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REVIEWARTICLE

Real-Time Liability Monitoring in Annuities Using Actuarial Dashboards on Streaming Data

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Abstract Annuities are specifically long-term financial products that convert your accumulated savings into a predictable income stream and that provide a necessary financial security during retirement. Unlike many years ago, modern life expectancy is on the rise, traditional Defined Benefit (DB) pension schemes are gradually being replaced by Defined Contribution (DC) plans, and individuals more and more have to manage their own retirement funds. This shift points to the increasing significance of predicting and controlling the annuity liabilities because they depend on factors including longevity, interest rates, market volatility, etc. Using traditional actuarial methods often means performing periodic and static assessment, which may not account for the quick changing economic and demographic trends. Following such modernization of the technique, this paper proposes a real-time data streaming and actuarial dashboard-based approach for annuity liability management. This presents how the joining of predictive analytics with constant knowledge streams can present actuaries with dynamic, online knowledge of liability profiles, permitting more exact hazard evaluation and goal-making in a proactive way. The paper goes on to describe the structure and types of annuities and asset liability management models and to discuss key technologies for streaming data analysis and analyze the effectiveness of dashboards in increasing transparency and operational responsiveness. In order to make liability monitoring more up-to-date, this method improves financial planning and associated assessment with the use of data integration tools and enhanced visualization. This helps to reduce risks and ensure that retirement systems can be sustained over the long term.

Keywords Annuities, Actuarial Liabilities, Asset-Liability Management (ALM), Predictive Analytics, Streaming Data, Contingent Liabilities, Traditional Defined Benefit (DB), Defined Contribution (DC).

I. INTRODUCTION

A conventional life annuity is the simplest and most popular method of converting a lump sum of wealth into an annuity that pays a steady stream of income for the rest of your life. The biggest advantage of annuities isn't really an advantage at all. In fact, the primary reason you should choose them is to avoid running out of money, and the longer you live, the more you need to avoid running out of money. In the decumulation stage of Defined Contribution (DC) pension plans, when people have savings but no workplace pensions, annuities play a significant role [1]. In the UK and other developed economies, annuities have become a more relevant means of converting accumulated funds to reliable income streams because they enable individuals to do that.

Pension systems have changed a great deal over the past century. Defined Benefit (DB) schemes prevailed in the early 20th century, with employers making the retirement income provision [2]. Yet, with a transition towards DC schemes, individuals are expected to take charge of retirement income, sometimes with less certainty about whether their funds will be adequate. By virtue of this transition, annuities play an increased role but also bring new risks, especially the ability to make accurate forecasts and control annuity liabilities over long time horizons [3]. The problem of how long individuals will live and how economic conditions will change is central to pricing and managing annuity products that actuaries are asked to forecast.

As advanced data analytics have been ingested into actuarial practice, new opportunities for effective actuarial practice to the management of annuity risks have emerged. Predictive modelling and real-time data streaming make it feasible to monitor liabilities continuously and dynamically alter actuarial assumptions[4]. Having actuarial dashboards, integrating the real-time data streams, provides a wonderful opportunity to deal with the complexity of the annuity portfolio. These dashboards allow the actuaries to get live insight into their liabilities, understand emerging risks, and proactively bring changes to their models.

The paper investigates the improvement of real-time liability surveillance through streaming data integration with actuarial dashboards within the annuity sector. Annuity obligations may be better understood with more accuracy and finer detail, thanks to the use of predictive modelling with continuous data streams. The system creates enhanced prospects for risk management together with financial planning capabilities, which supply immediate solutions to demographic alterations and market uncertainty along with other outside influences. The increasing complexity in annuity markets makes real-time actuarial dashboards emerge as an effective solution to preserve the sustainability and stability of pension systems in developing environments.

- *Structure of the paper*

This paper is organized as follows: Section I of this paper introduces annuities and explains their retirement functions. Annuity types, together with their essential characteristics, receive consideration in Section II. Section III outlines vital factors that retirees need to consider. Section IV reviews market trends. Section V offers guidance on product selection. The VI part of the paper includes a section about upcoming trends in addition to digital innovations.

