Award Winner

Quantum Solutions for Catastrophic Complexity in Life and Health Insurance

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OVERVIEW

Catastrophe modeling for life and health insurance companies is an increasingly urgent area of focus, driven by the growing frequency and severity of climate-related events. While catastrophe models have traditionally been associated with property and casualty insurance, there is now a rising recognition that events like wildfires, hurricanes, heatwaves, and floods can have substantial and sometimes delayed impacts on human mortality and morbidity. These impacts pose challenges to insurers who are responsible for quantifying not only the direct loss of life but also the longer-term health consequences, medical claims, mental health burdens, and systemic risks that can stress healthcare infrastructure.

The recent wildfires in the Los Angeles area offer a stark example of the complexities involved. In 2023 and 2024, multiple fast-moving fires swept through densely populated regions of Southern California, displacing tens of thousands of residents and leading to prolonged exposure to hazardous air quality across a wide urban radius. While property insurers dealt with structural damage and evacuation claims, life and health insurers faced more nuanced questions: What was the increased short-term mortality among vulnerable populations, such as the elderly or those with pre-existing respiratory conditions? What is the long-term impact on people with chronic cardiovascular or pulmonary diseases exacerbated by smoke exposure? How do insurers account for behavioral health effects like anxiety, PTSD, or stress-related illnesses in affected populations?

EXPLORING FIRST-ORDER AND SECOND-ORDER IMPACTS

Unlike the acute nature of property damage, the human health impacts of wildfires unfold over varying time scales. Mortality spikes may occur within days due to respiratory failure, but other consequences such as increased incidence of asthma, heart disease complications, or even suicide rates linked to displacement and economic stress may emerge over months or years. This complicates the use of traditional actuarial models, which often assume relatively stable population baselines and well-defined temporal boundaries for claims.

Additionally, the geographical and demographic patterns of wildfire exposure introduce further modeling complexity. The LA wildfires highlighted how health impacts may extend well beyond the immediate burn area. Smoke plumes affected air quality across multiple counties, reaching people who were not directly in the evacuation zones. Modeling this spatial diffusion of risk requires integrating data from meteorological systems, satellite imagery, hospital admissions, and even wearable health monitors where available.

Moreover, the social determinants of health, such as income, mobility, access to healthcare, and housing quality, play a critical role in determining outcomes. Populations with fewer resources are often more vulnerable to the same physical exposures, leading to asymmetric claims impacts that must be accounted for in a robust catastrophe model.

Insurers must also consider the operational and regulatory environment during catastrophes. During the LA wildfires, healthcare delivery was disrupted due to hospital evacuations, power outages, and overwhelmed emergency services. Claims processing, member communications, and care coordination all face logistical hurdles in such scenarios. These systemic stresses can result in delays in care, gaps in medication adherence, or even higher-than-expected mortality rates; not because of the fire directly, but due to healthcare system breakdowns. Capturing these systemic effects requires models that go beyond traditional mortality tables and instead simulate the interplay between environmental, health system, and population-level variables.

Finally, there is growing recognition that models must be dynamic, not static. A wildfire's impact is not a one-time event as it triggers a cascade of effects that evolve over time. This includes the psychological burden on survivors, the impact on children's health and development, and the strain on public health systems. These secondary and tertiary effects challenge conventional actuarial assumptions and demand more flexible, multi-layered models that incorporate feedback loops, delayed effects, and the compounding impact of repeated events.

ENTER THE QUANTUM DRAGON

Quantum computing, while still in its nascent stages, offers a compelling new lens through which actuaries can approach the increasingly complex task of modeling life and health insurance impacts from natural catastrophes, such as wildfires. As wildfire events like these grow in both frequency and severity, conventional methods, though highly refined, often struggle to capture the full dimensionality and uncertainty inherent in such systems. Actuaries, tasked with assessing and pricing risk across a broad spectrum of demographic, geographic, and epidemiological variables, may find that quantum approaches offer novel frameworks to rethink how such problems are formulated and solved.

