations of parameters.

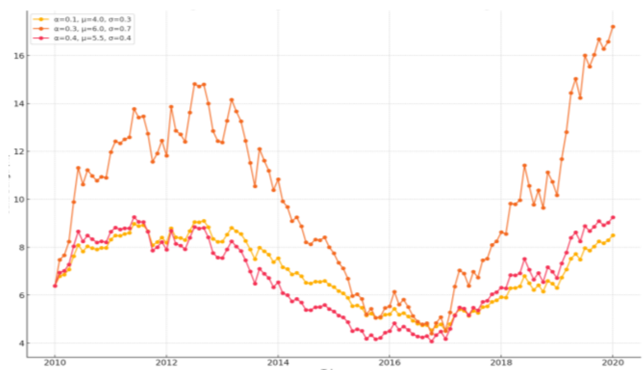

Figure 4. Additional Simulation of CIR Model Interest Rate Levels

This graph shows additional simulations of interest rates using the CIR model with the Milstein method and three different parameter variations. The results show significant differences in the interest rate pattern depending on the parameters used. Parameters with α=0.3α=0.3, μ=6.0μ=6.0, and σ=0.7σ=0.7 produce larger fluctuations and a sharp spike in interest rates after 2017, reaching more than 16% in 2020. Meanwhile, parameters with α=0.1α=0.1, μ=4.0μ=4.0, and σ=0.3σ=0.3 produce more stable and lower interest rates, with a peak around 10% before declining again. These simulations show that changes in the parameters of the CIR model can significantly affect the results of interest rate projections, reflecting the sensitivity of the model to parameter settings and the importance of proper calibration.

The simulation will be compared with historical data to evaluate the accuracy of the model. The steps taken include the use of evaluation metrics such as Mean Squared Error (MSE) or Mean Absolute Error (MAE) to measure the difference between the simulation results and historical data, so that we can understand how close the model is to reality. In addition, a comparison plot is created that displays historical data and simulation results visually, allowing for visual analysis of the model's suitability to the actual data. Evaluation Metrics Mean Squared Error (MSE): 28.37, Mean Absolute Error (MAE): 4.50 the graph shows the comparison between historical data and simulation results using the selected parameters α=0.3, μ=6.0, σ=0.7 the following are the results of the CIR model validation:

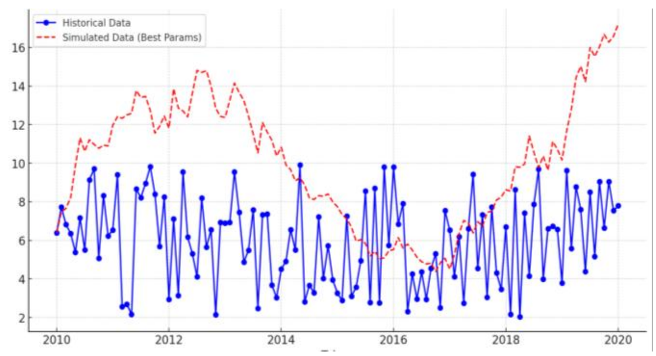

Figure 5. CIR Model Validation with Historical Data

This graph shows the validation of the CIR model by comparing historical interest rate data (shown by the blue line) and the best simulated data using the CIR model (shown by the red dotted line). The results show that while the CIR model successfully captures the general trend of interest rate increases and decreases, especially the sharp increase after 2016, the model tends to produce higher values than historical data, especially in the period 2012-2014 and after 2017. This shows that while the CIR model is able to project long-term trends, there is a significant difference in the volatility produced by the model compared to reality, indicating the need for further parameter calibration or model adjustment to more accurately reflect historical data.

After forming the interest rate level, the Cox Ingersoll Ross Model is continued by determining the pension benefits using the Cox Ingersoll Ross Model and discounting the pension benefits based on the simulation results. The volatility of interest rates (σ) in the CIR model affects the magnitude of the simulated interest rate value. Fluctuating interest rates produce variations in the present value of pension benefits, reflecting uncertainty in the financial market. The parameters used (α = 0.3, μ = 6.0, σ = 0.7), the simulation shows that although interest rates tend to return to their long-term average (μ = 6.0), the presence of volatility causes discounts to vary from year to year.