- Understanding Annuities And Liabilities

Annuities represent long-term financial products that provide a payment series for retirement purposes to individuals. Insurance contracts establish agreements between people and their insurance companies through which the insurer pays recurring payments to individuals for their investments of cash [5]. Actuarially significant liabilities associated with these products exist because they last for many decades, yet they depend heavily on things like increased life expectancy and interest rate fluctuations together with market forces. Insurance company financial stability, along with policyholder protection, heavily relies on accurate monitoring of these liabilities [6]. A detailed examination of annuity structures, together with liability nature and management challenges experienced by actuaries, will be the focus of this section.

- *Overview of Annuities*

An annuity is a written contract that links you with a life insurance provider. After you pay your premiums, the insurance provider will pay you at predetermined intervals. Annuity contracts do not meet the requirements for life insurance. In the case of your death, your family will receive benefits from your life insurance policy. It may accumulate money by buying an annuity, which will cover your future income needs [7]. Annuities differ from certificates or savings accounts. Thus, they shouldn't be bought for immediate use. The ideal way to use income payments from an annuity contract is to fund your retirement. The only way to receive a guaranteed income for the duration of your life is through an annuity. The owner, the annuitant, and the beneficiary are the three parties involved in an annuity contract.

The owner is the person who buys the annuity, makes the premium payments, and has the option to give it up. In addition to being the one who often specifies the beneficiary under the contract, the owner is also liable for any taxes owed upon surrender or payout.

The Annuitant: is the individual who will receive the annuity payments and whose age and life expectancy will be utilised to determine the annuity's benefits. Although it is not necessary, the annuitant and the owner are typically the same individual.

The Beneficiary: obtains the death benefit following the annuitant's passing, either in a single payment or in many installments over time.

- *Types of Annuities*

The two most common varieties of annuities are fixed and variable.

Fixed Annuity: The insurance provider promises you a minimum interest rate as your fixed annuity account grows [8]. The interest rates might change. Most people would agree that fixed annuities are a safer bet. You might earn more or less than what you would with a savings account with a bank with a guaranteed rate. One kind of fixed annuity is an equity index or fixed index annuity. You have the option to split your premiums between a set account and one that tracks the performance of a certain stock index, such as One notable index is the Standard & Poor's 500 Stock Price Index, or the Dow Jones Industrial Average.

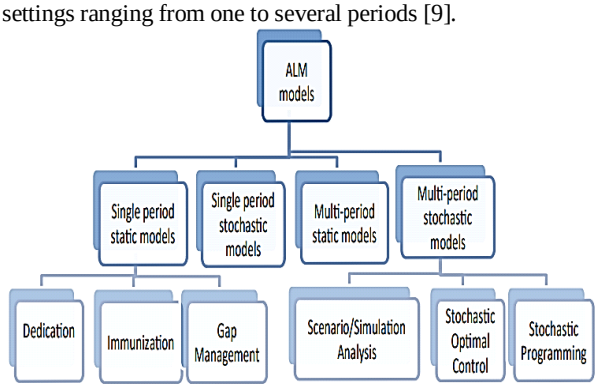
Variable Annuities: It provide the annuity bearer the opportunity to earn higher returns than the average fixed annuity but come with more risk and more active commitment. There are no assurances of profit from these annuities, as they are so reliant on stock market success. It risk losing some or all of your initial investment if the annuity fund does not perform well. The main distinctions between fixed and variable annuities are shown in Table I.

I) Summarizing the key differences between Fixed Annuities and Variable Annuities.

Feature	Fixed Annuity	Variable Annuity
Interest Rate	Guaranteed minimum interest rate, but can fluctuate	No guaranteed rate, dependent on market performance
Risk Level	Lower risk, more conservative	Higher risk, potential for loss or gain based on market performance
Returns	May be higher or lower than a savings account	Potential for higher returns based on stock market performance
Premium Allocation	Funds are allocated to a fixed account or equity index account	Funds are allocated to a range of investment options (stocks, bonds, etc.)
Involvement of Annuity Holder	Minimal involvement, as it's a conservative investment	Requires more active management and decisions from the annuity holder
Performance Dependence	Less dependent on stock market fluctuations	Highly dependent on stock market performance
Example Products	Equity index annuities, fixed index annuities	Mutual fund-based variable annuities
Potential Loss	Limited to the initial investment or minimum guaranteed rate	Loss of principal is possible depending on market conditions
Suitability	Suitable for conservative investors seeking stability	Suitable for investors seeking potential higher returns with a higher risk tolerance

