Catastrophe and Climate

Catastrophe Modeling for Life & Health Insurance Examining LA Wildfires Impacts: A Collection of Essays

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SOA Research INSTITUTE
SOCIETAL PURPOSE

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A Collection of Essays

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INTRODUCTION

The Society of Actuaries Research Institute (SOA) Catastrophe & Climate Strategic Research Program issued a call for essays to explore considerations for catastrophe modeling for life and health insurance companies; with a priority to highlight the recent Los Angeles, California area wildfires. The goal is to explore the impacts to insurer modeling of catastrophic events, and to help to define what constitutes a "catastrophe" while seeking to explore the best framework to cover these events and the role of life & health insurance, and actuaries, to improve catastrophe models for morbidity and mortality.

The award winners, chosen for creativity, originality, and the extent to which an idea might help promote further thought in this area, are noted here:

Quantum Solutions for Catastrophic Complexity in Life and Health Insurance
Syed Danish Ali, CSPA

Where There's Smoke There's Fire: Actuarial Considerations in Catastrophe Modeling
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Gregory Whittaker, FSA, FASSA

Thank you for your interest in this essay collection. We welcome your feedback via the survey banners embedded in this document.

THE CALL FOR ESSAYS

BACKGROUND AND PURPOSE

Catastrophe models can be important to life & health insurance actuaries who model risks associated with disaster events. The recent wildfires in the Los Angeles, California (L.A.) area is an example of an extreme impact, not only from a property and economic perspective, but also from a mortality and morbidity

perspective. Some of the health impacts from the wildfire events relate to burn injuries, as well as toxic smoke and resulting poor air quality.

As of January 16, according to the Los Angeles Times: The long-term health effects of L.A. County wildfire smoke - Los Angeles Times,

- *The L.A. wildfires have coincided with a 16-fold rise in hospital visits for fire-related injuries, such as burns and smoke exposure.*
- *Although the smoke's immediate effect has begun to dissipate, lingering ash and toxic chemicals in burn areas probably will be a long-term public health concern*.

And as of January 17, at least 29 people had died directly as a result of the L.A. area wildfires. The long-term impact on mortality includes adverse health effects from lower air quality and burns, which are not yet known. California wildfires: What we know about the people killed

The Society of Actuaries Research Institute (SOA) Catastrophe & Climate Strategic Research Program seeks essays that explore considerations for catastrophe modeling for life and health insurance companies. A priority is to highlight the recent L.A. area wildfires as an example.

Accepted essays that will be published on the SOA webpage should explore the impacts to insurers through modeling of catastrophe events and what constitutes a "catastrophe." Essays should discuss how to approach events that become so large in scope as not to be insurable because they may not be able to be diversified away as part of risk pooling, at which point the insurance mechanism breaks down. For life & health catastrophe risks, what is the best framework or mechanism to cover the event and what is the role of life & health insurance and actuaries? Essays could discuss how to improve catastrophe models for morbidity and mortality.

With these issues in mind, the Society of Actuaries Research Institute is interested in an exploration of this topic from a variety of perspectives. The result of this effort is intended to initiate discussion regarding the impact of catastrophe events on life & health insurance and to set the stage for future research.

SCOPE

We seek essays that pertain to life & health insurance catastrophe events that may impact the U.S. and Canadian insurance markets. For essays studying markets beyond the U.S. and Canada, it will be preferable to note how conclusions are applicable irrespective of the market.

Illustrative points of the essay in the context of the L.A. area wildfires and how they have, and in the future may, influence insurance company practices should be highlighted as part of the essay.