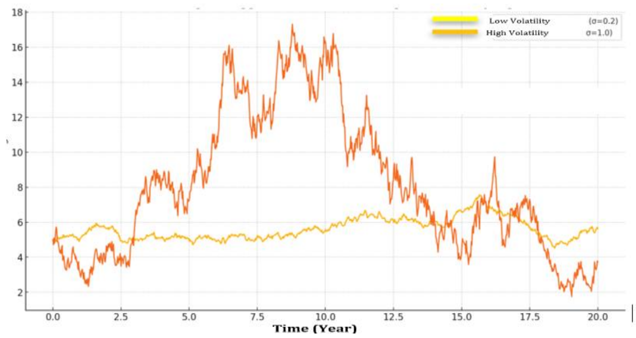

Figure 6. Interest rates using the CIR Model with Volatility

This graph shows how interest rate volatility can affect interest rate movements over time. Larger fluctuations in high volatility can result in a lower present value of pension benefits compared to low volatility, which is more stable. Velocity of Reversion of Interest Rates (α) in the Cox-Ingersoll-Ross (CIR) Model Low Velocity of Reversion (α=0.1): Interest rates tend to move more slowly back to their long-run average (μ=6.0) causing them to be further from their average for a longer period of time. High Velocity of Reversion (α=0.6α=0.6): Interest rates quickly revert to their long-run average. Interest rates are more controlled and tend to stabilize more quickly around their average.

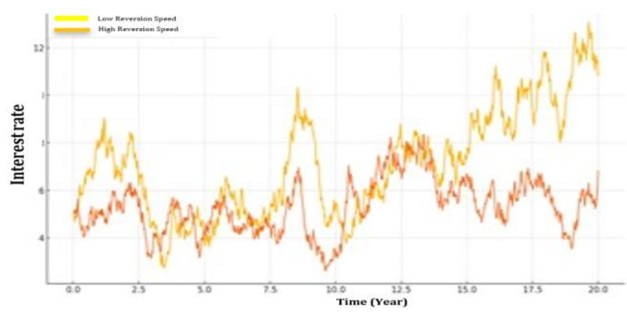

Figure 7. Interest rates using different reversion rates

This graph provides evidence that higher reversion rates cause interest rates to stabilize more quickly around their mean, while lower reversion rates result in larger and longer fluctuations before interest rates return to their mean. Small changes in interest rates have an immediate impact on the present value of pension benefits. Even a 1% change in interest rates can cause a significant change in the present value as seen in 1% Interest Rate Reduction = Reducing the interest rate by 1% increases the present value of the pension benefit to 1,369,911,369.91 units and 1% Interest Rate Increase = Increasing the interest rate by 1% decreases the present value of the pension benefit to 1,365,581,365.58 units.

The results of calculating the present value of pension benefits using two approaches, 1. Present Value with Fixed Interest Rate (5%): 124,622.10124,622.10 units produces a much larger present value because it assumes that the interest rate remains constant at 5% during the benefit payment period. This does not consider the actual fluctuations that occur in the market, 2. Present Value with CIR Model (Low Volatility): 1,367,741,367.74 units Produces a lower and more realistic present value because it takes into account the fluctuations in interest rates that occur in the long term, which better reflects the actual financial market conditions. This model also takes into account the risk of changes in interest rates that may occur, providing a more dynamic and realistic picture. From the two approaches, the pension benefits that will be received by participants at retirement can be formulated as follows:

$$Iuran\ Normal = \frac{\sum_{t-1}^{R-x} v^t.\ p(x+t).B(x+t)}{\sum_{t-1}^{R-x} v^t.p(x+t)} \quad (3)$$

where x is the current age of the participant. R is the normal retirement age. $B(x+t)$ the value of the pension benefit at age x+t. $p(x+t)$ the probability of the participant surviving to age x+t. $v = \frac{1}{1+i}$ the discount factor with i being the discount interest rate. After all the formulations are found, it will be continued with Building an E-Learning System (Aparicio et al., 2016)to Calculate Pension Funds Using the Cox Ingersoll Ross Interest Rate Model (Jamieson Bolder, 2001).

