

The Potential Impact of AI on Human Longevity and the Consequences for Modeling Future Survival/Mortality: A Collection of Essays

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The Potential Impact of AI on Human Longevity and the Consequences for Modeling Future Survival/Mortality

A Collection of Essays

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The Potential Impact of AI on Human Longevity and the Consequences for Modeling Future Survival/Mortality

A Collection of Essays

Introduction and Acknowledgments

INTRODUCTION

The Society of Actuaries (SOA) Research Institute’s Mortality and Longevity Strategic Research Program Steering Committee established a call for essays series to gather a variety of perspectives on the application of AI to mortality and longevity. The objective of this call for essays, the second in the series, is to create a resource that focuses on the use of AI to potentially extend human longevity and the implications for modeling future survival/mortality.

The collection includes nine essays that were accepted for publication from all submissions. Two essays were chosen for prizes based on their creativity, originality, and likelihood of further thought on the subject matter.

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| Prize Winner | From Gompertz to AI: The Evolution of Mortality Modeling in an Age of Longevity Breakthroughs Stefanos Orfanos, FSA, CERA |
| Prize Winner | Modernizing Mortality Modeling: The Actuary’s Response to AI-Driven Longevity Gains Nii Amoo Decardi-Nelson, Graduate Student (MSc Mathematics) |

THE CALL FOR ESSAYS

At the Society of Actuaries Research Institute, calls for essays are substantively different from calls for short research papers. Research Institute research papers are required to be fact-based and objective and to avoid advocacy, especially with respect to public policy. Research papers published by the Research Institute may inform readers about public policy topics but must refrain from taking a position on or advocating for a public policy issue.

Essays that the Research Institute published may be fact-based, short research papers. Alternatively, they may be more experiential in nature as a means of highlighting issues or calling for change, although they must refrain from advocating for or taking a position on a specific legislative or regulatory initiative. Both types of essays were invited in this call for essays, and both types of essays are included in this collection.

For context, the two sections of the call for essays that outline the subject matter request are replicated below.

BACKGROUND AND PURPOSE

There are risks and opportunities of using artificial intelligence (AI) on mortality and longevity.

The Society of Actuaries (SOA) Research Institute's Mortality and Longevity Strategic Research Program is interested in exploring the application of AI to mortality and longevity from a variety of perspectives. The result of this effort is intended to provide useful resources for readers to increase awareness and discussion around this topic and to set the stage for future research.

The first essay collection in the series explored the use of AI in actuarial practice for modeling and forecasting mortality. These essays are [now available](#) on the SOA website.

For this call for essays, the second in a series, essays will focus on the use of AI to potentially extend human longevity and the implications for modeling future survival/mortality.

SAMPLE TOPICS OF INTEREST FOR ESSAYS

Reports concerning the use of AI to potentially improve human health and longevity have become increasingly frequent. The Mortality and Longevity Strategic Research Program Steering Committee seeks essays that address the use of AI to potentially extend human longevity and its impact on modeling future mortality/survival. This invitation has been deliberately written broadly to provide respondents the flexibility to address this topic from one or more perspectives and approaches. Respondents are free to choose from one or more of the sample topics below or propose others that fall within the scope of the area described in the above section. Please note that the list is not meant to be exhaustive but merely examples of proposed topics that might be considered.

Sample topics include:

- How might the use of AI impact mortality improvement, life expectancy, healthy life expectancy, or life span over the next 5, 10, or 20 years?
- How might the use of AI to improve life expectancy or healthy life expectancy impact traditional actuarial methods for projecting future mortality, survival, or populations?
- Should actuaries account for the potential increase in human lifespans due to AI in its current mortality/survival assumptions or mortality/survival models. And why?
- How might the use of AI to increase an individual's lifespan impact human behavior, and what are the consequences of such impacts to actuarial mortality/survival modeling?
- How or to what extent should the impacts of AI be incorporated into alternative future scenarios for pricing, reserving, or capital assessment of life insurance, annuities or pensions?
- What are the implications of AI's potential to increase human longevity to the life and health insurance and annuity industries?

ACKNOWLEDGMENTS

The SOA Research Institute thanks the Mortality and Longevity Strategic Research Program Steering Committee for their careful review and judging of the submitted essays, especially Larry Stern, FSA, MAAA and Yutaro Kameda, FSA. Any views and ideas expressed in the essays are the author's alone and may not reflect the Committee's views and ideas nor those of their employers, the authors' employers, the Society of Actuaries, the Society of Actuaries Research Institute, nor Society of Actuaries members.

Prize Winner

From Gompertz to AI: The Evolution of Mortality Modeling in an Age of Longevity Breakthroughs

Stefanos Orfanos, FSA, CERA

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The following essay was generated with the help of Anthropic's Claude Sonnet 3.5 and OpenAI's GPT-4o. A list of prompts can be provided upon request.

INTRODUCTION

In 1825, London insurance actuary Benjamin Gompertz observed a striking regularity in mortality patterns: after early adulthood, human death rates increase exponentially with age. Known as Gompertz's Law, this finding suggested that aging followed a predictable mathematical curve—one as inevitable as compound interest, yet even more consequential.

Imagine the human body as a bustling metropolis, with trillions of cells functioning like citizens going about their daily business. In Gompertz's time, aging was viewed much like the inevitable decay of a city's infrastructure—roads cracking, buildings weathering, power lines fraying. But a city is far more than its infrastructure. It is a highly interconnected ecosystem of transportation networks, power plants, waste management, communication lines, and millions of individual decisions and interactions. Similarly, we now know that aging isn't simply about wear and tear. It's about the gradual breakdown of cellular communication networks, the accumulation of molecular garbage in our biological streets, the failing power plants of our mitochondria, and the emergence of problematic "neighborhoods" of senescent cells that poison their surroundings.

This richer understanding began emerging in mortality modeling in 1960, when Bernard Strehler and Albert Mildvan proposed their vitality theory of aging. Rather than viewing death as inevitable system failure, they suggested each individual possessed a certain level of "vitality" that could resist and recover from damage. Their theory recognized aging as a dynamic process, where the accumulation of damaged cells constantly competed with the body's repair mechanisms. This view gained mathematical sophistication through Anatoli Yashin's work introducing stochastic elements to capture the effect of myriad factors not explicitly included in the model.

Enter artificial intelligence (AI), and with it, a revolution in our understanding of the human body as a biological metropolis. In research laboratories worldwide, AI systems perform the arduous work of mapping complex relationships between cellular damage and systemic aging that help reveal how cascading failures contribute to the exponential rise in mortality rates that Gompertz observed. More importantly, these technologies suggest that such failures might be preventable or even reversible. This raises a profound question for actuarial science: how do we model mortality in a world where the aging process itself becomes increasingly negotiable?

THE DIVERGENCE OF CHRONOLOGICAL AND BIOLOGICAL AGE

The separation of chronological and biological age originates in cellular biology. AI systems have succeeded in explaining how nine fundamental hallmarks of aging interact to create the mortality patterns we observe in populations, ranging from genomic instability to altered intercellular communication, and each representing a potential target for intervention. This deep understanding reveals why traditional actuarial models, based on aggregate statistics, fail to capture the full complexity of human aging.

Cellular senescence represents one of the most promising targets for intervention. AI systems have identified protein signatures unique to these "zombie" cells, which cease dividing but release inflammatory compounds that damage neighboring tissues. These cells accumulate exponentially with age, providing a biological foundation for Gompertz's mortality law. AI-designed senolytics—drugs that selectively eliminate senescent cells—have been shown to reduce biological age markers by several years in early-stage research. Improvements in mitochondrial function appear to enhance energy production and stem cell performance, creating synergies with senolytic treatments.

Biological aging clocks incorporate hundreds of biomarkers, from blood parameters to epigenetic methylation patterns, revealing that individuals of the same chronological age can differ in biological age by decades. These metrics predict mortality more accurately than traditional actuarial factors. New mortality models must therefore incorporate both chronological and biological aging rates, with traditional mortality curves splitting into multiple trajectories based on access to and effectiveness of various interventions.

The temporal dynamics of these interventions pose particular challenges. Unlike conventional medical treatments, which often show diminishing returns, AI-designed longevity therapies exhibit compounding effects. Clearing senescent cells reduces inflammation, enhances stem cell function, and improves cognitive performance. Current research with AI systems has identified combinations of interventions that target multiple aging mechanisms simultaneously, producing mortality reductions greater than the sum of their individual effects.

The impact extends beyond measurement to fundamental questions about mortality projection. While traditional actuarial methods rely on past mortality trends, assuming continuity in improvement rates, AI-driven breakthroughs in both physical and cognitive aging signal a period of discontinuous change. As our ability to influence biological age advances, the basic relationship between chronological age and mortality risk may require thorough reconsideration.

THE TERM STRUCTURE OF LONGEVITY MODELING

AI-driven advances in longevity present uncharted territory for the actuarial profession. Any significant shifts in survival rates would likely unfold across multiple time horizons, each requiring distinct approaches to modeling, product design, and risk management.

In the immediate term, measurement and credibility take center stage. Early adopters of AI-guided health interventions may exhibit survival rates that diverge from population averages. Traditional actuarial theory provides tools for distinguishing genuine trends from statistical noise. The difficulty lies in gathering sufficient data from what are initially small, potentially unrepresentative populations while maintaining appropriate conservatism in estimates.

The intermediate horizon necessitates innovation in product design and risk transfer. Insurers and pension funds are already developing responsive solutions. Participating annuities now incorporate mortality-linked adjustments, while pension plans implement conditional indexation tied to funding status. These features create natural feedback mechanisms between longevity experience and benefit levels.


Legacy books demand particular attention during this period. Many insurers and pension funds hold substantial portfolios of annuities and pensions written without risk-sharing features, often extending decades into the future with guaranteed benefit levels. The reinsurance market is expanding its toolkit for transferring this longevity risk, though pricing reflects substantial uncertainty. These existing exposures could face severe impacts from AI-driven longevity gains, as their long-dated guaranteed benefits were priced without contemplating significant biological age reversal.

The long-term horizon raises fundamental questions about solvency and capital adequacy. Current regulatory frameworks, such as Solvency II in Europe, require insurers to evaluate mortality improvement scenarios in their capital modeling. However, these scenarios typically assume relatively stable progression. As evidence of accelerated improvements materializes, stress testing approaches and capital requirements may need revision.

Throughout this evolution, materiality remains the actuary's compass. The profession's historical experience provides valuable context: improvements in life expectancy, whether from medical advances or public health measures, have typically unfolded gradually enough for actuarial methods to evolve with them. And while AI-driven gains may require new approaches, the key principle of actuarial prudence endures. Success in this fluid landscape hinges on developing flexible frameworks that incorporate new evidence while maintaining the reliability that has long characterized actuarial work.

* * * * *


Stefanos Orfanos, FSA, CERA is a Clinical Assistant Professor at Georgia State University. He can be reached at sorfanos@gsu.edu.



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Modernizing Mortality Modeling: The Actuary's Response to AI-Driven Longevity Gains

Nii Amoo Decardi-Nelson, Graduate Student (MSc. Mathematics)

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INTRODUCTION

Mainstream adoption of artificial intelligence (AI) has ushered in a transformative era across several industries. In particular, AI is redefining traditional approaches to disease prevention, diagnosis, and treatment in healthcare. By leveraging AI's capacity for rapid data analysis, pattern recognition, and decision-making, healthcare professionals are unlocking new ways to preserve and enhance human lives. Below are some ways AI is pushing the boundaries of healthcare, with a particular focus on how its applications contribute to mortality improvements and extending life expectancy.

- **Diagnostic Services:** AI algorithms, such as those used in medical imaging, have enhanced diagnostic accuracy, aiding in early disease detection and treatment.
- **Management of Chronic & Terminal Conditions:** Personalized care plans generated by AI models optimize treatment regimens based on individual patient responses, enhancing both outcomes and quality of life.
- **Life-Saving Procedures:** AI-enhanced surgical procedures result in increased precision and better outcomes.
- **Drug Discovery:** The adoption of AI significantly accelerates drug discovery times, making crucial medications available sooner, improving lives.
- **Gene Therapy:** AI advances gene therapy by analyzing genomic data and contributing to gene editing technologies, offering potential treatments for genetic disorders.

These innovations in AI-driven healthcare have not only reshaped the treatment landscape but also revealed new challenges and opportunities for actuarial practice. These advancements necessitate a re-evaluation of traditional mortality modeling techniques, which may struggle to account for the rapid and uneven shifts in longevity trends driven by AI's integration. By understanding the limitations of current actuarial methods, professionals can explore ways to incorporate AI-driven insights into their models, ensuring relevance in an evolving healthcare environment.

TRADITIONAL MORTALITY MODELLING

The actuarial profession has long relied on established models such as the Lee-Carter and Cairns-Blake-Dowd models to project mortality and longevity trends. However, these traditional approaches face limitations in an era of AI-driven healthcare advancements.

- **Lee-Carter Model:** This model decomposes historical mortality rates into age-specific factors, a time-dependent mortality trend, and random error components (Lee, 1992). It assumes stable patterns in mortality improvements over time and is often used as a benchmark tool for long-term survival projections.
- **Cairns-Blake-Dowd Model (CBD):** Focuses on age-cohort dynamics, this model is particularly suited for older populations where mortality variations are more pronounced (Cairns, 2006).