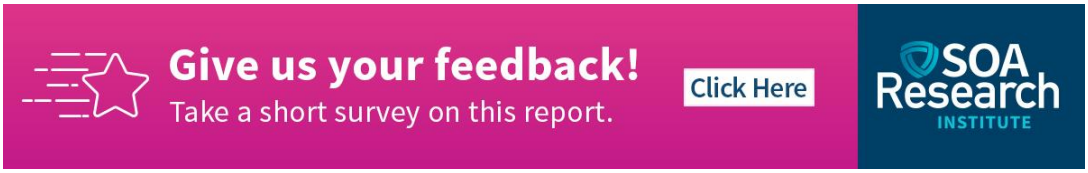
SAMPLE TOPICS OF INTEREST FOR ESSAYS

This invitation is written broadly to allow respondents the flexibility to address this topic from one or a range of perspectives and approaches. Respondents are free to choose from one or more of the following sample topics below or propose others that fall within the scope of this Call for Essays as described in the above section. Please note that this list merely consists of examples of proposed topics that may be covered. Respondents are welcome to address other questions or topics that fall under the general scope of this call for essays.

Sample topics include:

- What are the unique considerations for life, health, and property-casualty insurers in managing and modeling risks associated with catastrophic events?

- What are the parallels between “insurability” for property, life, and health risks in the aftermath of singular large-scale events or in the aggregate of smaller / mid-sized events?
- Discuss current catastrophe modeling approaches, including event definitions, damage functions, data/sources, and output quantities relevant to life, health, and/or property-casualty insurance? In this context, catastrophe modeling includes forecasting future risks and testing for solvency/soundness.
- Are current modeling approaches adequate for the needs of property-casualty, life, and health insurers? If not, what modifications to existing approaches or new approaches should be explored?
- What risk transfer mechanism(s) could life and/or health insurers implement in preparation for possible future catastrophic events beyond traditional risk pooling mechanisms, assuming that catastrophes may be too large to be pooled?
- Should life and health insurers reflect the risks associated with catastrophes such as the L.A. wildfires in their liabilities or economic capital or should they be reflected in premiums? If so, how? What effect do these risks have on the sustainability of the life or health insurance industry and/or on individual insurers?
- How could non-property focused catastrophe models simulate scenarios to test life & health insurer solvency?
- If partnerships (e.g., involving private and public sector participants) are considered, what mechanisms would be beneficial to address catastrophe events?
- What lessons can be learned by property-casualty, life, and/or health insurers from the L.A. wildfires?
- What types of resilience should be emphasized to minimize the loss of life, health, or property?
- What role might artificial intelligence (AI) and other advanced analytical techniques play in identifying, measuring, and mitigating risks for property-casualty, life, and/or health insurers?



Award Winner

Quantum Solutions for Catastrophic Complexity in Life and Health Insurance

Syed Danish Ali, CSPA

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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 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.

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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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Award Winner

Where There's Smoke There's Fire: Actuarial Considerations in Catastrophe Modeling

Lauren Lee, SOA Candidate

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While catastrophe models contend with countless hypotheticals, they reveal one certainty in the wake of the 2025 LA area wildfires: catastrophes are here to stay. The two largest of the LA wildfires, Eaton and Palisades, rank in the top ten deadliest[1] wildfires in California history and the top three most destructive.[2] Insured losses are estimated to range between $28 to $75 billion with total losses exceeding $250 billion,[3] squarely establishing the LA wildfires to be the costliest natural disaster in U.S. history. Wildfires' immediate effects are already battering the insurance industry in an existential crisis,[4] but the numbers only tell part of the story. Indeed, this is only the beginning, for the health and life insurance industries face repercussions,[5] not only in the immediate time horizon, but also decades down the line. Actuaries of any field must therefore adapt to the shifts in the wind: pricing and prediction mechanisms are now only part of the picture. A holistic actuarial practice centered around risk reduction and resilience is key to the survival of people, infrastructure, and the industry itself.

Modern catastrophe modeling took root in the 1950s,[6] but there has yet to be an official definition of "catastrophe" consistent across all insurance disciplines. The property and casualty (P&C) industry defines natural or manmade disasters that are unusually severe as catastrophes when claims surpass a dollar threshold of $25 million.[7] On the other hand, there is no such agreed upon dollar threshold for the health and life insurance industries. An August 2024 report published by the SOA Research Institute does, however, define traditional catastrophes as low frequency, high severity events, further noting that the term "catastrophe" has recently broadened "to recognize risks from downstream consequences and the accumulating impact of the initial" events that are higher frequency and lower severity than traditional catastrophes.[8] In light of these considerations, this essay will define catastrophes as either 1) low frequency, high severity events in the traditional sense; or 2) events that occur at relatively higher frequency and lower severity. Both types of events are catastrophes in the sense that, in the long term, costs add to significantly high exposure.