Disasters like wildfires influence mortality and morbidity in life and health insurance and are particularly complex due to the interplay of direct physical threats, long-term health effects, behavioral changes, infrastructure disruption, and emergency response efficacy. Traditional computing platforms have developed intricate simulations and scenario generation tools, but these rely on simplifications or approximations to keep models tractable. This is where quantum computing can begin to play a supporting role: by extending the range of what is computationally feasible in the future and by introducing new modeling strategies that actuaries can explore today.

Quantum algorithms such as quantum annealing[1] or variational quantum eigensolvers[2] can provide ways to model systems where variables are highly interdependent and uncertainty plays a central role. For wildfire scenarios, this means potentially improving how we simulate population displacement, exposure to air pollutants, delayed healthcare access, and follow-on impacts like increased mortality due to stress or chronic conditions. These effects unfold in nonlinear, often stochastic ways that don't always lend

[1] McGeoch, C. (2014). "Adiabatic Quantum Computation and Quantum Annealing: Theory and Practice." Synthesis Lectures on Quantum Computing, Morgan & Claypool.
[2] Peruzzo, A., McClean, J., Shadbolt, P., et al. (2014). "A variational eigenvalue solver on a photonic quantum processor." *Nature Communications*, 5, 4213.

themselves neatly to conventional Monte Carlo or regression-based models. By embedding the entire Quantum Amplitude Estimation (QAE) circuit within a Grover search[3,4], we can identify the parameter modifications that lead to exceeding the threshold that trigger mortality and morbidity risks, successfully implementing the sensitivity analysis.

While it would be premature to suggest that quantum computers today outperform classical machines in these domains, early-stage work, such as that shared by JoS QUANTUM[5] on modeling wildfire risks, demonstrates that quantum techniques can already replicate and, in some cases, enrich scenario generation or spatial modeling processes.

The word limit for this article is far too constrained to fully explore the comparative advantages, let alone provide complete demonstrations with real-world insurance datasets. Instead, the purpose here is to light a path and to raise awareness of how quantum computing frameworks could complement current actuarial practices and to encourage actuaries and data scientists alike to experiment with these tools. Given actuaries' necessary skepticism and focus on validation and credibility, such experimentation should start modestly: small proofs-of-concept, collaborations with quantum research institutions, or simulation comparisons under controlled conditions.

The future potential of quantum computing lies in its ability to model high-dimensional systems and probability distributions in a fundamentally different and faster way than is currently possible. As quantum hardware improves and more algorithms become accessible, actuaries could eventually use these tools to assess cascading risks, optimize reinsurance strategies under uncertainty, and even integrate behavioral economics or agent-based modeling more efficiently than is possible with traditional machines. While this may seem speculative today, the very same could have been said a few decades ago about modern machine learning techniques, which are now central to the actuarial toolkit.

By introducing quantum computing into the conversation around catastrophe modeling for life and health impacts, we invite a shift in mindset. Not a rejection of current tools, but an expansion of what we consider possible. The goal is not to present definitive answers, but to explore new questions. For actuaries concerned with the increasingly volatile intersection of climate, health, and insurance, quantum computing may eventually offer a new way to navigate the uncertainty that defines our work.

CONCLUSION

As LA and other wildfires illustrate, catastrophe modeling for life and health insurance is no longer a theoretical exercise; it is a practical necessity. Developing models that can accurately reflect both the immediate and long-term consequences of such events will be essential for insurers to fulfill their obligations, price products appropriately, and protect the populations they serve. It also reinforces the need for interdisciplinary collaboration, drawing on climate science, epidemiology, data science, and emerging technologies, including quantum computing, to capture the full complexity of catastrophe-driven health outcomes.

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[3] Brassard, G., Høyer, P., Mosca, M., & Tapp, A. (2002). "Quantum Amplitude Amplification and Estimation." *Contemporary Mathematics*, 305, 53–74.
[4] Grover, L. K. (1996). "A Fast Quantum Mechanical Algorithm for Database Search." Proceedings of the 28th Annual ACM Symposium on the Theory of Computing, 212–219.
[5] JoS QUANTUM. (2022, October 11). "Wildfire risks modeling with a quantum computer." LinkedIn. Retrieved from https://www.linkedin.com/pulse/wildfire-risks-modeling-quantum-computer-jos-quantum-uihwe/

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