LIMITATIONS OF CURRENT MODELS IN AN AI-DRIVEN WORLD

- **Capturing Step-Change Mortality Improvements:** Traditional models assume that past trends persist without drastic disruptions. However, AI-driven healthcare innovations can spur abrupt changes. For example, a drug that cures cancer would create a sudden and stable mortality improvement, an effect legacy models might struggle to capture immediately.
- **Uneven Improvements Across Populations:** Mortality improvements from AI advancements are unlikely to be uniform. Variations in technological adoption, healthcare infrastructure, and socioeconomic factors create disparities. Research highlights gaps in healthcare access across the U.S. (GoodRx, 2021), indicating that certain populations may benefit less from AI-driven therapies. Additionally, the high cost of novel treatments could render them inaccessible for low-income or uninsured individuals, further contributing to these uneven benefits. These are some population-specific dynamics that traditional models fail to account for as they often rely on uniform improvement rates across broader cohorts.

INTEGRATING AI INTO MORTALITY MODELS

To address these limitations, actuaries can leverage AI, specifically machine learning (ML), in their mortality modeling processes. This requires a structured approach that combines advanced technological tools with actuarial expertise. Here's how actuaries can accomplish this:

- **Expand Data Sources:** Actuaries should consider integrating diverse datasets, such as electronic health records (EHRs), wearable device data, genomic information, and socioeconomic indicators. AI models thrive on high-quality, granular data, which can illuminate trends and disparities overlooked by traditional models.
- **Model Selection and Development:**
 - Utilize ML techniques, such as neural networks and ensemble methods (e.g., gradient boosting machines), to model mortality trends. These models are particularly suited for detecting non-linear interactions between multiple variables.
 - Develop hybrid models that combine AI-driven predictions with insights from traditional actuarial approaches, ensuring continuity while enhancing accuracy.
- **Algorithm Transparency and Explainability:** Since AI models can be complex, incorporating explainable AI (XAI) methods ensures predictions are interpretable. Actuaries can validate models with stakeholders and address regulatory concerns without sacrificing performance.
- **Scenario Testing and Simulation:** Actuaries can employ AI tools to conduct detailed scenario analyses. For example, they could assess the long-term impact of a new AI-enabled therapy on specific demographic cohorts, simulating its ripple effects on mortality assumptions.
- **Cross-Disciplinary Collaboration:** Actuaries should collaborate with data scientists, healthcare professionals, and policymakers to align AI models with practical applications and ensure robust decision-making processes.

BENEFITS

As actuaries adapt to technology and incorporate AI techniques into the mortality modelling process, some benefits that will accrue to stakeholders include:

- **Improved Accuracy of Mortality Estimates:** AI significantly enhances accuracy. For instance, a study by Peddamukkula, 2024 reported an 18.7% improvement in predictive performance over traditional approaches.
- **Impact on Financial Products:**
 - **Annuities:** Precise mortality predictions help minimize mispricing risks, reducing financial strain caused by extended lifespans on annuity reserves.

- **Pensions and Social Security:** Accurate longevity forecasts, anticipating changes in the population's life expectancy, help inform sustainable benefit structures and investment strategies to maintain solvency.
- **Personalized Insurance and Annuities:** AI enables granular segmentation and dynamic benefit structures linked to cohort longevity forecasts, enhancing product personalization and customer satisfaction.
- **Market Expansion and Equity:** AI can identify underserved or overlooked markets by analyzing demographic and socioeconomic data, enabling insurers to better target these populations. This helps expand market reach and promotes equity by ensuring that a broader range of consumers, including those in marginalized groups, have access to suitable insurance products.

CHALLENGES AND CONSIDERATIONS


- **Bias in Data:** AI models reflect the biases in training data. Systemic disparities in healthcare access could perpetuate inequalities, impacting fairness.
- **Data Privacy and Security:** Ensuring compliance with diverse regulations across different jurisdictions (e.g., GDPR in Europe or HIPAA in the U.S.) can complicate the use of sensitive healthcare and lifestyle data for AI modeling.
- **Over-Reliance on AI:** Without adequate human oversight, heavy reliance on AI could undermine sound actuarial judgment, particularly when models lack explainability.
- **Retirement Age Adjustments:** Retirement age might need to be revised upwards on account of the increased life expectancy and quality of life due to AI's impact on healthcare. This adjustment ensures the period between retirement age and death can be adequately funded to prevent financial strain on retirement systems.
- **Regulatory Hurdles:** Regulatory bodies may be slow to adapt to the rapid advancement of AI technologies, creating uncertainty for actuaries attempting to implement AI-driven models within existing frameworks.

CONCLUSION

The integration of AI (ML) into mortality modeling presents both tremendous opportunities and significant challenges for the actuarial profession. As AI continues to reshape the landscape of healthcare and longevity, it is critical for actuaries to remain proactive in adapting their methodologies and practices, ensuring that they are equipped to navigate the evolving future of mortality forecasting. By embracing these innovations responsibly, the actuarial profession can play a pivotal role in making informed, equitable, and sustainable decisions in the face of rapidly improving life expectancy.

* * * * *


Nii Amoo Decardi-Nelson is a graduate student in MSc. Mathematics (concentration: Actuarial Science) at the University of Wisconsin, Milwaukee. He can be reached at niiamoo@uwm.edu.



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How Might the Use of AI to Improve Life Expectancy Impact Traditional Actuarial Methods for Projecting Future Mortality?

Emily Dave, FSA, FIA

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INTRODUCTION

Traditional actuarial methods, as well as many of the newer data-driven approaches for projecting future mortality rates, may not work well when there are potential disruptive new drivers like artificial intelligence (AI) that could significantly impact life expectancy in the future.

The key challenge is that most existing mortality projection methods rely primarily on extrapolating historical trends and patterns into the future. However, disruptive technologies like advanced AI have the potential to alter historical trajectories of mortality improvement in ways that past data cannot adequately capture.

Specifically, AI breakthroughs have the potential to enable radically new healthcare capabilities like highly accurate early disease detection and prevention, personalized treatment planning, improving drug discovery, and enhancing human longevity via wearables and robotics or human-AI integration.

These kinds of paradigm shifts could lead to faster declines in future mortality rates compared to what historical data would predict based on previous trends.

The existing mortality models may miss or underestimate the impact of AI because the AI-driven disruptions have no close analogues in the historical data that the models were trained on. The effects could play out in complex, non-linear ways that require fundamentally different modeling approaches. Solely relying on conventional actuarial techniques, which are focused on extrapolating from the past, will become increasingly inadequate for projecting future mortality.

Accounting for difficult-to-predict disruptive drivers remains an open challenge for mortality forecasting. There are also complications in deciding whether to update central best estimate assumptions, or whether the impacts should rather be allowed for economic capital assessments that are more focused on lower probability events. Monitoring technological developments will be crucial. To accurately model the sweeping influences of forces like AI, new prospective frameworks need to be considered.

WHY SHOULD ACTUARIES CONSIDER AI WHEN PROJECTING FUTURE MORTALITY?

Actuaries need to seriously consider the potential impacts of AI when modeling future life expectancy and actively decide how to include potential impacts of this technology. This is important for several reasons, including:

1. Longevity Risk Management - Life insurers and pension plans face major longevity risk if mortality rates decline faster than anticipated. AI-driven healthcare breakthroughs could significantly extend lifespan, causing reserves to be underfunded. Properly accounting for this risk is critical.

2. Medical Transformations - AI systems may achieve human-level or better abilities to understand biology, develop new drugs/treatments, and provide highly personalized precision medicine. This could accelerate improvements to mortality in ways that traditional methods miss.
3. Human Enhancements - Future AI capabilities could make it possible to directly enhance human biology through neural implants, genetic engineering, nanotechnology, and more. This blurs the line between medical treatments and human augmentation, impacting mortality in currently unpredictable ways. This could even lead to changes in the viability of certain insurance coverage, so understanding the potential impacts, even at a very high level, could be of critical importance when considering future strategy and risk management.
4. Change of Risk Factors - The disease burdens and risk factors driving mortality could radically change due to AI introducing new environmental exposures, disrupting socioeconomic systems, altering human behavior/lifestyles, etc.
5. Competitive Advantage - Taking a lead in proactively studying and modeling the cutting-edge intersections of AI and mortality could provide companies with a strategic edge over those who do not engage with this topic.
6. Reputation - The actuarial profession is highly regarded and offers valuable insights. Proactively studying AI's mortality impacts allows the actuarial profession to get ahead of a potentially seismic issue, reinforce its public reputation for foresight and analytical expertise, and position itself as an influential voice in managing technological disruptions.

There are potential limiting factors that constrain the impact of AI on extending human lifespan such as, technological hurdles, biological complexities, and important ethical considerations. However, given the tremendously high potential impact of AI as a potentially "longevity-enhancing" force, actuaries and insurers have strong incentives to put focused effort into understanding the potential impacts of this technology. Monitoring AI milestones may become as critical as tracking medical research. Actuaries need to consider the deficiencies of current modeling techniques for exploring this topic and making appropriate quantifications.

LIMITATIONS OF TRADITIONAL MODELING METHODS: WHY THESE CANNOT ADEQUATELY CAPTURE THE EFFECTS OF AI

Traditional actuarial methods for projecting future mortality rates have limitations when it comes to accounting for the potential impacts of disruptive technological forces like AI. While valuable for many applications, methods like the Lee-Carter model or deterministic alternatives that rely primarily on extrapolating past trends can struggle with the following issues:

- The "Precedent Problem" - Past data reflects mortality patterns driven by the social, economic, technological, and epidemiological conditions of previous eras. Projecting these historical patterns forward assumes an inherent continuity and stability in the underlying drivers of mortality changes. However, truly disruptive forces like radical new AI capabilities can fundamentally alter these drivers in unprecedented ways, invalidating that core assumption. This would render any projections that they make unreliable.
- "Horizon Bias" - Most modeling techniques are optimized for making short-to-medium term projections by capturing recent changes in mortality rates. But longer-term forecasts become increasingly uncertain, especially when anticipating potential disruptions whose timing is unknown. An AI breakthrough could rapidly reshape long-term mortality outlooks in uncertain, non-linear ways that models which are closely fitted to past experience won't capture.
- "Empirical Boundaries" - Historical datasets only reflect mortality within the constraints of existing healthcare quality, disease burdens, biological limits, etc. Potential AI-catalyzed innovations like molecular nanotechnology or brain-computer interfaces could expand human health spans into new empirical regimes. Existing approaches would be unlikely to be able to accommodate such a regime shift.

- "Linearity Assumptions" - Many forecasting models assume predominantly linear, incremental processes governing mortality change. However, technological discontinuities like artificial general intelligence could trigger highly non-linear, exponential changes diverging sharply from linear extrapolations of the past.
- "Endogeneity Problem" - Most methods treat past drivers of mortality as exogenous inputs. But technologies like AI are endogenous, self-reinforcing processes whose advancement rates can themselves be altered by the capabilities they enable, creating complex feedback loops. This acts to magnify the effects of the disruptive technology.

In essence, an over-reliance on backwards-looking empirical data alone can lead to failing to adequately anticipate and model the full scope of potential paradigm shifts, such as the introduction of transformative AI. While historical data remains valuable, new frameworks integrating technological insights and expertise are needed to more robustly forecast life expectancy impacts from AI innovations.

ALTERNATIVE METHODS THAT COULD BE USED TO MODEL THE EFFECTS OF AI

To better account for potential technological disruptions like transformative AI, new frameworks may be needed that can:

1. Incorporate expert opinion on the likelihood and timing of key technology changes.
2. Model scenarios explicitly around breakthrough AI capabilities such as highly personalized medicine and human enhancements.
3. Calibrate appropriate adjustments to mortality trajectories to model exponential changes.
4. Integrate diverse data sources beyond just historical mortality experience.

THE CASE FOR A DRIVER-BASED APPROACH

One possible route to consider is a robust driver-based modeling approach. This shows promise as an alternative to the traditional pure backward-looking extrapolation.

Rather than solely relying on fitting to past mortality data, a driver-based framework attempts to disentangle the specific factors influencing mortality rates, quantify their impacts, and then project each driver's future trajectory based on subject matter analysis and simulations. The driver projections are then combined and translated into a projection of future mortality rates. This can be done for specific causes of death, or in aggregate for all-cause mortality. The actuary can then consider whether these projections represent a low probability event that should be allowed for when estimating capital requirements, or an outcome that should be incorporated into the best estimate basis (and if so, to what degree).

While implementing a comprehensive bottom-up driver model is undoubtedly complex, this framework allows actuaries to disentangle transitory effects from more persistent forces redefining longevity trajectories. It facilitates structured sensitivity testing and more transparent assumption-setting compared to opaque adjustments of raw historical data. While this approach relies on more subjective assessments, these could well be more reliable than the output of a more traditional extrapolative approach, in this context.

A driver-based approach to setting mortality rates could better account for the potential impacts of AI. Explicit AI drivers can be included in the projections, aligned with the latest expert opinion on how the technology will develop. AI progress would be treated as an explicit factor influencing mortality rates, similar to how other drivers like smoking, obesity, etc. are currently modeled. Specific AI measures could include adoption rates of AI-enabled medical technologies or the benefits of AI systems deployed in the healthcare value chain to improve efficiencies in healthcare delivery.

Expanding risk factor modeling to include certain AI developments like human enhancement technologies could create entirely new risk factors impacting mortality that need to be accounted for in driver-based models. These new risk factors can be included in a driver-based approach in a relatively straightforward way.