The definition of "catastrophe" is not the only aspect of P&C catastrophe modeling from which the life and health insurance companies may draw inspiration; life and health actuaries can learn from their P&C counterparts whose approach to catastrophe insurance would be best to adopt—or reject—for their own practice. The home insurance industry in the state of California has largely managed the risk of wildfires by either raising prices or taking its business out of the state entirely.[9] Allstate received the go-ahead to raise rates by 34% last August,[10] and State Farm recently obtained legal approval to soon raise premiums by 17%.[11] But for the insurance industry to weather the catastrophic storms to come, increasing prices or withdrawing businesses in risky locations is only a short-term solution. The fact that only $28-75 billion was insured out of the LA wildfires' total losses of $250 billion indicates that even now, insurance industries are markedly limited in their ability to cover catastrophic costs.[3] The traditional insurance mechanism in the face of catastrophe is already broken, and no amount of catastrophe modeling can single handedly diversify the risk away. To remain solvent in the era of climate change, insurers must look to risk reduction and resilience as additional tools in the actuary's toolbelt.

The immediate effects of wildfire on morbidity and mortality include burns, smoke exposure, asthma flare-ups, and death.[12] The long-term effects, however, are more enigmatic due to the lack of relevant longitudinal data and the connection that was only recently made between catastrophes and their downstream consequences.[13] Despite these limitations, scientists have strong reason to believe that wildfire may leave lingering health problems in individuals years after the incident. A 2024 study concluded that the 2018 Camp Fire in Paradise, California alone may have killed 12,000 Californians prematurely as a result of smoke exposure.[14] Just as how the requirement of flame-resistant materials in building codes is an essential part of P&C risk reduction, preventative care is key to risk reduction in life and health insurance. While P&C risk reduction focuses on reducing the physical spread of wildfire between homes,[15] life and health risk reduction would focus more on regular health check-ups for common issues after the fire had already happened. For example, health screenings often include tests for lead in the body,[16] which is a rampant wildfire pollutant. Early detection of health complications may lead to more effective treatments, better outcomes, and cheaper healthcare in the long run.[17] Building up preventative care would set the stage for resilience as well in the event that people fall ill as a result of wildfire complications.

Although there is no panacea for an issue as complex and consequential as wildfire risk management, holistic and constructive steps can still be taken to mitigate such catastrophes. Until recently, traditional insurance has largely operated by diversifying away accidents via risk pooling. But climate change is neither an accident, nor can its risk be diversified away amongst policyholders. By adopting an approach that focuses not only on modeling but also considers the processes before (i.e., risk reduction) and after (i.e., resilience) a catastrophe, life and health actuaries can better manage risks to morbidity and mortality. Insurers are dealing with a fundamental change in the natural landscape that has changed the underlying risk profile of everyone, and actuaries must embrace the new risk paradigm of catastrophe modeling. The profession is not alone in this endeavor, however: collaboration with scientific communities across a slew of interconnected disciplines can help actuaries think outside the box and enhance their models with domain knowledge unique to non-actuarial experts. The challenge may seem monumental, but the insurance industry is undoubtedly capable of fighting wildfire with fiery resolve.

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Award Winner

The Rising Heat: Catastrophe Modeling for Life and Health Insurance Amid LA's Wildfires

Sathiya Livingston

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INTRODUCTION

In recent years, Los Angeles has faced a dramatic rise in wildfires—both in frequency and intensity. These blazes are fueled by climate change, prolonged droughts, and urban expansion into areas naturally prone to fire. While wildfires have long been known for damaging property and natural landscapes, their impact now increasingly extends to human health and life expectancy.

Property and casualty (P&C) insurers have traditionally been at the forefront of managing wildfire risks, using catastrophe models to guide underwriting and financial reserves. But life and health insurers are just beginning to confront the full scope of these evolving risks—risks that extend beyond immediate damage to long-term health consequences.