- *Asset-liability management models*

The asset-liability optimization decision-making models may be broadly classified into four types, distinguished by the time horizon and environmental factors that will be considered: Simplified models for a single period of time (2) Single period stochastic models 3-time models that are static and (d) models that are stochastic throughout repeated periods. Figure 1 shows the results of these models, which expand risk measurements and ALM goals in settings ranging from one to several periods [9].



- ALM Model Classification
- **Single-period static models:** These models act as a hedge against small changes in interest rates and exchange rates that significantly impact the portfolio's overall value [10]. In order for investors to accept the behavior of the portfolio, it is made predictable. This category's primary tactics are commitment, vaccination, and gap/surplus management.

- **Dedication:** Dedication was the most common ALM tactic used by investment businesses and pension funds in the 1970s. Cash flow matching was initially utilized by Leibowitz, who called it "dedication" since it calls for allocating a multiple cash inflow to multiple cash withdrawals (assets).
- **Gap/surplus management:** This method calculates the discrepancy between asset and liability values and makes an effort to keep it within a respectable range of both positive and negative values. This approach is typically used by financial organizations to maintain their balance sheets.
- *Conversion from variable to fixed annuity at retirement*

The plan may allow or mandate the conversion of the variable benefit to a fixed benefit after retirement, or it may restrict the variable benefit adjustment to vested members who are still active and those who have terminated. The cost of this conversion is probably going to be low if the current market interest rates, at which the benefit may be successfully annuitized, are near the hurdle rate [11]. In the event that market rates deviate from the hurdle rate, the sponsor or other participants will be responsible for paying the conversion fee [12]. When computing the asset return used to establish the yearly benefit adjustment, assets supporting the benefits of a particular group of members are usually eliminated when that group is excluded from the adjustment. Presumably, the plan document would need to specify any such exclusion.

- Real-Time Data And Streaming Technologies

Real-time streaming data from IoT sensors is gathered from sources including machinery sensors, fishing vessel monitoring devices, and agricultural sensors [13]. The quantity of data that has to be further examined can subsequently be reduced by pre-processing this streaming data. Filtering the data, conducting basic data aggregation, and storing the data so that subscribers can get conditional notifications of data changes are examples of pre-processing. Data enters the CEP component for additional analysis after pre-processing, which often entails identifying patterns in time frames throughout the incoming data to create new, more intricate events. Whether made automatically by actuators or by people, these intricate events are released to aid in decision-making [14]. In order to aid people in making decisions, the scenarios can also be shown using visualization techniques. It's thought that the events that are identified might offer practical, real-time information for operational management, such as averting potential crop insect infestations or equipment crashes.

- *Data Stream Model*

The data stream paradigm assumes that part or all of the input data to be worked on comes as one or more continuous data streams rather than being randomly accessible from disc or memory. There are several ways that data streams are different from the traditional stored relation approach.

- The stream's data pieces come online.
- The order in which data components arrive to be processed, either inside a data stream or across data streams, is outside the system's control.
- Data streams may have infinite dimensions.
- An element from a data stream is either archived or deleted after processing; it is not readily retrievable unless it is specifically preserved in memory, which is usually little in comparison to the size of the data streams.
- *Tools and technologies employed for big data stream analysis*

Big data stream applications may create, run, deploy, and manage huge data streams with the help of big data stream platforms' capabilities and functionalities. Data streams must be able to be pulled in, processed, and then sent back as a single file by such systems. To examine massive data streams, a range of techniques and tools have been employed [15]. The open-source community and corporate technology providers have created a plethora of alternative big data streaming solutions in response to the increasing need for big data streaming analytics [16]. To make wise choices about data management, there are a few things to take into account while choosing large data streaming techniques and technologies. These are outlined in short below:

- **Shape of the Data:** Serialization solutions are necessary for streaming data sources in order to capture, store, and represent such high-velocity data.
- **Data Access:** The way that users and apps will access the data must be considered.
- **Availability and Consistency Requirement:** The availability and consistency of a distributed system cannot be guaranteed when network partitioning is present, according to the CAP theorem.
- **Workload Profile Required:** A platform with a spike load profile can benefit from a deployment of a platform with services. If it is possible to build up platform distribution on an Infrastructure as a Service cloud, this method can be selected because clients would only be charged when processing.
- **Latency Requirement:** If there has to be little delay or low latency, key-value storage could be investigated to improve the data loading process. Even better, an in-memory system that allows real-time processing of large datasets is required.
- *Recent advances in real-time streaming processing*
- The term "DevOps" was coined in 2009 by Patrick
- Debois, and since then, it has evolved into a comprehensive set of practices that emphasize
- automation, collaboration, and continuous improvement. The foundational principles of DevOps
- draw from Agile methodologies, Lean practices, and the Theory of Constraints. Humble and Farley
- (2010) in their seminal work "Continuous Delivery: Reliable Software Releases through Build,
- Test, and Deployment Automation" laid the groundwork for understanding CI/CD as integral
- components of the DevOps pipeline. They highlighted the importance of automating the build, test,
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Increasing understanding of the value of data is what led to the emergence of streaming processing. Data may be categorized into three types based on how timely it is. The data from the prior day is what it refer to as warm data. As a result, it refer to data collected

prior to the prior day as cold data, or historical data [17]. Traditionally, the data in a single day may even be considered hot data, despite the imprecise concept of hot data. But even in a few milliseconds, it is essential for an online marketplace like Taobao to differentiate between good and bad behaviour [18]. Real-time data is therefore the most useful, as it has already illustrated. As a result of its greater importance, real-time data processing technologies have steadily been the focus of the big data community. Tez and Spark Streaming are two examples of the stream data processing components that have been developed as a result of their work.

- Actuarial Dashboards: A Modern Monitoring Tool

In the evolving landscape of actuarial science, dashboards have emerged as powerful tools for real-time decision-making and monitoring. Traditionally, actuarial analysis relied heavily on static reports and periodic evaluations, often limiting the ability to respond swiftly to changing financial conditions. Actuarial dashboards overcome this limitation by offering dynamic, interactive visualizations of key metrics such as liability valuations, risk exposures, and cash flow projections on a centralized platform [19]. These dashboards integrate data from multiple sources, including real-time feeds, to provide up-to-date insights and enhance operational transparency. This section delves into the structure, functionality, and significance of actuarial dashboards in modern liability monitoring, especially within the context of streaming data and annuity products.

- *Dashboard Components and Visualization Metrics*

Dashboards are a useful tool for data reporting and communication. Their ability to accommodate various reporting formats makes them adaptable. Dashboards are increasingly being utilized to convey data and visualize analysis for non-business services, while they are still primarily utilized in business intelligence environments. Power BI and Tableau are two well-known dashboarding solutions. Other choices include Matillion, Excel, R + Shiny, Gecko board, and others [20]. The goal of these technologies is to make data report creation as easy and intuitive as feasible. These applications are strong and easy to use; establishing a dashboard with them is simple, and there are many online how-to manuals available. Despite this, dashboards suffer from the same restrictions as other data transmission methods.

- *Real-Time Monitoring (RTM)*

The phrase "real-time" usually refers to a system's ability to react rapidly, enabling the reaction to happen almost at the same time as the event. In many industries, real-time data processing has become crucial for prompt responses to transient occurrences. For example, a network administrator must monitor the port's real-time use statistics to see if the problem persists if a switch port in a computer network shows high bandwidth usage [21]. The ability to view and react to network events in real-time is a major benefit of RTM for network administrators and engineers. These events can include faults, failures, performance, health, utilisation, sluggish systems, and many more [22]. In real-time, or as they happen, they may utilize the event data and information to analyze and determine the current condition of the network systems as well as the general operations and procedures performed on the network data. By providing data or information that is thought to be accurate as of the time the command was delivered, RTM enables network managers to make educated decisions and monitor trends.