Given the highly uncertain, non-linear impacts of transformative AI, driver-based models used to understand the impacts on future mortality should embed scenario analysis to explore the alternative possibilities. This would involve modeling different trajectories for AI progress—a slow "AI as tool" scenario versus a fast "general AI" disruption scenario for example. This would help demonstrate the plausible range of future outcomes. Given the rapidly evolving developments in the field of AI, frequent updates to the scenarios would be required in order to ensure that they remain relevant and realistic.

Overall, a driver-based framework provides the flexibility to explicitly integrate AI progress as a driver of future mortality outcomes, adjust for transition effects, embed scenario analysis, and expand the risk model as needed to capture AI's potential mortality impacts. This suggests that it could be a particularly effective approach for modeling the impact of AI on mortality.

A transition toward driver-based prospective forecasting should be viewed as an evolutionary journey for the actuarial profession, not something achievable overnight. Even the most advanced driver-based models will necessarily rely on some anchoring to historical data and require careful justification of all subjective judgments. Dynamic updating protocols and advanced data integration methods will be essential to ensuring driver-based models remain credible as new information emerges.

This may require an expansion of the actuarial skill set and knowledge base. Foreseeing AI-driven mortality impacts will require tighter integration between actuaries and experts across disciplines like healthcare, data science, economics, and public policy. Actuaries will need to leverage knowledge and skills from across disciplines when setting assumptions.

CONCLUSION

The actuarial profession needs to proactively account for the potential impacts of advanced AI on future mortality rates and life expectancy trends.

An over-reliance on modeling techniques that primarily extrapolate from historical data could leave significant blind spots. Transformative AI capabilities in areas like healthcare, human enhancement technologies, and accelerated scientific discovery have the potential to fundamentally alter mortality trajectories in ways not well-captured by past experience alone. While promising for the potential to extend lifespans, the effects of such disruptive forces may play out in complex ways that conventional modeling techniques will struggle with.

To address this, actuaries should explore complementing traditional backward-looking methods with alternative, more forward looking techniques such as driver-based modeling frameworks.

Accounting for the potential impact of AI and implementing robust driver-based models will be challenging—requiring expanded data sources, enhanced simulation capabilities, strengthened processes, and interdisciplinary collaboration across multiple fields. However, developing these adaptable frameworks is important for effective longevity risk management as the life insurance and pension fund industries navigate an era of accelerating technological change.

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Emily Dave, FSA, FIA is a Longevity Actuary. She specializes in the development of longevity assumptions and longevity research. She can be reached at emilydave1@gmail.com.



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The Role of AI in Extending Human Longevity and the Implications for Mortality Modeling

Niranjan Rajendran, B.Sc. (Hons)

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INTRODUCTION

Technological advances have consistently pushed the boundaries of human life expectancy. Each medical leap has lengthened and improved human lives, from the discovery of penicillin to the deployment of new surgical techniques. In recent years, a rapidly evolving wave of innovations in artificial intelligence (AI) has begun to reshape how we approach medicine and our fundamental understanding of human health and survival. This essay explores how AI might extend human longevity and discusses the implications for modeling future mortality and survival, particularly from an actuarial perspective.

AI'S POTENTIAL TO IMPROVE HUMAN LONGEVITY

EARLY DETECTION AND PERSONALIZED TREATMENTS

One of the most powerful applications of AI in healthcare involves its capability for early disease detection and the identification of patient-specific treatment plans. By analyzing large datasets from medical records, wearable health devices, and genomic databases, AI systems can sift through terabytes of information and detect subtle patterns that human clinicians might overlook. For example, machine learning models now enable healthcare providers to spot the earliest signs of conditions like cancer or cardiovascular disease based on complex biomarkers and imaging data. Earlier diagnosis leads directly to a higher chance of successful intervention, which can extend both lifespan and health span.

Furthermore, AI-driven therapies go beyond basic disease detection. Precision medicine enabled by AI tailors interventions based on an individual's genetic profile, lifestyle factors, and environmental context. Recent breakthroughs in predictive analytics have demonstrated the possibility of forecasting disease risk and progression, allowing physicians to adjust treatment plans in real time. As these technologies improve, they hold the potential to transform once-fatal diseases into chronic conditions, substantially impacting mortality rates and reshaping life expectancy across different populations.

DRUG DISCOVERY AND BIOTECHNOLOGY

Drug discovery is another area in which AI has shown promise. Traditional development processes for pharmaceuticals can require a decade of testing and billions of dollars in investment. In contrast, AI algorithms can comb through existing databases of compounds and proteins to identify promising therapeutic targets more efficiently. This accelerates the identification of potential drug candidates, shortens the timeline of preclinical testing, and increases the likelihood of finding effective treatments.

Within the biotechnology sphere, AI has aided in the development of customized interventions such as CRISPR-based gene editing and cell-based therapies. AI helps accelerate the trial-and-error process needed to refine these complex therapeutic approaches. As a result, new treatments may reach patients faster and address previously intractable health conditions, potentially reducing mortality from genetic disorders and chronic diseases.

LIFESTYLE AND BEHAVIORAL INTERVENTIONS

While biomedical applications draw much of the spotlight, AI-driven lifestyle, and behavioral interventions also hold significant potential. Wearable devices, smartphone apps, and virtual coaching systems powered by AI can support sustained behavior change monitoring everything from daily physical activity levels to sleep patterns. By offering personalized feedback and motivation, AI-based platforms can help individuals adhere to health regimens designed for the long term. Over time, these interventions may reduce the risk of preventable conditions such as obesity, Type 2 diabetes, and hypertension, further contributing to improvements in population-level longevity.

IMPLICATIONS FOR FUTURE MORTALITY AND SURVIVAL MODELING

RETHINKING TRADITIONAL ACTUARIAL ASSUMPTIONS

Actuarial models have traditionally relied on historical mortality data to forecast future survival rates and life expectancies. As AI-driven medical innovations start to influence morbidity and mortality on a mass scale, these historical trends may no longer adequately predict the future. If AI significantly extends both average and healthy lifespans, actuaries will need to adapt their models to avoid underestimating survival rates. For the life insurance industry, underestimating future lifespans can result in premium mispricing and inadequate reserves.

However, the path to longevity increases is not straightforward or uniform. The pace of adoption varies by region and socioeconomic factors, which can widen gaps in mortality improvement across populations. Traditional actuarial models often incorporate conservative estimates of future mortality improvements based on past trends. But if we see a rapid, AI-driven decline in disease prevalence or a surge in the standard of care, these estimates could fall short. New models may need to incorporate a range of possible AI adoption scenarios, adjusting for disparities in healthcare access, varying regulatory environments, and shifts in human behavior.

NEED FOR ALTERNATIVE SCENARIOS

Instead of relying on a single best estimate of future mortality changes, the actuarial field may increasingly consider alternative scenario analyses.

These scenarios could address variables such as:

- **Speed of AI Integration into Healthcare:** A scenario might consider a full-scale integration of AI in healthcare, where drug discovery and personalized treatments revolutionize chronic disease management. Conversely, a more conservative scenario would assume AI remains limited to specific areas, such as diagnosing certain cancers.
- **Regulatory and Ethical Concerns:** Policy and ethical constraints could slow down the adoption of AI-driven therapies. Alternatively, an environment with fewer regulatory hurdles could accelerate AI adoption significantly.
- **Socioeconomic Disparities:** The uneven availability of AI-based healthcare solutions could generate divergent mortality patterns between high-income and lower-income populations.

By embracing these scenarios, actuaries, insurers, and policymakers can better understand the range of possible outcomes for mortality over the next five, 10, or 20 years, improving the resilience of financial systems that depend on accurate forecasts.

BEHAVIORAL SHIFTS AND THEIR EFFECT ON ACTUARIAL MODELING

Beyond direct medical interventions, an extension of healthy lifespans resulting from AI-based preventive and wellness strategies may inspire broader lifestyle changes. As individuals live longer and maintain good health into older ages, they may alter how they plan for retirement, approach insurance coverage, and weigh financial and personal risks.

For instance, if AI-driven systems help older adults remain independent longer, there could be an increased demand for long-term care insurance products that cover advanced ages but might pay out later, given improvements in healthy life expectancy. Alternatively, seniors may choose to continue working or contributing to society in some capacity, leading to shifts in saving and consumption patterns. Each of these possibilities necessitates new modeling strategies that incorporate shifting timelines and behaviors.

INDUSTRY IMPLICATIONS: LIFE INSURANCE, ANNUITIES, AND PENSIONS

PRICING AND RESERVES

As AI extends longevity, both the life insurance and annuity industries could face significant pressure to reevaluate their underwriting guidelines. Premiums for life insurance products have historically been based on well-established mortality tables. If healthier and longer-living individuals dominate the insured pool, insurers might need to reduce premiums in competitive markets or amend underwriting criteria. Conversely, if certain populations experience more rapid benefits from AI-based therapies, insurers must carefully account for selection effects that may lead to anti-selection if these individuals seek coverage at standard rates.

For annuity providers, the longevity risk grows even more prominent. If people consistently live longer than anticipated, annuity reserves could prove insufficient over time, threatening solvency. Consequently, more dynamic reserve modeling that can adapt annually to emerging data on AI-driven longevity improvements will become necessary.

PRODUCT INNOVATION

The life and health insurance industries will likely respond to AI-driven longevity trends with innovative product offerings. New coverage types might include incentives for policyholders who engage with AI-based health monitoring devices or adjust premiums based on real-time data. Employers may design pension plans that reward active health monitoring and AI-driven preventive care. While these new product lines present revenue opportunities, they also introduce additional complexity and regulatory considerations.

CONCLUSION


Artificial intelligence has already begun to reshape the landscape of healthcare, and its potential to extend human longevity is both exciting and disruptive. From early disease detection to personalized treatments and real-time behavioral interventions, AI may drive a transformative wave of mortality improvement in the coming years. However, the impact will likely be uneven across different populations, and the magnitude and timing of these changes remain uncertain.

For actuaries, insurance companies, and policymakers, this uncertainty represents both a challenge and an opportunity. Traditional mortality models, which rely heavily on past data, may lose accuracy in predicting a future shaped by new and rapidly evolving AI applications. Scenario-based modeling that accounts for varying rates of AI adoption and regulatory environments becomes essential. Moreover, changing behaviors and social structures brought about by longer, healthier lives may require entirely new assumptions about consumer choices, financial planning, and product design.

Ultimately, AI's potential to increase human longevity demands proactive adaptation in actuarial science and risk management. By embracing flexible modeling techniques and integrating cutting-edge research, the actuarial community can help ensure that the life insurance, annuity, and pension sectors remain robust in an era where rapidly improving health outcomes could alter life expectancies in ways never seen before.

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Niranjan Rajendran, B.Sc. (Hons) in Finance and Insurance Mathematics, Actuarial Trainee at Allianz Life Insurance Lanka Ltd. He can be reached at rajandranniranjan3@gmail.com.



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AI-Driven Disruption: Bridging Health Disparities, Preparing for Longevity Shocks, and Exploring Extreme Life Extension

Kailan Shang, FSA, CFA, PRM, SCJP

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INTRODUCTION

Artificial intelligence (AI) is driving unprecedented changes in healthcare, influencing not only how diseases are diagnosed and treated but also how longevity is perceived and managed. AI technologies, including machine learning and predictive analytics, enable faster drug discovery, improved diagnostics, and personalized treatment plans. These advancements are reshaping expectations for human health and lifespans, prompting questions about how mortality models should evolve to reflect these rapid changes.

Actuaries have traditionally relied on historical trends and gradual improvements in life expectancy to inform their models. However, AI's capacity to accelerate medical innovation introduces uncertainty that is difficult to quantify using traditional techniques. Breakthroughs in aging research, driven by AI's ability to analyze complex biological datasets, could extend lifespans significantly beyond historical precedents. On the other hand, the integration of AI into healthcare systems introduces risks such as data biases, unequal access, and systemic vulnerabilities that may exacerbate health disparities or, in some scenarios, shorten lives.

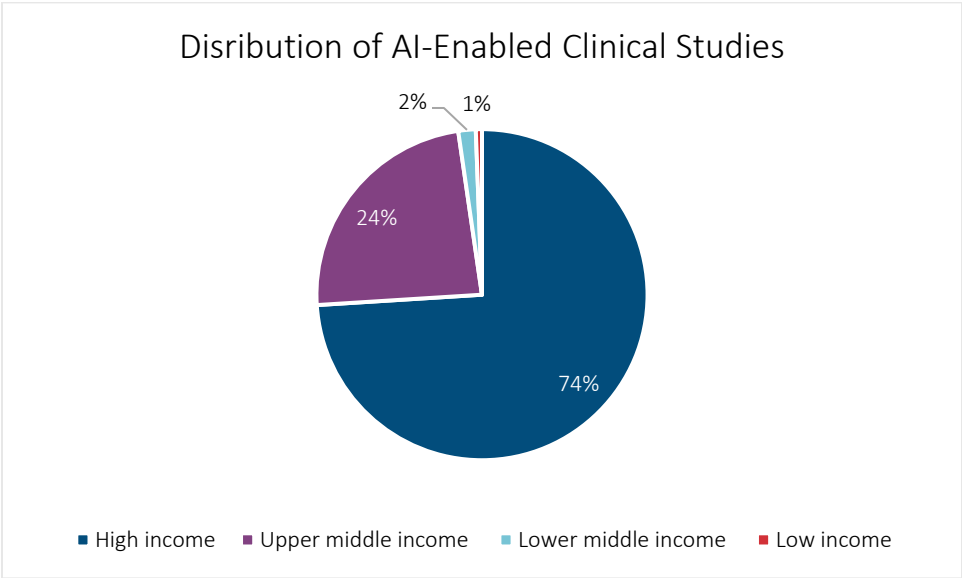
This essay explores three areas where AI may impact longevity: reducing health disparities, preparing for longevity shocks, and addressing extreme life extension.