This essay dives into how wildfires in the Los Angeles area are reshaping life and health insurance. It explores why traditional actuarial methods fall short, discusses new catastrophe modeling techniques designed specifically for life and health risks, and highlights the growing role of artificial intelligence and data analytics in better forecasting and managing these threats. The goal is to build a more comprehensive, tech-enabled approach that captures the real human cost of these environmental disasters.

REFRAMING CATASTROPHE RISK IN LIFE AND HEALTH INSURANCE

When it comes to catastrophe risk, property and casualty insurers have led the way by focusing on the immediate physical damage—homes, infrastructure, and vehicles destroyed by wildfires. But wildfires affect much more than buildings and property; they deeply impact people's health and well-being in ways that are often hidden or delayed.

For life and health insurers, this presents a complex challenge. Unlike property damage, health impacts from wildfire exposure can take months or even years to fully emerge. Issues such as chronic respiratory problems, heart complications, and mental health disorders may develop gradually, making it tough to connect these conditions directly to a wildfire event when underwriting policies or calculating reserves.

Traditional actuarial models tend to lean heavily on historical mortality and morbidity data, assuming that environmental conditions stay relatively stable. This approach is becoming less effective as climate change introduces new and interconnected risks. For example, wildfire smoke worsens existing health problems in vulnerable groups like older adults, low-income communities, and those with disabilities—yet insurance underwriting often lacks the detailed insight to reflect these nuances.

THE HUMAN TOLL OF LA WILDFIRES: MORTALITY, MORBIDITY, AND DISPLACEMENT

Los Angeles County, home to over 10 million people, has witnessed some of California's worst wildfires. The 2018 Woolsey Fire alone scorched nearly 100,000 acres, destroyed more than 1,600 buildings, and caused multiple deaths. But beyond the visible destruction, the health effects have been deeply felt:

- Rising Mortality: Research published in 2020 in the *Journal of the American Heart Association* linked wildfire smoke exposure to a 42% increase in sudden cardiac arrests in affected areas. Deaths also spike among seniors and those with chronic conditions.
- Long-Term Illness: Prolonged exposure to fine particulate matter (PM2.5) during wildfire seasons contributes to chronic bronchitis, worsened asthma, reduced lung capacity in children, and increased risks of stroke and heart disease.
- Mental Health Impact: The psychological trauma from wildfires rivals the physical damage. A 2021 University of California study found nearly 30% of evacuees suffered PTSD, anxiety, or depression up to a year after displacement.
- Displacement and Healthcare Access: Wildfires disrupt transportation and medical infrastructure. Clinics close, pharmacies run low on medications, and emergency responses slow down, especially hitting marginalized communities who often can't afford to relocate or find alternative care.

Together, these factors create a growing, complex mix of claims that life and health insurers must price and manage. Yet, traditional actuarial tools struggle to fully capture these intertwined health and social consequences.

TRADITIONAL MODELING LIMITATIONS AND EMERGING GAPS

Life and health insurers typically base risk assessments on historical trends, demographics, and individual health profiles—factors like age, occupation, lifestyle, and medical history. These models work well in stable settings but falter when confronted with dynamic, multifaceted catastrophes like wildfires. Key challenges include:

- Delayed Effects: Many wildfire-related health problems emerge long after the fire, making it hard to link cause and effect.
- Interconnected Risks: Wildfires often happen alongside heatwaves, power outages, and spikes in air pollution, creating overlapping risks that traditional models cannot untangle.
- Unequal Exposure: Even within the same area, individuals experience wildly different levels of exposure depending on housing quality, job type (like outdoor work), and access to clean air and healthcare.
- Fragmented Data: Health records, environmental data, and insurance claims often live in separate systems, limiting the ability to build a comprehensive risk picture.

Addressing these gaps requires a fundamental shift—a move toward models that combine actuarial skills with cutting-edge data science, real-time monitoring, and cross-disciplinary collaboration.