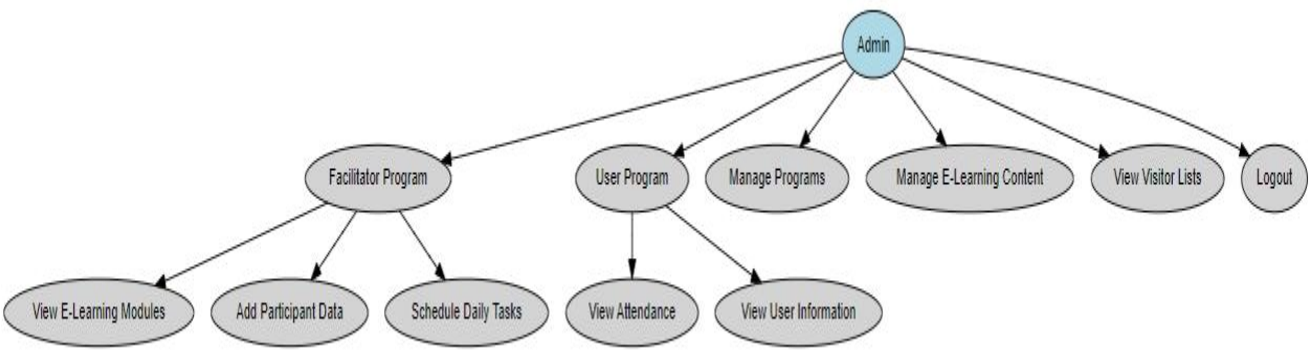

Figure 8. Use Case Figure of the Pension Fund E-Learning System

The figure shown is a Use Case Figure that illustrates the interaction between various types of users (actors) with the Pension Fund E-Learning system. This figure shows three main actors: Admin, Registered Users, and General Users. Admin has three use cases, namely managing users, managing E-Learning content, and viewing calculation reports. Registered Users can access the E-Learning module, perform pension fund calculations, and save and view calculation results. Meanwhile, General Users have the option to register an account, view general information, and log in to the system. This figure illustrates how each actor interacts with the system to perform specific tasks relevant to their role.

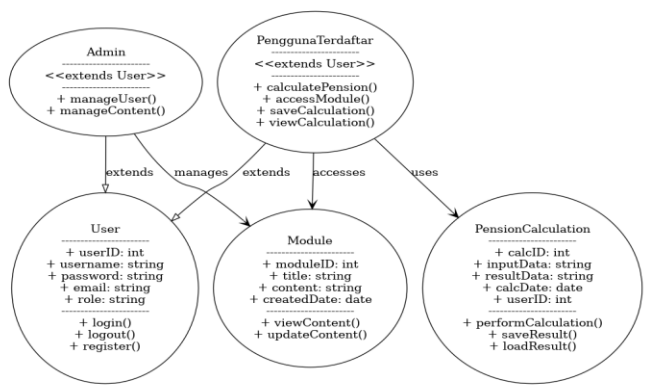

Figure 9. Class Figure of the Pension Fund E-Learning System

The figure shown is a Class Figure for an E-Learning system that calculates pension funds using the Cox-Ingersoll-Ross (CIR) interest rate model (Coffie et al., 2024). This figure illustrates several main classes in the system, including User, Admin, RegisteredUser, Module, and Pension Calculation. User is a base class that has attributes such as user ID, username, password, email, and role, as well as methods for login, logout, and register. Admin and Registered User are derived classes from User, where Admin has the ability to manage users and content, while Registered User can perform pension calculations, access modules, and save and view calculation results. Module is responsible for storing and managing e-learning content, while Pension Calculation stores pension fund calculation data performed by users. This figure also shows the relationships between classes, such as Admin who manages Module, and Registered User who accesses Module and uses Pension Calculation. This figure provides a clear view of the structure and interactions between components in the system.