REDUCING HEALTH DISPARITIES THROUGH AI

Health disparities, defined as differences in health outcomes among various population groups, remain a global challenge. Factors such as socioeconomic status, geographic location, and systemic inequities contribute to significant variations in life expectancy. Individuals in high-income countries typically live longer than those in low-income nations, while within countries, racial and ethnic minorities often experience worse health outcomes due to barriers in accessing quality care.

AI offers promising solutions to address these disparities. However, the implementation and impact of AI-driven healthcare innovations remain uneven across different income levels. Yang et al. (2024) analyzed 159 AI-enabled clinical studies finding the disparity by income level as illustrated in Figure 1.

Figure 1
DISTRIBUTION OF AI-ENABLED CLINICAL STUDIES BY INCOME LEVEL OF COUNTRIES



It highlights the concentration of AI healthcare research and applications in wealthier regions, emphasizing the need for strategies to extend these innovations and applications to underserved areas.

Diagnostic tools powered by AI can be used to enhance accuracy and accessibility, particularly in underserved regions. For example, studies have shown that AI-based tools consistently outperform human doctors in diagnosing certain conditions, as listed in Table 1.

Table 1
SAMPLE COMPARISON OF HUMAN AND AI MEDICAL DIAGNOSTIC ACCURACY

| Condition | Human Doctor Accuracy (%) | AI Accuracy (%) | Source |
|----------------------|---------------------------|-----------------|--------------------------------------|
| Prostate Cancer | 67 | 84 | UCLA Study discussed in Heady (2024) |
| Skin Cancer | 75 | 90 | Topol (2019) |
| Diabetic Retinopathy | 85 | 92 | Xu (2023) |

These advancements enable earlier and more precise interventions, improving outcomes for populations with limited access to specialists. In addition, as discussed in Topol (2019), telemedicine platforms that leverage AI for triaging patients and recommending treatments have increased healthcare access in rural and low-resource settings.

Personalized medicine is another transformative application of AI. By analyzing genetic, environmental, and lifestyle data, AI can tailor treatments to individual patients. This is particularly important in managing chronic conditions such as diabetes and cardiovascular disease, which disproportionately affect marginalized populations. Tailored interventions not only improve individual outcomes but also reduce the overall burden on healthcare systems, creating opportunities for actuaries to model more equitable longevity improvements across populations.

However, challenges such as algorithmic biases and unequal access to AI technologies must be addressed. Biases in training data can perpetuate or worsen existing disparities. Obermeyer et al. (2019) demonstrated that an algorithm used to allocate healthcare resources underestimated the needs of Black patients, leading to inequitable treatment allocation. Actuaries need to examine these biases in mortality models to ensure equitable assumptions across demographic groups.

In addition, AI's role in resource optimization can help identify and address geographic health disparities. Geospatial analysis using AI has been employed to map disease prevalence, such as cervical cancer hotspots, enabling targeted interventions in high-risk areas. Actuaries can incorporate such data into regional mortality assumptions, reflecting variations in access to AI-driven healthcare improvements.

LONGEVITY SHOCKS AND ACTUARIAL PREPAREDNESS

While addressing health disparities represents a key opportunity for AI, its ability to accelerate medical innovation also increases the risk of longevity shocks. These unexpected leaps in life expectancy present unique challenges for actuarial modeling and financial systems. Longevity shocks, or sudden and significant increases in life expectancy due to technological breakthroughs, pose substantial challenges for actuaries. Unlike gradual improvements in mortality rates, these shocks are difficult to anticipate and can disrupt financial systems reliant on stable mortality assumptions, such as pensions, life insurance, and annuities.

AI-driven medical advancements increase the likelihood of longevity shocks. As mentioned in Ouyang (2022), AI has accelerated drug discovery, reducing development timelines for certain diseases. Such advancements could lead to rapid improvements in treating chronic conditions and extend lifespans. AI's application in aging research, such as identifying senolytic drugs that target aging cells, raises the chances of delaying or reversing the aging process, as discussed in Sinclair (2019).

Longevity shocks present unique challenges for actuarial systems. Three illustrative scenarios are described below.

- In the **Gradual Improvement** scenario, a 5-year increase in life expectancy occurs over a 20- to 30-year period, driven by continued advancements in public health and healthcare access. Pension liabilities rise moderately as payout periods extend, while life insurance reserves require minor adjustments. This scenario aligns with historical trends and is manageable through periodic updates to mortality tables and funding assumptions.
- The **AI-Driven Longevity** scenario assumes a 10-year increase in life expectancy, fueled by breakthroughs in AI-enabled medical research, such as personalized medicine and early diagnostics. This accelerated improvement creates significant risks for pension systems, as liabilities grow rapidly and necessitate changes to retirement ages or contribution levels. For life insurance, reserves face substantial pressure due to longer benefit durations, requiring dynamic modeling techniques to reflect increased uncertainty.
- In the **Extreme Life Extension** scenario, a transformative 20-year increase in life expectancy occurs, driven by advances in aging science, such as cellular repair and genetic engineering. Pension systems face existential risks, with many plans becoming unsustainable without drastic reforms. Insurance reserves, particularly for annuities, fall critically short, as traditional pricing models fail to capture the extended payout periods. Preparing for such extreme outcomes requires actuaries to explore alternative scenarios, incorporate emerging longevity risks, and stress-test financial systems against unprecedented changes. Stochastic modeling may be used as well to simulate a range of potential outcomes, including extreme scenarios where AI-driven innovations extend lifespans dramatically.

These scenarios emphasize the need for actuaries to adapt their methods to account for varying levels of longevity risk. Actuaries must monitor developments in AI and biotechnology to detect early indicators of longevity shocks. By proactively adjusting assumptions and developing mitigation plans, actuaries can contribute to ensuring the long-term sustainability of financial systems.

THE PATH TO EXTREME LIFE EXTENSION?

AI's role in advancing aging research has fueled discussions about the potential for extreme life extension, where human aging processes are significantly delayed or reversed. Breakthroughs in cellular repair, genetic editing, and

AI-guided therapies could extend lifespans well beyond current expectations, challenging the traditional assumptions that underpin actuarial models.

For example, Sinclair (2019) describes how AI-enabled research has accelerated the discovery of therapies targeting the root causes of aging, such as cellular senescence and DNA damage. These advancements suggest a future where life expectancy is no longer constrained by biological aging, requiring actuaries to rethink mortality projections, retirement ages, and healthcare cost assumptions.

However, extreme life extension also raises ethical and societal questions. Access to life-extending technologies may be limited to wealthy populations, exacerbating health disparities. Beyond health equity, extreme life extension raises broader societal challenges, including intergenerational equity, resource allocation, and the sustainability of social support systems. Actuaries must consider these inequities when modeling future mortality trends, ensuring that projections account for variations in access to AI-driven healthcare innovations.

On the other hand, AI introduces risks that could shorten lifespans in some scenarios. Algorithmic biases, cyberattacks on AI-driven healthcare systems, and mismanagement of AI technologies could lead to systemic failures or unequal access to care. For example, a flawed algorithm could prioritize certain populations over others, limiting the benefits of life-extending interventions for marginalized groups (Obermeyer et al., 2019). Actuaries must incorporate such risks into their models, accounting for potential adverse outcomes alongside the benefits of AI advancements.


CONCLUSION

AI is transforming healthcare and longevity, presenting both opportunities and challenges for actuaries. By reducing health disparities, AI could narrow gaps in life expectancy, requiring actuaries to revise mortality assumptions and develop more equitable models. The possibility of longevity shocks, driven by AI breakthroughs, introduces uncertainty that necessitates dynamic tools such as stochastic modeling and scenario analysis. In addition, extreme life extension challenges traditional actuarial assumptions about finite lifespans, while the potential for life-shortening scenarios highlights the need for ethical safeguards and robust frameworks.

Actuaries are uniquely positioned to bridge technological advancements with financial sustainability. By adopting forward-looking methodologies and interdisciplinary collaboration, actuaries can ensure that financial systems remain resilient and adapt to AI's dual-edged impact on human longevity.

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Kailan Shang, FSA, CFA, PRM, SCJP is a Director at Aon PathWise. He can be reached at klshang81@gmail.com.



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Implications of AI Advancement on Human Lifespan and Considerations for Mortality Assumption Setting

Peik Hong Tan, FSA

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INTRODUCTION

In recent years, we have observed rapid development of artificial intelligence (AI) across various industries, especially the healthcare system. The advancement of AI presents unprecedented changes in ways of life which could inadvertently affect human lifespan. The key questions that this essay is trying to address are: (1) Could AI be the key to unlocking longer lives? (2) If the answer is yes, then what does this mean to the current traditional mortality assumption setting?

EFFECTS OF AI ADVANCEMENT ON HUMAN LIFESPAN

Advancements in AI are expected to significantly extend human lifespan and quality of life. This can be done by improving the healthcare system through the following ways:

- Early detection and intervention of diseases.
- Precision medication tailored to individual needs.
- Enhanced treatment and management of chronic conditions.

EARLY DETECTION AND INTERVENTION

AI-powered diagnostic tools are transforming disease detection and prevention processes. For example, AI can help detect diseases earlier through advanced imaging and biopsy analysis. Or AI would also be able to identify early signs of cognitive decline like Alzheimer's through speech analysis or brain imaging. What this means is that intervention and prevention can start earlier. Unlike now in which some chronic diseases would only be detected at a late stage when intervention can no longer have an effect, early detection and intervention can result in a positive effect on human lifespan.

PRECISION MEDICATION

AI expands medical research, which is inclusive of precision medication and advancement in drug discovery. For example, AI can evaluate all criteria inclusive of DNA data, lifestyle, and clinical information to generate personalized medication. In addition, it will also have the capability of real-time monitoring and adjusting medication dependent on the patient's latest condition. Thus, the recovery process can be accelerated with optimized medication. This precision ensures maximum treatment effectiveness, improving outcomes significantly.

ENHANCED TREATMENT OF CHRONIC DISEASES

AI facilitates treatment of chronic diseases through high-precision surgery and cutting-edge medical robotic technologies. For example, AI robotic systems can assist in cardiovascular related surgery through delicate procedures like valve replacement or bypass surgery. Or for cancer, AI can support in removing tumors while minimizing damage to surrounding healthy tissues. AI also uses real-time imaging and data analysis to enhance surgical precision. This can definitely eliminate operational risk due to human errors or fatigue, especially in long surgeries. In short, we can expect the success probability of chronic disease treatment to increase with AI.

REAL-WORLD AI EXAMPLES

Some of the actual AI tools available in the healthcare system are Google DeepMind (which is an AI model capable of detecting over 50 eye diseases), IBM Watson Health (which is capable of assisting in creating personalized cancer treatment plans by analyzing patient data and providing recommendations), Intuitive Surgical's da Vinci System (which is an advanced robotic surgery platform that enhances precision in cardiovascular and cancer surgeries), and many others. With this in mind, it is essential for us to understand that there are already cutting-edge AI tools that are in development stages and likely to be adopted in the future. The next step is understanding the implications of change in human lifespan to current traditional mortality assumptions.

IMPLICATIONS OF CHANGE IN HUMAN LIFESPAN DUE TO AI TO CURRENT MORTALITY ASSUMPTIONS

Typically, our mortality assumptions would have accounted for mortality improvement assumptions, which are meant to project longevity trends. These mortality improvement assumptions normally would incorporate both current observable medical and societal advancements.

Now that AI has come into the picture, in which has the power to significantly extend human longevity, the question comes down to how we should incorporate the advancement of AI into the mortality assumptions. The challenges with this lie in the fact that the timeline and magnitude of AI advancement is largely uncertain at this stage; however, its transformative potential cannot be ignored.

There are several strategies of incorporating AI advancements into mortality assumptions that can be considered at this stage, mainly:

- Leveraging expert insights.
- Identifying and monitoring core leading indicators.
- Conducting scenario testing.
- Adopting a conservative approach on mortality assumptions.

LEVERAGE EXPERT INSIGHTS

Consultation with healthcare AI experts would be needed. Sample insights that would be needed are as follows:

- Healthcare AI tools under development.
- Stage of the development of AI tools, whether it is early stage or close to full development.
- Number of healthcare institutions using AI for diagnostics and treatment.
- Any plan timelines for broader adoption.

These insights are essential such that we can have a view of where AI stands now, how it is going to be integrated, and when it is expected to be achieved. With this insight, we can estimate the timeline for AI adoption, helping us determine when noticeable improvements in mortality rates may become observable.

IDENTIFY AND MONITOR CORE LEADING INDICATORS

It is also essential to identify the core leading indicators. Collaboration across healthcare and insurance industries would be needed to pool resources on monitoring of these indicators. Below are examples of core leading indicators for monitoring:

- Tracking of reductions of late-stage chronic disease with adoption of AI early detection imaging tools.
- Declines in neurodegenerative diseases with the adoption of AI brain imaging tools.
- Increase in surgery success rates with the assistance of AI robotic systems.
- Comparative analysis of AI diagnostic tools versus traditional methods.

By tracking these indicators, we can identify trends and establish evidence-based benchmarks that can help monitor the potential impact of AI on longevity. Additionally, continuous monitoring is essential such that we can refine mortality assumptions to reflect emerging evidence of AI's effectiveness over time.