NEXT-GENERATION MODELING FRAMEWORKS: FROM SCENARIO ANALYSIS TO AI-DRIVEN INSIGHTS

Emerging technologies and innovative modeling techniques are beginning to fill these gaps:

- Scenario-Based Models: Instead of relying on past averages, these models simulate a variety of future wildfire scenarios, factoring in wind patterns, smoke spread, and evacuation behaviors. This helps insurers visualize potential outcomes and prepare accordingly.
- Agent-Based Models (ABMs): ABMs simulate how individuals behave during catastrophes—how they move, make decisions, and differ by demographics—allowing more granular assessment of exposure risk across populations.

- Stochastic Mortality Models: These models integrate environmental factors like air quality and temperature to dynamically project mortality risks, helping insurers design products and pricing that adapt to evolving conditions.
- Remote Sensing and GIS: Satellite data and geographic mapping provide real-time views of fire spread, overlaid with demographic information, pinpointing populations at greatest risk.
- Artificial Intelligence (AI) and Machine Learning: AI can process massive amounts of claims, electronic health records, and public health data to identify trends and predict peaks in health impacts from wildfire seasons.
- Natural Language Processing (NLP): NLP tools analyze clinical notes and insurance claims to detect underreported health effects linked to wildfire exposure, such as chronic stress or sleep disturbances.

Together, these tools mark a shift from reacting to wildfire risks after the fact toward anticipating claims and intervening earlier to reduce severity.

PRACTICAL APPLICATIONS: UNDERWRITING, PRODUCT DESIGN, AND CLAIMS MANAGEMENT

Applying catastrophe modeling in life and health insurance can transform operations:

- Better Underwriting: Environmental exposure scores can refine individual risk profiles, allowing for more precise underwriting. People living in high-smoke areas, for instance, can be assessed differently.
- Dynamic Pricing: Premiums might adjust in near real-time based on air quality, mobility data, or even wearable health devices.
- Innovative Products: Insurers could offer short-term life insurance covering wildfire seasons or packages that combine life, health, and evacuation support.
- Claims Automation: AI can triage claims post-disaster, prioritizing those most urgent and speeding up payments for severe cases.
- Proactive Outreach: Predictive models can flag high-risk clients and trigger health alerts or evacuation advice before conditions worsen, potentially reducing claims.

REGULATORY AND ETHICAL CONSIDERATIONS

With greater use of AI and real-time data comes responsibility:

- Privacy: Using geolocation, medical records, and wearable data demands strict safeguards and clear consent processes.
- Fairness: Models must be tested rigorously to prevent biased pricing that unfairly affects groups based on race, income, or neighborhood.
- Transparency: Regulators may require insurers to disclose model assumptions, conduct stress tests, and clearly communicate risks to consumers.

Ethical catastrophe modeling means balancing technical accuracy with fairness and societal good.

IMPLICATIONS FOR REINSURANCE AND CAPITAL MARKETS

Reinsurers and investors are also evolving how they manage wildfire risks:

- Mortality Catastrophe Bonds: Similar to property catastrophe bonds, these pay out if wildfire-related deaths exceed certain thresholds.
- Parametric Reinsurance: Contracts triggered by objective data—like air quality indexes or satellite fire detection—allow faster financial relief.
- Risk Pooling: Industry or regional pools spread wildfire losses more evenly across insurers.

- Climate-Aligned Investments: Asset managers factor climate risks into portfolios, influencing insurers' capital and returns.

This merging of actuarial science, finance, and climate data promises new ways to handle systemic risks posed by wildfires.

CONCLUSION: TOWARD A RESILIENT FUTURE

The wildfires sweeping through Los Angeles reflect a rapidly changing risk landscape. For life and health insurers, traditional models no longer capture the full, evolving impact of these disasters on human health and mortality.

This essay calls for a fresh modeling approach—one that blends actuarial rigor with AI-powered analytics, real-time data integration, and ethical vigilance. The future of catastrophe modeling in life and health insurance lies where technology, human behavior, and environmental change meet.

To protect public health and build resilience, insurers must evolve beyond risk managers into proactive partners supporting climate adaptation and societal stability.