The figure shown is an Activity Figure for the pension fund calculation process using the Cox-Ingersoll-Ross (CIR) interest rate model in the E-Learning system. This figure maps the workflow from start to finish. The process begins with the user selecting the pension fund calculation module, where the system then displays a form for data input. The user enters the CIR model parameter data, after which the system processes the calculation based on the model. The calculation results are then displayed to the user, who is then given the option to save the calculation results. If the user chooses to save the results, the system will save them to the database, and the user can view the saved calculation results. This process ends with an End point after all steps are completed. This figure provides a clear picture of the sequence of steps taken by the user and the system in calculating pension funds.

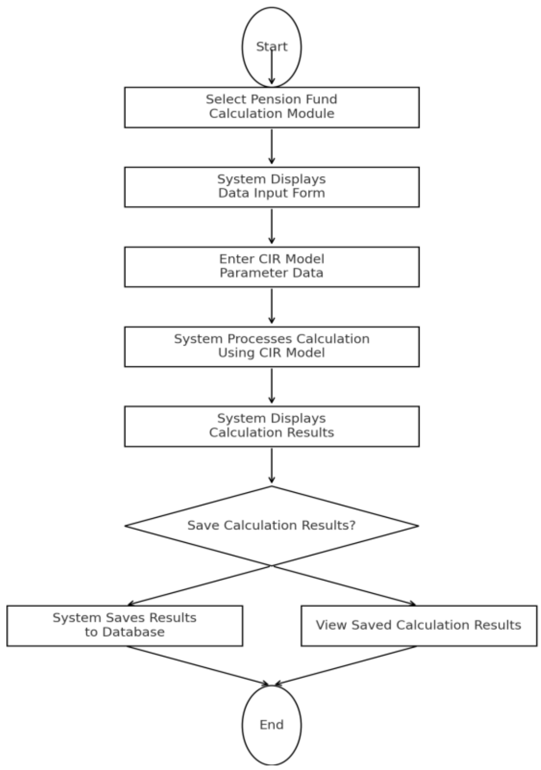

Figure 10. Activity Figure of the pension fund calculation process

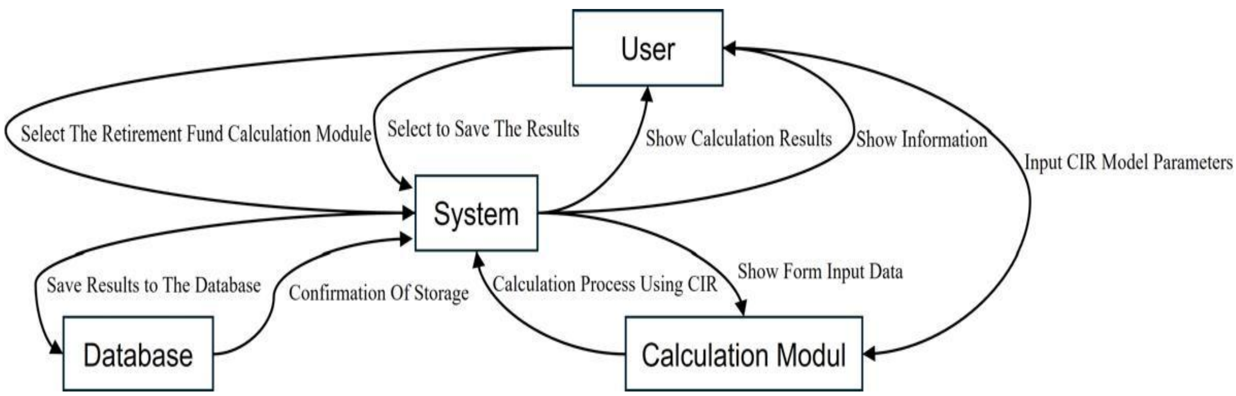

Figure 11. Sequence Figure of Pension Fund Calculation Scenario

The figure shown is a Sequence Figure that visualizes the interaction between the user, system, calculation module, and database during the pension fund calculation process using the Cox-Ingersoll-Ross (CIR) interest rate model (Bayraktar & Clément, 2025; Mishura et al., 2024). This figure shows the communication flow that starts from the user selecting the pension fund calculation module, followed by the system displaying a data input form. The user then enters the CIR model parameters, and the calculation module processes the data using the CIR model (González Olivares & Guizar, 2021). The calculation results are displayed by the system to the user, who can then choose to save the results. If the user decides to save, the system will save the calculation results to the database and display a save confirmation to the user. This figure describes in detail the sequence of steps that occur in the pension fund calculation process, from data input to saving the results to the database.