CONDUCT SCENARIO TESTING

Scenario testing remains an essential approach to evaluate AI advancement impact. Various scenario testing would be needed in different perspectives inclusive of:

- **Speed of AI adoption** – test scenarios assuming AI adoption from short-term (3-5 years), mid-term (5-10 years) and long-term (>10 years).
- **Intensity of AI adoption** – test scenarios assuming minimal effects (only have marginal effects), moderate effects (improves efficiency without dramatic change in results), and transformative effects (significant change in current practices, leading to significant increase in human lifespan).
- **Effects of AI on different age groups** – test scenarios considering different effects on different age groups. For age <18, consider AI impacts on early genetics or disease detection and effects of precision medication. For ages 18-40, consider AI impacts on early chronic disease detection and intervention. For ages >40, consider AI impacts on neurodegenerative disease detection and prevention.
- **Effects of AI on lifespan extension on different products** – test different levels of increase in lifespan due to AI-driven healthcare on different products. For example, +5 / +10 / +15 years and others. It is expected that reserving needs for different product types would differ if human lifespan were prolonged. For annuity / long-term care / retirement products, there would be a need to analyze the jump in reserve needs on different levels of lifespan extension.

ADOPT A CONSERVATIVE APPROACH ON MORTALITY ASSUMPTIONS

Given the uncertainty surrounding AI advancement, one of the strategies would be to adopt a conservative approach on mortality assumption setting. The timelines of AI enhancements and adoptions are currently unknown: developments could shift from incremental to transformational stage on varying periods. Additionally, while AI advancement shows promises of its ability to extend human longevity, it is not expected to have immediate effects in the short term. Rather this is a long-term process, in which on our current stage now, there is no clearly observable evidence of improvement in longevity.

With the above in mind, it is essential that we be careful to avoid overestimation of medical advancements, as this could lead to under-reserving of life insurance type products. Additionally, underestimation of reserving could also occur for annuity type or long-term care type products if AI breakthroughs lead to increase in longevity than initially assumed. Therefore, there needs to be a balance between applying expert judgement while also aligning it with evidence-based AI medical advancements on the mortality improvement assumptions.

However, what we can do is allow for margins within mortality improvement rates, for example assuming gradual improvements for mortality rates for certain age groups or causes of deaths depending on emerging evidence of AI adoption and its effectiveness. In addition to basing this on observable evidence, it is also essential to consider if there is a need to apply a forward-looking view on the AI advancement, largely dependent on the sensitivity of the underlying business to various scenarios of AI advancement.


SUMMARY

In summary, AI's huge potential to extend human longevity introduces both opportunities and challenges on mortality assumption setting. A lot of uncertainty remains on how AI could affect human longevity. Actuaries would need to approach this with agility and innovation given the changing environment. There needs to be a continuous process of monitoring of new evidence, leveraging expert insights, performing sensitivity, and adjusting assumptions accordingly if needed to ensure robust models.

As AI continues to evolve, the actuarial profession has the opportunity to lead in adapting methodologies that balance observable medical advancements with forward-looking insights. The future of mortality modeling lies in anticipating and responding to these advancements, ensuring accurate and sustainable assumptions in a constantly changing landscape.


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Peik Hong Tan, FSA is a valuation actuary at Swiss Re. She can be reached at peikhong.tan@gmail.com.



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Transformative Horizons: Generative AI's Role in Medicine and Mortality Modeling

Tianyang Wang, Ph.D., ASA, CFA, FRM

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INTRODUCTION

Generative AI has rapidly emerged as a transformative technology in the medical field, contributing to significant advancements in gene detection, AI-assisted surgeries, diagnostics, drug development, and cancer treatment. These breakthroughs not only enhance human longevity but also redefine the capabilities of modern medicine. This essay explores the successful applications of generative AI in healthcare, highlighting specific examples, their implications for human longevity, and the critical adjustments required in mortality modeling to reflect these advancements.

GENE DETECTION AND PRECISION MEDICINE

Generative AI has revolutionized genomics by enabling precise detection of genetic mutations and predispositions to diseases. Tools like Google DeepVariant use AI to analyze genomic sequences with unparalleled accuracy, identifying rare genetic disorders that were previously difficult to detect. For instance, the ability to detect BRCA mutations linked to breast and ovarian cancer has allowed high-risk individuals to pursue early interventions, significantly increasing survival rates. Such precision medicine approaches personalize treatments, optimizing effectiveness while minimizing side effects, thereby contributing to longer and healthier lives.

The implications for longevity are profound. Early detection of genetic predispositions enables proactive healthcare, allowing individuals to mitigate risks through lifestyle changes, targeted screenings, and preventive treatments. For mortality modeling, this trend necessitates incorporating genetic risk factors and their mitigation into predictive frameworks. Traditional models based on population averages may become less reliable as personalized medicine reshapes survival probabilities.

AI-ASSISTED SURGERIES

AI-powered robotic systems are transforming surgical practices by enhancing precision and reducing risks. The da Vinci Surgical System, for example, uses AI to assist surgeons in performing minimally invasive procedures with extreme accuracy. Generative AI algorithms predict potential complications in real time, enabling surgeons to adjust their techniques proactively. These advancements have proven particularly effective in complex procedures, such as neurosurgery and cardiac surgery, where precision is critical to patient survival.

The impact on longevity is significant. By reducing surgical complications and recovery times, AI-assisted surgeries improve survival rates and quality of life, particularly for older adults who are at higher risk during invasive procedures. Mortality modeling must adapt to reflect these improvements, accounting for lower post-surgical mortality rates and extended life expectancies due to successful interventions.

ADVANCED DIAGNOSTICS

Generative AI excels in diagnostic applications, leveraging deep learning to interpret medical imaging and detect diseases at early stages. Examples include:

- **Cancer Detection:** AI tools like IBM Watson Health analyze radiology scans to identify tumors with higher sensitivity than traditional methods. A study in *Nature* reported that Google's AI model outperformed radiologists in detecting breast cancer from mammograms, reducing false negatives by 9.4%. Early detection significantly enhances survival rates and reduces the need for aggressive treatments.
- **Rare Disease Identification:** AI platforms such as Face2Gene analyze facial features and genetic data to diagnose rare conditions like Noonan syndrome. These tools have accelerated diagnostic timelines, giving patients quicker access to life-saving treatments.

Improved diagnostics contribute directly to longevity by enabling early and accurate identification of life-threatening conditions. As diagnostic tools evolve, mortality models must incorporate early detection data to better predict survival outcomes and long-term health trajectories.

DRUG DEVELOPMENT

Generative AI is revolutionizing drug discovery by identifying promising compounds and optimizing trial designs. Companies like Insilico Medicine and Atomwise use AI to screen billions of molecules, significantly reducing the time and cost of bringing new drugs to market. A notable success story is AI's role in developing Baricitinib as a treatment for severe COVID-19 cases. Within months, AI algorithms identified the drug's potential, expediting its inclusion in clinical trials and approval processes.

AI-driven drug development impacts longevity by accelerating the availability of treatments for previously incurable diseases. Mortality models must adjust to reflect the potential for rapid medical breakthroughs, incorporating scenarios where new therapies extend survival for specific patient populations.

BREAKTHROUGHS IN CANCER TREATMENT

AI is at the forefront of personalized cancer therapies, combining genomics and real-time patient data to tailor treatment plans. Generative AI models predict tumor growth patterns and optimize radiation therapy protocols. For example, Tempus, an AI-driven platform, integrates clinical and molecular data to guide oncologists in selecting the most effective chemotherapy regimens. Additionally, CAR-T cell therapy—a cutting-edge cancer treatment—relies on AI to engineer immune cells that target specific cancer markers with precision.

The implications for longevity are profound. By personalizing cancer treatments, AI improves survival rates and reduces treatment-related morbidity. Actuarial models must account for these advancements, incorporating varying cancer survival rates based on the availability and effectiveness of AI-driven therapies.

PREDICTIVE HEALTHCARE ANALYTICS

AI algorithms analyze vast datasets to identify disease patterns, enabling early interventions. For example, deep learning models in oncology detect early-stage cancers from imaging data with unparalleled accuracy, significantly improving survival rates. AI tools have also been deployed to monitor chronic conditions such as diabetes and cardiovascular diseases. For instance, AI-powered predictive models assess risk factors, allowing physicians to intervene before complications arise.

Beyond detection, AI's capacity for real-time patient monitoring ensures proactive management of health. Tools such as wearable patches monitor vital signs like heart rate, oxygen saturation, and blood pressure continuously,

alerting healthcare providers to abnormalities. This level of personalization directly impacts life expectancy by reducing preventable deaths and hospitalizations. Incorporating these advancements into mortality models requires integrating predictive data streams that reflect disease onset and mitigation at an individual level.

LIFESTYLE AND WELLNESS OPTIMIZATION

Wearable AI devices are pivotal in promoting healthier lifestyles by tracking sleep patterns, activity levels, and caloric intake. Devices like Fitbit and Apple Watch collect comprehensive health metrics, delivering personalized recommendations to users. For instance, algorithms analyze exercise routines and suggest optimal intensity levels to improve cardiovascular health or weight management strategies tailored to individual needs.

AI-assisted dietary apps also analyze users' nutritional habits, offering meal plans that align with their health goals. By addressing lifestyle-related risks such as obesity and sedentary behavior, these tools contribute to the prevention of chronic diseases, significantly impacting longevity. Mortality modeling must consider the widespread adoption of such devices, integrating metrics that reflect improved lifestyle behaviors and their long-term effects on survival probabilities.

LONGEVITY AND MORTALITY MODELING

The advancements discussed above significantly influence human longevity, necessitating major changes in how mortality is modeled. Key considerations include:

- **Dynamic Mortality Trends:** Traditional mortality tables, which rely on historical data, may not adequately capture the rapid advancements driven by AI. For example, predictive analytics can alter population-level risk trajectories by detecting and addressing diseases earlier than previously possible. Dynamic models that integrate real-time healthcare data are essential for accurate predictions. Incorporating dynamic variables such as AI-prompted interventions ensures that mortality projections remain relevant in an era of rapid medical innovation.
- **Heterogeneity in Longevity Gains:** Disparities in access to AI-driven healthcare introduce variability in longevity outcomes. Individuals with access to advanced diagnostic tools and treatments may experience substantial gains, while others may not benefit equally. For instance, rural populations often lack the infrastructure to implement wearable technology or AI-based monitoring systems. Mortality models must incorporate socio-economic and geographic factors, highlighting the uneven distribution of longevity gains and their broader implications.
- **Integration of Non-Traditional Data Sources:** AI generates vast amounts of unstructured data, such as metrics from wearable devices, genomic information, and social determinants of health. Incorporating these diverse data sources into mortality models enhances predictive accuracy and provides insights into emerging longevity trends. For example, genomic data predicting disease susceptibility could refine actuarial assumptions on life expectancy, leading to more tailored insurance products.
- **Ethical and Privacy Considerations:** The use of sensitive health data raises ethical concerns about privacy and consent. As wearable devices and AI monitoring systems collect extensive personal data, adherence to regulations like GDPR and HIPAA becomes critical. Mortality modeling must balance the integration of AI-driven insights with strict data protection frameworks, ensuring public trust and compliance with ethical standards.
- **Extended Life Expectancy:** AI-driven healthcare innovations are likely to increase the prevalence of centenarians, shifting the distribution of survival probabilities. For example, AI tools that enhance cancer detection and management contribute to longer lifespans by reducing mortality from previously terminal illnesses. Actuarial models must reflect this trend by extending projections to account for an aging population with improved health spans.

BROADER IMPLICATIONS AND CHALLENGES

While generative AI holds immense potential for enhancing longevity, it also presents challenges:


- **Data Quality and Bias:** Ensuring high-quality, unbiased data is critical for accurate predictions. Models trained on non-representative datasets may perpetuate healthcare disparities, requiring rigorous validation and continuous improvement. For example, AI models used for diagnosing skin conditions may underperform on darker skin tones if the training data lacks diversity.
- **Regulatory Frameworks:** Adapting regulatory frameworks to govern AI applications in healthcare is essential. Collaboration among policymakers, technologists, and actuaries is necessary to establish ethical and practical guidelines that safeguard patient rights while fostering innovation.
- **Ethical Dilemmas:** The integration of AI into healthcare raises ethical questions about accountability and fairness. For instance, AI-driven recommendations for high-cost treatments might inadvertently disadvantage low-income patients. Clear guidelines and human oversight are crucial to ensuring equitable access to AI-driven advancements.

CONCLUSION

Generative AI stands at the forefront of a new era in healthcare and actuarial science, significantly enhancing human longevity and transforming mortality modeling. By embracing real-time analytics, addressing ethical considerations, and refining actuarial frameworks, the profession can navigate these advancements effectively. Harnessing AI responsibly ensures that extended longevity benefits society equitably while preserving the integrity of actuarial practices. These advancements not only improve patient outcomes but also hold the potential to extend human longevity significantly, transforming healthcare into a more precise, efficient, and equitable domain.

* * * * *


Tianyang Wang, Ph.D., ASA, CFA, FRM is a Professor of Finance at Colorado State University. He can be reached at tianyang.wang@colodstate.edu.



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AI as a Principal Driver of Mortality Improvement

Gordon Woo, Ph.D.

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INTRODUCTION

Mortality improvements can be generated by positive changes in population lifestyle, the health environment, advances in drug discovery, progress in regenerative medicine, and the biology of aging. To complement traditional actuarial models, a prospective longevity risk model framework was formulated sixteen years ago¹ explicitly recognizing these five classes of mortality improvement. The 20th century history of mortality improvement was punctuated by significant drivers, e.g. sanitation, public health services, vaccination, antibiotics, etc. But so far this century, there has yet to appear a major systemic driver of future mortality improvement. However, with the award of the 2024 Nobel Chemistry prize to Google DeepMind pioneers, AI promises to be this long-awaited 21st century driver, with notable advances anticipated across the spectrum of medical discovery, as well as in the health environment, and potentially also in the other classes.