* * * * *

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Award Winner

Catastrophe Modeling for Life and Health Insurance: How It Can Be Similar and Different to Property and Casualty Insurance

Rajeshwari VS, FIA

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INTRODUCTION

In 2005 any single natural or manmade disaster causing losses of $5 million or more was termed a catastrophe by the insurance industry. By 2020 this number had been revised to $25 million to accommodate inflation and increasing residential and commercial development of disaster-prone areas. Not only are there more people and construction in harm's way now, but the number and severity of the incidents (floods, wildfires, and storms) is also increasing. Traditionally, catastrophe modeling used in property insurance refers to a probabilistic simulation-based approach to estimate losses from catastrophes—natural disasters such as earthquakes, hurricanes, wildfires, etc., and manmade acts of terrorism. Sophisticated catastrophe models have the ability to forecast hazards from weather, seismic activity, other geographic and atmospheric data, and generate more accurate risk scenarios. Along with properties—buildings and contents—there is also a human cost of disasters, with people living in these areas suffering injuries, losing lives and livelihoods. However, catastrophe modeling is still in experimental stages across the life and health insurance industry—even in developed insurance markets—due to inherent differences in the nature of damages, interactions of risks and, the greater complexity of modeling the impacts of a catastrophic event on mortality and morbidity compared to damage to buildings. The rest of this essay explores some of these challenges, including aspects of property catastrophe modeling that can be applied to and potentially form the basic elements of a framework to assess catastrophe risks for life and health insurance.

IS IT WORTHWHILE EXTRAPOLATING THE 4-BOX PROPERTY CATASTROPHE MODEL FOR LIFE AND HEALTH?

There are fundamental differences in catastrophe modeling for life and health insurance versus property beginning with the definition of a catastrophe. While its mostly natural perils and manmade acts such as terrorism that cause property damage, there could be a wider range of events that can have catastrophic consequences for life and health of a local population, causing death, injury, or illness to a large number of people. Most events can be classified into the following:

- Natural perils—earthquakes, hurricanes, tornadoes, floods, wildfires, etc.
- Manmade perils—terrorism (chemical, biological, nuclear, and other Weapons of Mass Destruction (WMD))
- Infectious diseases—epidemics/pandemics
- Mental health impacts—social isolation, anxiety/other mental health impacts from lockdowns, overuse of technology, etc.
- Climate change—more abnormal weather-related illnesses, vector borne diseases, mortality from excess heat and cold

- Emerging risks—PFAS, micro and nano plastics, artificial intelligence (AI), and other emerging technologies

The most common 4-box models consider hazard rate, exposure, vulnerability, and financial aspects to generate estimates of losses from natural perils, i.e., these models simulate events (based on frequency of occurrence of the peril), use the distribution of assets in peril-prone areas (exposure), and assess damage based on the characteristics of the properties (age, building type, construction material, etc.). A basic extrapolation of this approach to a potential catastrophe model for mortality and morbidity is shown in Table 1.

Table 1
EXTENDING A TYPICAL 4-BOX APPROACH FROM PROPERTY TO LIFE AND HEALTH

Modules	Property	Morbidity	Mortality
Event/Hazard	Quite similar to natural perils, infectious diseases, and other emerging risks (tech/AI, PFAS etc.) need to be considered for mortality and morbidity		
Exposure	Assets at risk, such as buildings, infrastructure, and contents, by their location and value	Number of people at risk, insureds especially, along with demographics, location, and health details	
Vulnerability	Extent of damage based on factors like construction type, age, and local building codes	Extent of damage to health based on age, location, pre-existing conditions, lifestyle/living conditions	
Financial	Transforming the expected damage into monetary terms using deductibles, limits, and other (re)insurance conditions		

However, this approach will have limited usefulness in the context of life and health insurance in quantifying exposure, vulnerability, and financial aspects in ways similar to property models owing to challenges in data collection, grouping, and analysis. But the major differences would be due to the nature of the business itself and the possibility of both short- and long-term impacts on human health.