- *Assessing the Dashboard Proposal and Associated Challenges*

The impact of retirement dashboards on user outcomes has not yet been formally shown. For instance, in Sweden, compared to 13% of non-dashboard users, 48% of dashboard users said they understood their pension benefits well enough to make active management decisions; however, it is unclear what caused this difference. Individuals with better financial literacy or experience with retirement planning may be more likely to utilize a dashboard, and/or utilizing a dashboard may improve comprehension [23]. A third of nonusers do not have internet connection, but half of Sweden's working population uses the dashboard purposefully. Dashboards may be able to ease some of the challenging issues that retirement savers encounter, according to the experiences that other nations have had with them thus far [24]. However, there are substantial obstacles to developing a dashboard, but they are certain that they can be overcome.

- Literature Of Review

In the following section, related work is presented focusing on liability monitoring in annuities using actuarial dashboards, highlighting existing methodologies, data visualization techniques, and incorporating real-time data for efficient risk analysis and judgement.

Perumalsamy, Shanmugam and Althati (2022) Annuities provide retirement income, but their design and pricing are determined by risk and mortality prediction. Although consistent, conventional actuarial methods seldom include market volatility or personal risk profiles. Examined are advanced artificial intelligence and machine learning tools to enhance annuity prediction analytics for pricing and risk assessment. The research begins with demographics, stationary death, and annuity pricing. Examined is then the theoretical foundation of AI and ML techniques like RF and unsupervised methods such as GBMs and k-means clustering. From complex data sources like financial histories and medical records, RNNs and CNNs find latent trends and improve risk prediction [25].

Lowe et al. (2021) the viewpoint of the Future Pensions Landscape working group of the IFoA. The dashboard's goals are examined in the paper, along with any functionality that could be needed to meet them. It also draws attention to how challenging it is to maintain uniformity across various benefits and to coordinate with other pension mailings. Finally, it examines how the dashboard may be improved to help members comprehend what their retirement benefits would entail as well as the opportunity it provides for more modelling and financial planning [26]

Hassani, Unger and Beneki (2020) This article covers a wide range of topics, including the cost of vehicle insurance policies, mortality and healthcare modelling, harvest, climate, and cyber risk calculation, and assessing the risk of natural disasters, such as earthquakes, floods, fires, hurricanes, tornadoes, and storms. They assess how big data is currently being used in these settings and how data analytics and data mining help insurance firms provide more accurate and predictive policy premium pricing [27].

Effiong and Enya (2020) study examines how the management of liquidity risk impacts the financial performance of consumer products companies. It aimed to ascertain how concerned consumer products companies were with managing their liquid cash, cash defense intervals, long-term loans, and fast ratios in order to enhance their financial performance. Data from the annual reports and accounts of the businesses under investigation were converted into liquidity measurement criteria. According to evaluations employing multiple regression analysis approaches, long-term debts, quick ratios, and cash defensive intervals have a major influence on EPS and ROA, whereas cash ratios and long-term debts have a sole impact on ROCE [28].

Mingbin Feng and Liu (2020) suggest and evaluate three Quasi-Monte Carlo path generating techniques for the valuation of sizable VA portfolios: Principal Component Analysis, Brownian Bridge, and Cholesky decomposition. At the contract and portfolio levels, their numerical findings show that all three PGMs provide estimates that are more accurate than those from the typical Monte Carlo

simulation. Long-term insurance policies known as variable annuities, which provide a wide range of investment-linked benefits, have been increasingly popular in the past ten years. For insurers, valuing big variable annuity portfolios accurately is crucial [29].

Brien (2020) recommends that regulators demand a value that is reasonable, impartial, objective, fair, transparent, and based on good principles. In place of judgment, a specified technique would be used. It comes to the conclusion that benefits that arise upon the scheme's termination should be evaluated, excluding Increases in future salary-related benefits that are seen to no longer represent a constructive obligation of employers. It is recommended that the valuation make use of asset market values, which is a well-accepted technique. Instead of moving them to an insurer (which might generate artificialities), liabilities should show that the trustees have fulfilled their obligations. According to a number of recent papers submitted to the profession, the discount rate must follow the "matching" technique, which is a risk-free, market-consistent rate [30].