NOBEL PRIZE IN CHEMISTRY 2024

In October 2024, Demis Hassabis, CEO of Google DeepMind, was awarded a half-share of the chemistry Nobel Prize with his colleague, John Jumper, for solving the 50 year-old grand challenge of the folding geometry of proteins, the complexity of which is determined by the sequence of their amino acids. Demis Hassabis turned to this challenge after Google DeepMind's AlphaGO program defeated a top GO champion in 2016; an AI feat that Elon Musk, co-founder of OpenAI, had reckoned was still a decade away. AlphaFold was launched by Google DeepMind in 2018. In an international test of protein modeling in 2020, AlphaFold2 attained a score nearly equivalent to the experimentally determined structure. By May 2022, AlphaFold2 had helped determine the structure of a key malaria parasite protein and worked out where antibodies that could block transmission of the parasite were likely to bind.

AlphaFold3, published online in May 2024, has the additional ability to model molecule interactions, supporting the scientific consensus that deep learning establishes a revolutionary road map for rational drug discovery. It was named by *Time* magazine as one of the best inventions of 2024, under the AI category. AlphaFold3's enhanced capabilities should enable drug developers to quickly identify promising targets and so have a major impact on drug R&D. A drug is essentially just a small molecule that ultimately attaches to a protein inside the body in some configuration to target a very specific pathology. Isomorphic Labs, spun out of Google DeepMind by Hassabis in 2021, has the goal of using machine learning to transform drug discovery. Hassabis expects AI to halve the time to discover new medicines, a process that can last more than a decade.

¹ Woo G. et al. (2009), "Prospective longevity risk analysis." *British Actuarial Journal*, 15, S1, pp.239-247.

In addition to expediting drug discovery, AI can accelerate the lengthy drug trial process and make it more efficient and successful. AI can assist with the recruitment of patients for trials, and with the use of wearables to gather patient data, streamlining the trial process. Notably, for Pfizer’s COVID vaccine trials, AI assisted with data cleaning, which saved several months of precious time. Altogether, clinical trial deployment timelines might be halved through the adoption of intelligent automation capabilities.

HOW OZEMPIC MIGHT HAVE BEEN DISCOVERED EARLIER WITH AI

To show how AI could transform the discovery of drugs, even blockbusters, insight is provided by the best-selling drug Ozempic, the Novo Nordisk brand name for semaglutide. As with many drug discoveries, it starts with serendipity. In 1990, endocrinologist, John Eng, became intrigued by research showing that venom from a southwestern U.S. lizard, known as the Gila monster, enlarged the pancreas where insulin is synthesized. The Gila monster, after long periods without food, can slow down its metabolism and maintain constant blood sugar levels. Dr. Eng assayed the venom and discovered a peptide, exendin, that triggers synthesis and release of insulin.

Exendin was similar in both structure and function to a hormone found in the human pancreas that stimulates insulin production. This led to the discovery of drugs that mimic the action of this hormone: Glucagon-Like Peptide-1 (GLP-1). The problem with GLP-1 is that enzymes in the blood cause it to degrade quickly. The development of the long-acting GLP-1 analogs liraglutide and semaglutide, has represented a significant advance in GLP-1-based therapies. Liraglutide was approved by the FDA for chronic weight management in adults in 2014; semaglutide was approved for medical use in the U.S. in 2017.

The development history of liraglutide and semaglutide has been documented by Novo Nordisk². Crucially, the drug discovery process involved a systematic scan of the entire amino acid GLP-1 sequence to understand the role of each of the thirty amino acids. This scan showed that specific amino acids were vital for GLP-1. This type of detailed scan is so much quicker using the deep learning of AlphaFold3. Counterfactually, had AlphaFold3 existed back in the 1990s, when GLP-1 was discovered serendipitously, liraglutide and semaglutide might well have been discovered in half the time.

In 2024, the FDA gave approval of semaglutide as the first treatment to reduce the risk of serious heart problems in overweight adults. Remarkably, people taking GLP-1s have seen their blood pressure and cholesterol levels improve. Improving health in this multi-disease manner may actually be a characteristic of slowing down the aging process. Such is the surprising health horizon of drug discovery to be boosted by AI in coming decades.

IMPROVED DISEASE DIAGNOSIS WITH AI

AI has already demonstrated significant promise for the present and future diagnosis of diseases. According to the Harvard School of Public Health, when using AI for diagnosis, there is 40% projected improvement in health outcomes. The application of AI in multiple medical models suggests that the integration of AI in the realms of diagnostic algorithms, programs of risk reduction and prevention, and improvements in scheduling could effectively reduce healthcare spending in the U.S. alone by as much as 5% to 10%. This might be especially beneficial for less affluent vulnerable communities, which have notably higher mortality rates.

AI-powered diagnostic technologies can help physicians decipher medical pictures like X-rays, magnetic resonance imaging, and computed tomography scans, resulting in quicker and more precise diagnoses. AI helps analyze digital pathology slides, finding potential cancerous cells. In genomics, AI can analyze complex genetic data, identifying

² Knudsen L.B. et al. (2019), “The Discovery and Development of Liraglutide and Semaglutide.” *Front. Endocrinology*/doi:10.3389/fendo.1019.00155.

mutations and risk factors for various diseases, allowing for personalized medicine and preventive interventions. In the future, AI may find obscure patterns in medical data, aiding in disease prediction and prevention before symptoms appear. Additionally, by combining genetic data, lifestyle data, and environmental variables, AI may help in the diagnosis of complicated diseases.

Malignancies, surgical complications, and neurological, cardiac, and urological issues are the five conditions that are most often misdiagnosed. Diagnostic errors are primarily cognitive and may be avoidable through assistance from AI. Already in 2025, AI examination of brain-imaging scans can enable faster and more accurate stroke detection, identifying when a blood vessel is blocked. To illustrate the importance of such AI-enhanced diagnostic technology, consider U.S. stroke misdiagnosis. Over 9% of stroke victims are initially misdiagnosed, but this percentage may be much higher for patients with non-specific or transient symptoms. Each year, about 800,000 people in the U.S. have strokes, and about 140,000 people die. AI has the potential of saving the lives of many thousands of American stroke victims annually.

FUTURE MORTALITY IMPROVEMENT WITH AI

AI is a systemic driver of improved health span, contributing to all the five classes of mortality improvement, as summarized below, telescoping the waiting period for future healthcare advances. For the middle-aged in 2025, this foreshortening of the medical progress horizon should be a source of hope and optimism about extending their golden years. Even baby boomers in 2025 can expect to benefit to a lesser extent from an AI health dividend; if not from an effective treatment for Alzheimer's within their lifetime, then from earlier, more accurate disease diagnoses.

[A] Lifestyle

Apart from AI applications to nudge healthier population consumption and exercise, additional effective weight-loss drugs might well be discovered through AI. These could have lifestyle benefits other than for obesity. Ozempic has been shown to decrease the abrupt surge of dopamine which is linked to nicotine addiction.³ Overdose deaths from opioids have been a growing U.S. mortality factor this century. AI is being used to search for non-addictive, non-opioid options to treat chronic pain.

[B] Health Environment

Throughout the health environment, AI is enhancing the quality of healthcare, especially in early disease diagnosis, where the benefit of AI may be 40% improvement in projected U.S. health outcomes. AI supports the diagnosis, characterization, and monitoring of patients using real-time data. The diagnosis of unfamiliar or complex symptoms is prone to cognitive errors. AI-assisted diagnostics are seen as the greatest hope in suppressing misdiagnoses and other medical errors. Issues that cause medical errors and erode the quality of care include low staffing levels, fatigue, and burnout. AI adoption can play a significant supportive role in addressing these capacity issues as well as promoting health equity for communities lacking adequate healthcare resources.

[C] Drug Discovery

Rather than rely on serendipitous drug discovery, rational drug design requires the enhanced resolution of molecular structure achievable with AI. Nobel laureate, Demis Hassabis, expects that drug discovery time might be halved with AI. With a similar anticipated AI benefit for the length of drugs trials, the whole development time for new drugs might be halved with AI. In projecting the future time for the delivery of new long-awaited drugs, AI

³ Wang W. et al. (2024), "Association of semaglutide with tobacco use disorder in patients with type 2 diabetes." *Annals of Internal Medicine*, 177, 8.

allows the time scale to be compressed accordingly, even if the delivery time for specific drug development remains intrinsically uncertain.

[D] Regenerative Medicine

Regenerative medicine has enormous potential for transforming healthcare with the development of 3D mini-organs (organoids), and the construction of artificial tissues using nanomedicine and 3D bio-printers. In the next few decades, revolutionary approaches in regenerative medicine are likely to emerge based on AI.⁴ The integration of AI and stem cell research not only expedites drug discovery processes but also paves the way for personalized medicine and targeted treatment strategies.

[E] Biology of Aging

Aging is an ongoing process of damage that is occurring within the body. One of the most promising routes to treat age-related diseases is to identify therapeutic interventions that selectively remove senescent cells from the body. Clinical research into senolytics is still at an early stage in 2025. But there are grounds for optimism. AI can expedite the search for new senolytic drugs that might slow the aging process, whilst avoiding potentially serious side effects. This is a very challenging and arduous search process. But already, neural networks have been trained to predict the senolytic activities of more than 800,000 molecules to reveal three drug candidates.⁵ Besides senolytics, AI can expedite the discovery of drugs, like Ozempic, that can lower mortality from multiple causes and so extend life expectancy.

LONGEVITY RISK MANAGEMENT FOR MILLENNIALS

The contributions of public health, pharmaceuticals, and other medical care to U.S. life expectancy changes for the quarter century period 1990 to 2015, prior to COVID, has been evaluated by health economists.⁶ Life expectancy in the U.S. increased 3.3 years between 1990 and 2015. Around 44% of improved life expectancy was attributable to public health; 35% was attributable to pharmaceuticals; 13% was attributable to other medical care, and the residual 8% was attributable to other factors—but not including AI. This quarter century increase in life expectancy of 3.3 years is much less than the three years per decade during the twentieth century, meriting categorization as radical life extension.⁷

The remarkable publication of AlphaFold3 in May 2024 marks a watershed in the use of AI for drug discovery, and more generally for healthcare innovation. According to 2024 Chemistry Nobel Laureate, Demis Hassabis, “*Just as mathematics turned out to be the right description language for physics, AI may turn out to play a similar role for biology.*” He anticipates revolutionary advances in drug discovery over the next five years.⁸ In November 2024, the prestigious *New England Journal of Medicine* issued a compendium of papers on the AI revolution in medicine. Allowing the period until the end of this decade for a rapid accelerated phase of AI development and upskilling throughout the healthcare industry, the subsequent quarter century period from 2030 to 2055 should be an exceptionally exciting and prolific time for public health advancements and pharmaceutical discoveries, yielding a greater increase in life expectancy in the U.S. than observed in the quarter century from 1990 to 2015.

⁴ Altyar A.E. et al. (2023), “Future regenerative medicine developments and their therapeutic applications.” *Biomedicine and Pharmacology*, 158, 114131.

⁵ Wong F. et al. (2023), “Discovering small molecule senolytics with deep neural networks.” *Nature Aging*, 3, 734-750.

⁶ Buxbaum J.D. et al. (2020), “Contributions of public health, pharmaceuticals, and other medical care to US life expectancy changes, 1990 to 2015.” *Health Affairs*, 39, 1546-1556.

⁷ Olshansky S.J. (2024), “Implausibility of radical life extension in humans in the twenty-first century.” *Nature aging*/doi.org/10.1038/s43587-024-00702-3.

⁸ Economist interview, November 18, 2024.


Given the anticipated halving of time for the development of new drug treatments, facilitated by AI, as well as AI-enabled advances in public health, the increase in U.S. life expectancy in this quarter century might reach five years, or an average of two years per decade. This is below the increase of three years per decade associated with radical life extension but is substantial nevertheless in the context of recent U.S. mortality experience.

In this 25 year time window extending into the second half of the 21st century, public healthcare should benefit from important advances that might not have been achievable until much later in the century, if at all, without AI. The impact of AI is to foreshorten the future horizon, bringing game-changing medical discoveries within the health span of more adult Americans.

Not just for Gen Z, but also for millennials in 2025, their retirement years should be enhanced by significantly increasing health spans, far less burdened by neurological disease, and reaping the health and longevity benefits of AI-accelerated progress in regenerative medicine and the biology of aging. According to an Urban Institute study,⁹ half of early millennials born in the 1980s will have inadequate retirement income at age 70, if there are Social Security shortfalls. Born in the latter part of the 20th century, between 1981 and 1996, before Google was founded in 1998, millennials need prudent longevity risk management informed by prospective AI progress by the middle of the 21st century. Prospective longevity risk analysis will help actuaries guide millennials in making key decisions about their future retirement. In particular, despite beginning to save for retirement at age 25, the early retirement aspirations of one-third of millennials may be unrealistic for those wishing to enjoy the extended health span provided to their generation by AI.

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Gordon Woo, Ph.D. is Senior Director-Analytics & Modelling at Moody's. He can be reached at gordon.woo@moody.com.



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⁹ Johnson R.W. et al. (2022), "How might millennials fare in retirement?" Urban Institute, Washington DC.