THE PROBLEM WITH THE "BOXES"

The 4-box catastrophe models, although probabilistic, rely on a lot of data—historical and scientific. Even if we argue that the hazard module that produces simulations of events can easily be extended to cover catastrophic events for life/health insurance (including those discussed on the previous section), we may not have reliable historical data or scientific studies to be able to estimate frequency (or return period) for some kinds of events (see the Data Challenges section below).

The exposure module for property uses location or the coordinates of a building to determine if this property gets damaged in the 'event' the hazard module simulated. In a similar life/health insurance situation, the entire local population can provide a suitable estimate of exposure for the entire insurance market and this can be scaled using market share for each insurer. At any given time, this would be an approximation with people traveling for leisure and work, before and after events. While a building's coordinates are static, the distance of a person from a fire or the epicenter of an earthquake is never static, and so no model can predict with much certainty the damage—extent of injury—they may suffer.

The vulnerability module would present the biggest challenges. The equivalent property module assesses how much damage a building would suffer in case the simulated event occurs. For health impacts, it's hard to say how much an average person's health suffers from a disaster. This would depend on age and fitness, distance from the epicenter of the event, previous medical history, lifestyle, smoking habits, education and affordability, any mitigation measures, or precautions they may have taken, and how soon they were evacuated and received medical help.

DATA CHALLENGES

Like all models, catastrophe models are calibrated with historical data. The question of how we use experience and adjust it to model our present reality has no straightforward answer. We live in a very different world now in terms of economic, technological/ medical advancements and demographics, than when some of those historical catastrophes occurred. How the same events might affect populations today could be very different from what we experienced in the past. Although populations are aging; medicine has greatly advanced, while many people may have sedentary lifestyles; there is also a lot more awareness about precautions; there are many more such counteracting trends. We may be able to derive assumptions for natural perils, infectious disease, and even terror attacks from history, but for the emerging risks such as climate, micro or nano plastics, and new technologies, we have virtually no data, only a few very reliable studies that make some predictions into the future.

A more practical difficulty to analyzing claims experience from catastrophic events is determining the distance/geographic boundaries in the case of medical expense claims. Natural perils occur within a defined geographic area and there is usually a 'consecutive hours' clause that reflects the time within which we can expect all property damage to have occurred. In other words, all claims from that catastrophic event would have occurred with a certain boundary of space and time enabling insurers to treat all claims arising in that stipulated zone and timeframe as originating from that event. There is no easy definition for an equivalent in health impacts, and it could be particularly challenging when symptoms appear later or persist until long after the event. For example, people in surrounding areas may inhale particulate matter which settles in airways or enters the bloodstream with symptoms appearing much later, over the course of days, months or years, and can linger. This could be exacerbated in people with long COVID. Health deterioration could also be exacerbated by a general decrease in living standards and wellbeing post a significant catastrophic event due to reduced economic activity and stressed infrastructure. To be able to perform a thorough analysis of the impacts of a catastrophic event on mortality, morbidity, and healthcare costs, we would also need to define for how long, how far, and how wide its impacts are likely to be felt.

Consider the following scenarios in the recent LA wildfires:

- An otherwise healthy, young firefighter develops breathing difficulties after a week. There is a direct causal link to the event.
- An elderly person living 5.5 miles downwind has an asthma attack within a few days of the fires breaking out. How likely would this be from the fire? Would this person report this if they are asthmatic and can self-medicate? If hospitalization occurs, would the hospitals report this as a case of illness from the wildfire, especially when we would not expect a reasonably healthy young adult to get ill from the smoke in the same location?
- Which of these two individuals would recover sooner—the young, fit firefighter with no history of asthma whose exposure was many times greater or the elderly asthmatic living farther away?
- If the elderly person requires frequent hospitalization for breathing difficulties and lung problems in subsequent weeks and finally succumbs a month later, does this add to the death count from the fire and would it be reported as such?

- Consider a more common scenario from asbestosis! The young firefighter retires years later, and experiences illness from PFAS in firefighting foam. How would we apportion costs across years and the various fires he has helped combat?
- People usually are advised to take precautions when they can see or smell smoke. Depending on the intensity of the fire and wind conditions at the time, the number of people who can see and/or smell smoke can vary greatly. So how do we know the number of people potentially exposed to any given event?