Table II presents an overview of the literature on real-time liability monitoring in annuities using actuarial dashboards, summarizing each study's approach, key findings, challenges, and proposed future directions.

I) Summary of literature study based on Real-time Liability Monitoring in Annuities

Authors	Study On	Approach	Key Findings	Challenges	Future Directions
Perumalsamy, Shanmugam and Althati (2022)	Enhancing annuity pricing and risk prediction with AI/ML	Use of Random Forests, K-means, GBMs, RNNs, CNNs, and feature engineering with socioeconomic, healthcare, and lifestyle data	AI/ML improves granularity in risk prediction; unstructured data like medical records yield better modeling	Integration of heterogeneous data sources; interpretability of complex models	Integrate advanced AI/ML models (e.g., Random Forests, GBMs, CNNs, RNNs) to enhance risk assessment and personalized pricing based on diverse data like medical and financial records.
Lowe et al. (2021)	Future Pension Dashboards for member decision support	Conceptual analysis of dashboard features and alignment with benefit types	Dashboards can aid real-time understanding of pension liabilities and enhance financial planning	Standardization across benefit types; consistent data formats	Develop standardized, user-centric dashboards aligned with broader pension communications for improved benefit modeling and retirement planning.
Hassani, Unger and Beneki (2020)	Big data's use in disaster risk and insurance pricing	Data tomining big data analytics used in several insurance fields	Big data enhances prediction accuracy for pricing and risk assessment across domains	Scalability of real-time systems; integration of streaming environmental data	Increase the use of data mining and big data to better forecast a variety of risks (such as cyber, climate, and disasters) and enhance premium pricing tactics.
Effiong and Enya (2020)	Liquidity management's effect on business performance	Regression analysis of liquidity ratios and their effect on EPS, ROA, and ROCE	Long-term debt and liquidity ratios significantly affect financial performance	Financial data translation to actuarial contexts	Incorporate liquidity risk metrics (e.g., quick ratios, debt structures) into actuarial dashboards to assess impacts on financial performance in real time.
Mingbin Feng and Liu (2020)	Reliable assessment of huge variable annuity portfolios	Quasi-Monte Carlo methods: Cholesky, PCA, Brownian Bridge	Improved valuation accuracy over standard Monte Carlo	Computational intensity; real-time application unexplored	Implement quasi-Monte Carlo path generating techniques (such as Brownian Bridge and PCA) for effective big variable annuity portfolio valuation.
Brien (2020)	Valuation of annuity liabilities with regulatory compliance	Normative analysis suggests risk-free market-consistent valuation	Advocates objective, transparent valuation principles	Implementing real-time consistent valuation across plans	Promote market-consistent, fair, and standardized valuation practices using prescribed methodologies and matching-based discount rates.

- Conclusion And Future Work

The evolving role of annuities in retirement planning, the increasing relevance of predictive analytics in actuarial practices, and the critical importance of understanding contingent liabilities in public finance. It provided an in-depth discussion on the structure and types of annuities, the challenges in managing long-term financial liabilities, and ALM models. It also looked at how streaming technology and real-time data may be used to improve decision-making in sectors like agriculture and insurance. By combining traditional actuarial methodologies with advanced data stream technologies, this paper emphasizes the necessity of flexible and knowledgeable methods for managing financial risk in the quickly changing environment of today. The implementation of modernizing insurance operations faces hurdles in uniting live heterogeneous data systems with traditional actuarial systems and maintaining accurate liability model calculations. The ongoing difficulties for performance maintenance and regulatory compliance present themselves in addition to existing problems.

Future studies should concentrate on creating comprehensive actuarial models by combining ML algorithms with Enhancing the precision of liability estimation and measurement with real-time data analytics. Research should investigate actual insurance company applications of big data stream technology for annuity portfolio supervision as a follow-up investigation. Research on evaluating how alternative ALM strategies function across various economic conditions through predictive modeling will help both administrators and financial organizations achieve improved fiscal stability as well as optimal retirement income strategies.

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