Chatting with AI about AI Driven Longevity

Nate Worrell, FSA and Lisanne Horvat-Gitsels, Ph.D.

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INTRODUCTION

This paper is an experiment with two generative AI tools: OpenAI's ChatGPT and Microsoft's Copilot, evaluating the responses from the same prompt between two systems.

The responses are edited for length and evaluated with actuarial commentary. The insights from the discussion will be used to inform a "prospective longevity risk analysis" designed by Gordon Woo et al.¹ The analysis attempts to parameterize improvements to mortality experience from five key drivers labelled as "vitagions": Lifestyle, Medical Intervention, and Health Environment, which drive mortality improvement today, plus Regenerative Medicine and Anti-Aging Processes that may exist in the future.

LIFESTYLE

Prompt: Provide a bullet list of the top three ways in which Artificial Intelligence could improve longevity by affecting lifestyle, where lifestyle is defined as: the principal individual lifestyle risk factors that affect health, such as smoking, obesity, and biometric risk factors.

CHATGPT

Personalized Health Recommendations

- Analyze individual health data to deliver tailored advice on diet, exercise, and sleep.
- Machine learning models can predict potential health risks and provide preventive strategies specific to the individual.
- Wearable devices with AI can offer real-time feedback to maintain healthy behaviors.

Behavioral Change Support

- AI-powered apps and virtual health coaches use behavioral psychology techniques, such as gamification and rewards, to help users modify lifestyle.
- Natural language processing (NLP) enables chatbots to offer empathetic, 24/7 support, addressing barriers to change.
- Predictive analytics can identify when users are at risk of lapsing into unhealthy behaviors.

¹ Woo G. et al. (2009) Prospective longevity risk analysis. *British Actuarial Journal*, 15, S1, pp.239-247.

Monitoring and Early Detection

- AI systems can track biometric risk factors, detecting early warning signs of disease.
- Continuous monitoring allows for proactive management of conditions like diabetes or hypertension, reducing their impact on longevity.

COPILLOT

- **Personalized health recommendations:** AI can analyze data from biometric sensors and health records to provide personalized recommendations for diet, exercise, and other lifestyle choices that can improve longevity.
- **Predictive analytics:** AI can analyze large datasets to identify patterns and predict individual health risks, allowing for targeted interventions to prevent chronic diseases associated with lifestyle factors.
- **Behavioral nudges:** AI-powered apps and devices can provide real-time feedback and reminders to encourage healthier habits, such as reminders to take medication, notifications to stand up and move around, or suggestions for healthier food choices.

ACTUARIAL REACTION

While biometrics have benefited from the increased proliferation of wearable devices like the Apple Watch and Fitbits, the degree to which they will have a meaningful impact on longevity is an open question.

First, it may be that there is a selection bias. Adopters of wearable health trackers may already be invested in optimal health.

Second, even with having information, there are barriers to lifestyle change. Diets, food habits, and exercise programs are hard to implement and maintain.

That said, it may be a “near-future” reality that doctors proscribe a virtual ‘longevity coach’ to monitor patient action and encourage healthy behavior between annual check-ups. Additionally, tailored education campaigns may be effective in combatting things like opioid addictions.

HEALTH ENVIRONMENT

Prompt: Provide a bullet list of the top three ways in which Artificial Intelligence could improve longevity by affecting the health environment, where the health environment is defined as: hygiene, sanitation, knowledge and awareness of health issues, access to healthcare, and other economic factors.

CHATGPT

Improved Access to Healthcare

- AI-powered telehealth platforms enable remote consultations, making healthcare accessible in underserved and rural areas.
- AI chatbots and virtual assistants provide 24/7 triage, reducing barriers to timely care.
- AI can optimize the distribution of medical resources in response to regional health needs.

Advancements in Hygiene and Sanitation

- AI-enabled sensors can detect water contamination, waste mismanagement, or air pollution, ensuring safer living environments.

- AI can predict failures in sanitation infrastructure and facilitate timely interventions to prevent disease outbreaks.
- AI tools can promote hygiene practices like handwashing through culturally tailored campaigns.

Enhanced Health Knowledge and Awareness

- AI analyzes demographic and social data to design effective, localized health awareness campaigns about diseases, nutrition, or preventive care.
- AI algorithms identify and counteract health-related misinformation.

COPILLOT

- **Early detection and diagnosis:** AI can analyze vast amounts of data to identify patterns and trends in disease outbreaks, allowing for early detection and response to prevent the spread of infectious diseases and improve overall public health.
- **Resource allocation:** AI can help optimize the allocation of healthcare resources by predicting demand for services, identifying areas with the greatest need for intervention, and streamlining processes to improve efficiency and access to care.
- **Health education and awareness:** AI-powered chatbots and virtual assistants can provide personalized health information, answer questions, and offer support to individuals seeking information about health issues, promoting awareness and empowering individuals to make informed decisions about their health.

ACTUARIAL REACTION

- Lack of access to healthcare is a known headwind for some populations. The possibility for AI based triage or even diagnostic services in underserved areas does seem to be a reasonable candidate to improve health outcomes.
- Copilot alluded to resource allocation. This could prove extremely helpful to monitor and control potential disease outbreaks. Being able to deliver early alerts and deploy needed providers and services to hot areas is something that could save a lot of lives.
- An area of concern may be allowing AI to develop “culturally tailored campaigns.” While there may be gains in effectiveness in increasing the relatability of education material to personal context, it seems as though this may present an area of risk relative to bias and discrimination.

MEDICAL INTERVENTION

Prompt: Provide a bullet list of the top three ways in which Artificial Intelligence could improve longevity by affecting medical intervention, where medical intervention is defined as: new medical treatments, including pharmaceuticals, biologics, and vaccines; improvements in diagnostics, surgical techniques, and the delivery of new or existing treatments.

CHATGPT

Accelerating Drug Discovery and Development

- Machine learning models can identify potential drug candidates and predict their efficacy and safety, significantly reducing the time and cost of drug development.
- AI can analyze large datasets to uncover new uses for existing pharmaceuticals, expediting treatments for emerging diseases.

- AI enables precision drug development by predicting how individual patients will respond to specific treatments based on genetic and molecular profiles.

Enhancing Diagnostics and Early Detection

- AI algorithms can analyze medical imaging with higher accuracy than traditional methods, enabling earlier detection of conditions like cancer or neurological diseases.
- AI systems can identify subtle patterns in health data to predict diseases before symptoms manifest.

Advancing Surgical Techniques and Treatment Delivery

- AI-powered robotic systems enhance precision and reduce human error in complex surgeries, minimizing recovery time and complications.
- AI can recommend the most effective treatment plans by analyzing patient data and comparing it with clinical guidelines and outcomes.
- AI accelerates the design of vaccines as demonstrated during the COVID-19 pandemic.

COPILLOT

- **Precision medicine:** AI can analyze genetic and clinical data to develop personalized treatment plans tailored to an individual's unique genetic makeup, increasing the effectiveness of treatments and reducing side effects.
- **Drug discovery and development:** AI can accelerate the drug discovery process by analyzing large datasets to identify potential drug candidates, predict their efficacy, and optimize their design, leading to the development of new and more effective treatments for various diseases.
- **Surgical assistance:** AI-powered surgical robots can assist surgeons in performing complex procedures with greater precision and accuracy, reducing the risk of complications and improving patient outcomes. AI can also analyze medical imaging data to assist in the early detection and diagnosis of diseases, improving the effectiveness of treatment and reducing the need for invasive procedures.

ACTUARIAL REACTION

The answers here are harmonious, and this area does seem to show the most promise for dramatically increasing longevity and improving health span. AI radically changes the possibility space and timetable for discovery and development, particularly in the pharmaceutical space.

[From a statement by Eli Lilly](#), *"The goal is to grow what Lilly calls its "digital worker-equivalent workforce," a concept that the company says helps quantify the hours saved by using technology instead of human labor. Lilly said that its efforts, which began in 2022 and now span more than 100 projects, are equivalent to around 1.4 million hours of human activity, or around 160 years of 24/7 work. Lilly told Insider its goal is to bring this number to 2.4 million hours, or about 274 years."* (Emphasis added)

One area that may not have been directly called out is the reduction of medical errors, a known cause of fatalities in the healthcare system. Improvements in AI based diagnostics, coupled with doctor expertise could reduce the number of mortal mistakes that occur every year.

REGENERATIVE MEDICINE AND ANTI-AGING PROCESSES

Prompt: Provide a bullet list of the top three ways in which Artificial Intelligence could improve longevity by affecting regenerative medicine and anti-aging processes. Regenerative medicine covers techniques for repairing and renewing cells and organs, including stem cell therapy and nanomedicine. Anti-aging processes cover discoveries that directly affect the human aging process and may decrease an individual's effective biological age below actual chronological age.

CHATGPT

Enhancing Regenerative Therapies

- AI can analyze cell differentiation processes to improve stem cell therapies for repairing damaged tissues and organs, including the heart, brain, and liver.
- AI designs nanoscale delivery systems that target specific cells for precision treatment, such as repairing cellular damage or regenerating tissues.
- AI facilitates the design and production of bio printed tissues and organs by analyzing biological structures and optimizing scaffold materials.

Advancing Anti-Aging Research

- AI algorithms analyze biomarkers, epigenetic changes, and physiological data to assess biological age, enabling targeted anti-aging interventions.
- AI accelerates the discovery of genes, molecules, and cellular pathways linked to aging, helping develop therapies to slow or reverse aging processes.
- AI simulates aging processes to predict the effectiveness of anti-aging drugs or therapies, reducing the time required for clinical trials.

Personalized Regenerative and Anti-Aging Protocols

- AI can design personalized anti-aging plans by integrating data from genomics, proteomics, and lifestyle factors, optimizing treatments for each individual.
- AI-powered tools track cellular damage and repair mechanisms in real-time, enabling proactive interventions to maintain youthfulness.
- AI can model how regenerative techniques (e.g., stem cells, CRISPR) and anti-aging drugs (e.g., senolytics) interact, maximizing their combined benefits for longevity.

COPILLOT

- **Personalized regenerative therapies:** AI can analyze individual genetic and health data to develop personalized regenerative medicine treatments, such as stem cell therapy or gene editing, tailored to address specific age-related conditions and promote tissue regeneration.
- **Drug discovery for anti-aging:** AI can accelerate the discovery of potential anti-aging compounds by analyzing large datasets to identify molecules that target key pathways involved in the aging process, leading to the development of new treatments that can slow down or reverse aging at a cellular level.
- **Predictive modeling for longevity:** AI can analyze biological markers, lifestyle data, and environmental factors to predict an individual's risk of age-related diseases and mortality, providing insights that can inform personalized interventions to extend healthy lifespan and improve overall longevity.

ACTUARIAL REACTION

Like drug discovery, the value of AI based techniques in these spaces comes from the ability to study large and complicated datasets (human genomes, biological pathways, etc.) as well as doing complicated calculations (predicting protein folds, etc.). In short, AI may be able to “do” and “see” what humans cannot.

Even with the discovery of a new pathway or protocol to address an aging pathway, it is yet to be shown to what extent the ability to replace or regenerate body parts can extend life. Likewise, accomplishing something like eliminating cellular senescence may only have a muted effect on aging. Improvements coming from these areas are quite speculative.

MODELLED OUTCOMES

The model for the prospective longevity risk analysis is a hybrid model that blends actuarial techniques for initial parameterization of mortality improvements with medically informed stochastic modeling of the underlying drivers of mortality improvement in the future.

Given the stochastic nature of medical advancements in geroscience, predicting future mortality trends faces significant uncertainty due to the unpredictable trajectory of medical science. This highlights the challenge for actuaries in forecasting mortality improvements amidst the inherent randomness in medical breakthroughs as well as societal progress.

The stochastic results can be sorted by exceedance probabilities of how likely an outcome is greater than a certain value. For this essay, the latest U.S. model was used, utilizing data through 2022. To supplement and contextualize the stochastic results, deterministic scenarios representing AI’s potential impact for each vitagion were selected and mapped on the stochastic distribution (Table 1).

Table 1
SELECTED DETERMINISTIC SCENARIOS REPRESENTING THE POTENTIAL IMPACT OF AI ON EACH DRIVER OF MORTALITY IMPROVEMENTS (“VITAGIONS”)

| Vitagion | Deterministic scenario | Description |
|--|---|--|
| Lifestyle | Obesity declines faster than expected | Obesity declines at a level calibrated to match a 1-in-100 scenario of obesity decline. This path supports the calibration of lifestyle long-duration trend volatility within the model. |
| Health environment | Pandemic response improves outlook for mortality improvement | The COVID-19 vaccines provide a highly visible proof-of-concept for the use of mRNA techniques. This success results in improving the outlook for the treatment of infectious diseases and applying the technology to chronic diseases. |
| Medical intervention | Medical Breakthroughs: Improvement shock for medical intervention for all causes of death | Medical breakthroughs for all causes of death driven by advances in medicine, a decrease drug development time, and streamlined clinical trials. |
| Regenerative medicine + anti-aging processes | Regenerative Medicine and Anti-Aging Processes Shocks (2 scenarios) | The annualized 1-in-200 liability impact of Regenerative Medicine and Anti-Aging on the model’s central view. Given the vitagion’s volatility parameter, this translates to the expected progress happening in 37 years instead of 50 years. |

Next, the stochastic model was updated based on the parameters of the selected deterministic scenarios to estimate the impact of AI on all vitagions simultaneously. The stochastic models run 100,000 simulations with valuation year set to 2024 and base mortality set to “Pri2012_Total_Employee” rolled forward to 2019 (see Appendix). The outcome was life expectancies for a 50-year-old male and female.