Analysis of interest rate data for the period 2010 to 2020, obtained an average interest rate of 5.99% with a standard deviation of 2.25%, indicating moderate variation in the data. The range of interest rates between 2.04% to 9.91% shows quite significant fluctuations, reflecting market dynamics during the period. The distribution of the data shows that 25% of the lowest interest rates are below 4.12%, while the highest 25% are above 7.58%, with a median of 6.30%. This shows that although interest rates have quite large fluctuations, most values are in a relatively stable range.

The interest rate trend graph from 2010 to 2020 shows significant fluctuations, without a consistent pattern of increase or decrease. This shows that interest rates are highly influenced by various macroeconomic factors such as monetary policy, inflation, and global market conditions. In this context, the use of the Cox Ingersoll Ross (CIR) model for interest rate simulation becomes relevant to predict future trends (Chernova et al., 2024; Prykhodko & Ralchenko, 2025). Initial simulations using the Milstein method with the CIR model showed a sharp increase in interest rates after 2017, indicating the sensitivity of the model to the parameters used (Takam Soh et al., 2021). This spike reflects how the volatility (σ) and adjustment speed (α) parameters in the CIR model can significantly affect the simulation results.

The simulation results are then validated against historical data using evaluation metrics such as Mean Squared Error (MSE) and Mean Absolute Error (MAE). Although the CIR model is able to capture the general trend of interest rates, especially the sharp increase after 2016, the significant difference in volatility between the simulation results and historical data suggests that the model still needs further calibration (Guan et al., 2024). Model parameters such as α, μ, and σ play a critical role in determining the accuracy of the projections, and adjustments to these parameters need to be made to ensure that the simulation results reflect more realistic market conditions.

Additional simulations with varying parameters show that small changes in the values of α, μ, and σ can produce significant differences in interest rate projections. For example, parameters with lower volatility produce more stable interest rates, while higher volatility causes larger fluctuations. This highlights the importance of proper calibration in the use of CIR models, especially in practical applications such as pension fund calculations. The impact of interest rate volatility on the present value of pension benefits is also significant, with larger fluctuations leading to higher variations in pension benefit discounting.

The integration of the CIR model into an e-learning system for calculating pension funds shows great potential in improving (Abdullahi Sakanko et al., 2023) users' financial literacy. Through interactive simulations generated by the CIR model, users can understand how changes in interest rates can affect their pension funds. Use Case, Class, Activity, and Sequence figures provide clear guidance on how the system functions, showing the interaction between users and the system to perform pension fund calculations. These figures detail the process from data input, simulation, to saving results, ensuring that the e-learning system is well designed to meet user needs.

Conclusion

The integration of the CIR model (Chan et al., 2007) into an e-learning system not only helps users project their retirement funds more accurately, but also improves (Schenk-Hoppé et al., 2023) their financial literacy by providing a deeper understanding of how interest rates work and how they can affect retirement planning. The interactive and historical data-driven simulation process, as explained in the discussion, ensures that the platform fulfills its goal of providing a powerful and practical learning tool for users. Specifically, it can be said that the CIR model, well integrated into an e-learning system, can provide a powerful tool for projecting interest rates and calculating retirement funds. However, the simulation results show that the accuracy of the model is highly dependent on the calibration of the parameters. Proper simulation and validation are needed to ensure that the model can be used effectively in real-world scenarios. With continuous improvement and adjustment, the system can become an effective educational tool to help individuals better plan their retirement.

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Author Contributions

All authors have real contributions in completing this manuscript

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Conflicts of Interest

No conflicts of interest

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