The median life expectancy (p50) for a 50-year-old male and female was 33.7 and 35.2 years, respectively, under the model. Table 2 provides the deterministic scenarios quantified isolating AI impacts by vitagion.

Table 2

LIFE EXPECTANCY AT AGE 50 ACCORDING TO THE STOCHASTIC MODEL AND AI-IMPACTED VITAGION DETERMINISTIC SCENARIOS

| Deterministic Scenario | Male | Female |
|------------------------|-------------|-------------|
| Median Life Expectancy | 33.7 (p>50) | 35.2 (p>50) |
| Medical Intervention | 36.2 (p>97) | 38.2 (p>98) |
| Health Environment | 34.3 (p>77) | 35.9 (p>80) |
| Lifestyle | 34.1 (p>73) | 35.7 (p>76) |
| Regenerative Medicine | 34.1 (p>72) | 35.6 (p>75) |
| Anti-Aging Processes | 34.0 (p>65) | 35.5 (p>69) |

Figures 1 and 2 present the life expectancy distributions of the original and updated model. The updated model representing AI’s impact on all vitagions simultaneously increased the median life expectancy to 35.9 and 37.4 years for males and females, respectively. These represent the 97th percentile on the original stochastic distribution. The greater spread of the updated distribution indicates that some individuals will benefit from AI more than others and experience greater mortality improvements.

Figure 1
LIFE EXPECTANCY DISTRIBUTION FOR A 50-YEAR-OLD MALE

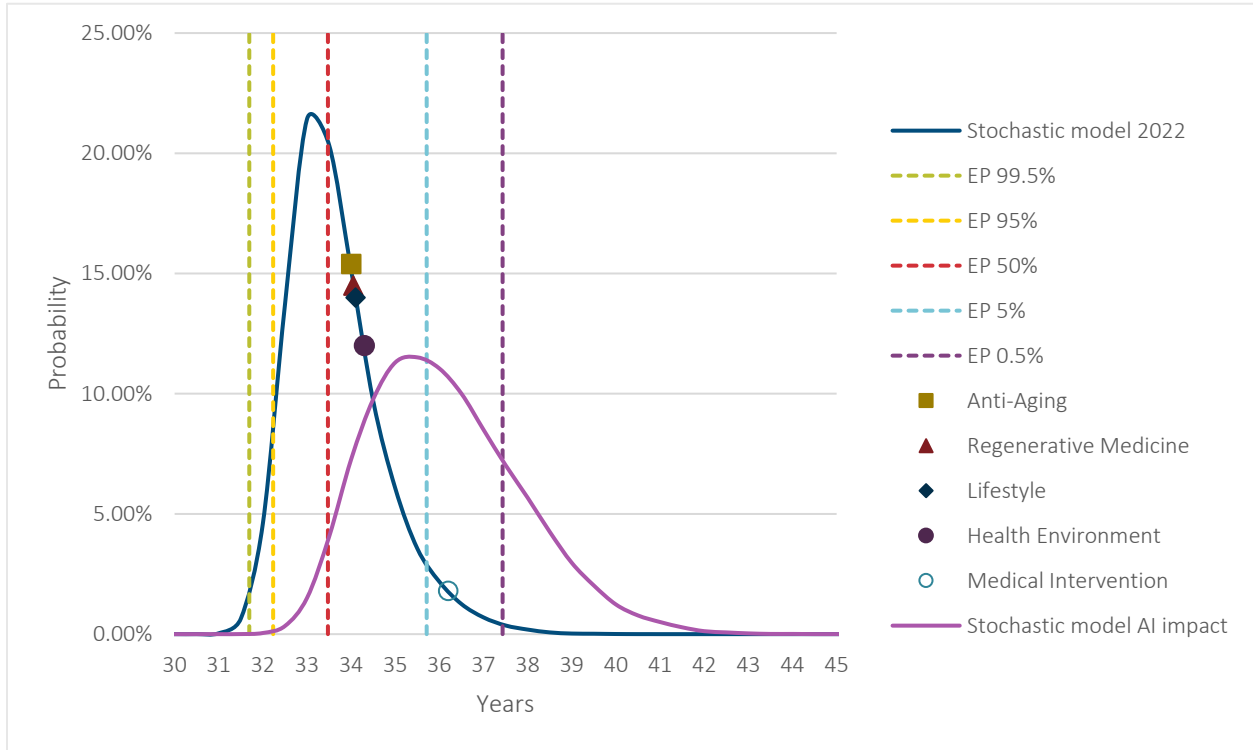
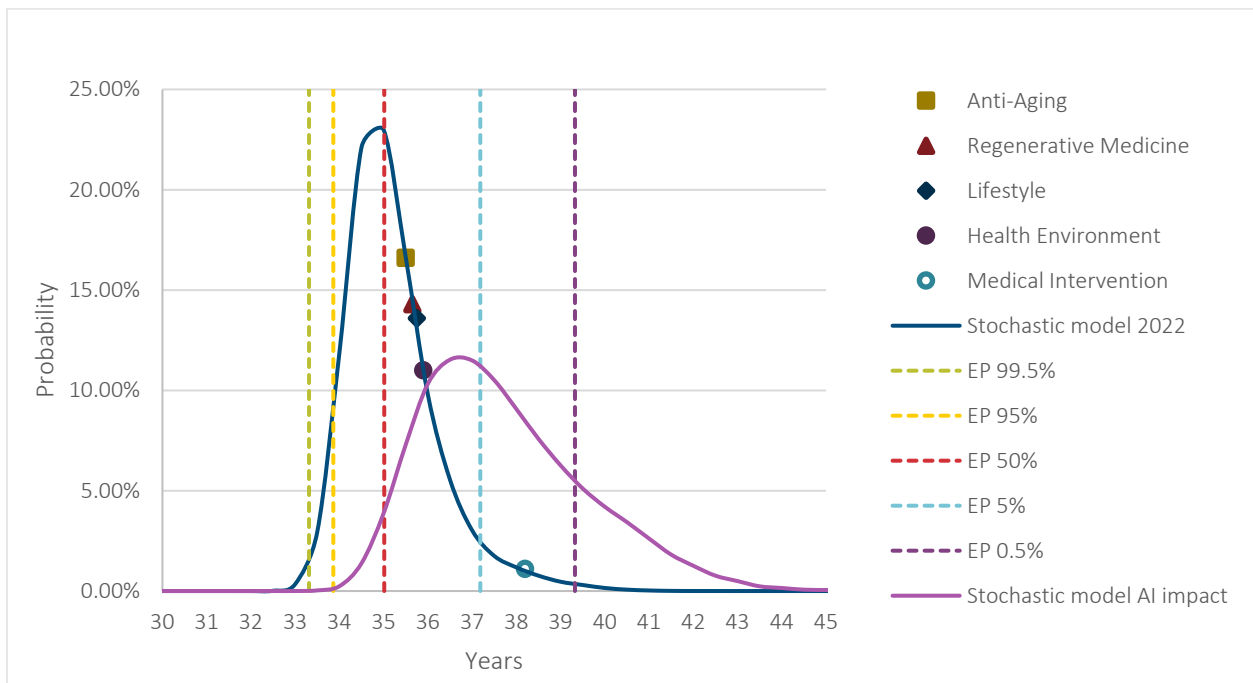



Figure 2
LIFE EXPECTANCY DISTRIBUTION FOR A 50-YEAR-OLD FEMALE



* * * * *

Nate Worrel, FSA, is Director of Customer Success at Moody’s. He can be reached at nathan.worrell@moodys.com.


Lisanne Horvat-Gitsels, Ph.D., is Assistant Director of Analytics and Modelling at Moody’s. She can be reached at lisanne.horvatgitsels@moodys.com.



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APPENDIX

| SOA Mortality Table | Pri2012_Total_Employee | Pri2012_Total_Employee |
|------------------------|------------------------|------------------------|
| Rolled forward to 2019 | Pri_2012_2019_F | Pri_2012_2019_M |
| Sex | Female | Male |
| 20 | 0.0002 | 0.0006 |
| 21 | 0.0002 | 0.0006 |
| 22 | 0.0002 | 0.0006 |
| 23 | 0.0002 | 0.0006 |
| 24 | 0.0002 | 0.0006 |
| 25 | 0.0002 | 0.0006 |
| 26 | 0.0002 | 0.0007 |
| 27 | 0.0002 | 0.0007 |
| 28 | 0.0003 | 0.0007 |
| 29 | 0.0003 | 0.0007 |
| 30 | 0.0003 | 0.0007 |
| 31 | 0.0003 | 0.0007 |
| 32 | 0.0003 | 0.0008 |
| 33 | 0.0003 | 0.0008 |
| 34 | 0.0003 | 0.0008 |
| 35 | 0.0004 | 0.0008 |
| 36 | 0.0004 | 0.0008 |
| 37 | 0.0004 | 0.0009 |
| 38 | 0.0004 | 0.0009 |
| 39 | 0.0005 | 0.0009 |
| 40 | 0.0005 | 0.0009 |
| 41 | 0.0005 | 0.0009 |
| 42 | 0.0006 | 0.0009 |
| 43 | 0.0006 | 0.001 |
| 44 | 0.0006 | 0.001 |
| 45 | 0.0007 | 0.001 |
| 46 | 0.0007 | 0.0011 |
| 47 | 0.0008 | 0.0011 |
| 48 | 0.0008 | 0.0012 |
| 49 | 0.0009 | 0.0013 |
| 50 | 0.0026 | 0.0047 |
| 51 | 0.0029 | 0.0049 |
| 52 | 0.0031 | 0.0052 |

| SOA Mortality Table | Pri2012_Total_Employee | Pri2012_Total_Employee |
|------------------------|------------------------|------------------------|
| Rolled forward to 2019 | Pri_2012_2019_F | Pri_2012_2019_M |
| 53 | 0.0034 | 0.0055 |
| 54 | 0.0037 | 0.0059 |
| 55 | 0.0041 | 0.0063 |
| 56 | 0.0045 | 0.0068 |
| 57 | 0.0049 | 0.0073 |
| 58 | 0.0053 | 0.0078 |
| 59 | 0.0057 | 0.0083 |
| 60 | 0.0061 | 0.0088 |
| 61 | 0.0065 | 0.0092 |
| 62 | 0.007 | 0.0095 |
| 63 | 0.0074 | 0.01 |
| 64 | 0.0078 | 0.0104 |
| 65 | 0.0083 | 0.0111 |
| 66 | 0.0088 | 0.0119 |
| 67 | 0.0095 | 0.0128 |
| 68 | 0.0102 | 0.0139 |
| 69 | 0.0111 | 0.0152 |
| 70 | 0.0122 | 0.0166 |
| 71 | 0.0135 | 0.0183 |
| 72 | 0.015 | 0.0201 |
| 73 | 0.0168 | 0.0223 |
| 74 | 0.0189 | 0.0247 |
| 75 | 0.0213 | 0.0274 |
| 76 | 0.0241 | 0.0305 |
| 77 | 0.0273 | 0.034 |
| 78 | 0.0308 | 0.0381 |
| 79 | 0.0348 | 0.0427 |
| 80 | 0.0392 | 0.0479 |
| 81 | 0.044 | 0.0539 |
| 82 | 0.0493 | 0.0605 |
| 83 | 0.0552 | 0.068 |
| 84 | 0.0618 | 0.0764 |
| 85 | 0.0692 | 0.0859 |
| 86 | 0.0776 | 0.0965 |
| 87 | 0.0869 | 0.1084 |

| SOA Mortality Table | Pri2012_Total_Employee | Pri2012_Total_Employee |
|------------------------|------------------------|------------------------|
| Rolled forward to 2019 | Pri_2012_2019_F | Pri_2012_2019_M |
| 88 | 0.0973 | 0.1216 |
| 89 | 0.1089 | 0.136 |
| 90 | 0.1219 | 0.1517 |
| 91 | 0.1352 | 0.168 |
| 92 | 0.149 | 0.1848 |
| 93 | 0.1634 | 0.2016 |
| 94 | 0.1781 | 0.2185 |
| 95 | 0.1933 | 0.2354 |
| 96 | 0.2095 | 0.2536 |
| 97 | 0.2264 | 0.2721 |
| 98 | 0.2441 | 0.2909 |
| 99 | 0.2623 | 0.31 |
| 100 | 0.2811 | 0.3292 |
| 101 | 0.3004 | 0.3485 |
| 102 | 0.3197 | 0.3676 |
| 103 | 0.3391 | 0.3863 |
| 104 | 0.3583 | 0.4045 |
| 105 | 0.3772 | 0.4222 |
| 106 | 0.3957 | 0.4392 |
| 107 | 0.4137 | 0.4554 |
| 108 | 0.431 | 0.471 |
| 109 | 0.4477 | 0.4855 |
| 110 | 0.4635 | 0.4947 |
| 111 | 0.4786 | 0.4958 |
| 112 | 0.4927 | 0.4969 |
| 113 | 0.4987 | 0.4978 |
| 114 | 0.4993 | 0.499 |
| 115 | 0.5 | 0.5 |
| 116 | 0.5 | 0.5 |
| 117 | 0.5 | 0.5 |
| 118 | 0.5 | 0.5 |
| 119 | 0.5 | 0.5 |
| 120 | 1 | 1 |

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Society of Actuaries Research Institute
8770 W Bryn Mawr Ave, Suite 1000
Chicago, IL 60631
www.SOA.org