It is possible to identify many such grey areas in recording and attributing claims to a specific event, from the healthcare and life insurance perspective.

QUANTIFYING THE ECONOMIC COSTS OF HEALTH IMPACTS FROM CATASTROPHIC EVENTS

In recent years, with more catastrophic events, there has been an increasing number of studies on the human cost of disasters, trying to quantify the economic impacts on health. Floods, earthquakes, and terror attacks are short duration, high impact events. Loss of life is more likely than prolonged illness. These studies could be very useful in the context of wildfires which have a high possibility of longer-term health consequences, although the exposure time is larger, providing the opportunity to save lives and reduce impacts.

Studies in Canada[1], Australia[2], Portugal[3] and the U.S.[4] have attempted to estimate health care costs from particulate matter (PM2.5) exposures during wildfires in terms of premature deaths, heath care costs related to premature deaths, and acute and chronic illnesses. We look at four measures that have been calculated in these studies here.

MORTALITY IMPACTS: VALUE OF STATISTICAL LIFE (VSL)

Value of Statistical Life (VSL) is the per unit cost of premature mortality and is mostly measured as "willingness to pay" for mortality risk reduction, through precautions, purchasing insurance, and any other risk mitigation measures. A higher VSL could represent a lower mortality risk from a given event.

MORTALITY IMPACTS: YEARS OF LIFE LOST (YLL)

Years of Life Lost (YLL) is a common public health measure usually used in the context of diseases. It measures the premature mortality of a population in terms of the number of life-years lost.

$$\begin{aligned} &Years\ of\ life\ lost\ (YLL) \\ &\quad = Number\ of\ lives\ at\ a\ certain\ age\ and\ of\ a\ certain\ sex\ lost\ due\ to\ a\ particular\ cause \\ &\quad * life\ expectancy\ for\ that\ age\ and\ sex \end{aligned}$$

Several studies[5] estimate the costs from premature mortality due to PM2.5 exposure during wildfires using the YLL.

[1] Health impact analysis of PM2.5 from wildfire smoke in Canada (2013–2015, 2017–2018) - ScienceDirect

[2] Extreme air pollution events from bushfires and dust storms and their association with mortality in Sydney, Australia 1994–2007 - ScienceDirect

[3] Health and economic burden of wildland fires PM2.5-related pollution in Portugal – A longitudinal study - ScienceDirect

[4] How to measure the economic health cost of wildfires - A systematic review of the literature for northern America

[5] Impacts on Urban VOCs and PM2.5 during a Wildfire Episode

MORBIDITY IMPACTS: COST OF ILLNESS (COI)

Cost of Illness (COI) is a measure that reflects the costs of resources, medical care, the opportunity cost of being sick (lost wages), and the additional stresses from illness. A study based on the 2009 LA Station fire yielded an estimate of 3.3 symptom days on average, 8.7 days among 38% of the people surveyed and an average cost per exposed day of $9.50. The COI doesn't consider lost recreation days, pain or discomfort with no resulting hospitalization, or cost of preventive measures people have adopted.

MORBIDITY IMPACTS: WILLINGNESS TO PAY (WTP)

Like the VSL measure, morbidity impacts can also be measured by the costs people incur to avoid being sick. In the same Station Fire study, the WTP was much higher than COI, at $84.42 per person.

USEFULNESS IN ACTUARIAL WORK

These measures do not easily convert into mortality or morbidity adjustments for actuarial modeling, and would vary by awareness, affluence, age, distance from disaster-prone areas, and attitudes. However, they still provide useful starting points to quantify financial losses from wildfire incidents. In pricing and capital management, they can form the basis for risk margins and catastrophe loadings. They can also be used in risk management, planning interventions, mitigations, and disaster relief. Such measures can help assess the risk a person represents during underwriting. For example, in the case of a wildfire, an individual with a high VSL or WTP could represent a potentially lower risk with respect to mortality, because they have purchased safety measures such as air filters/purifiers, emergency kits, or created a fire-resistant zone around homes. These studies have focused on large groups and estimated VSL for entire populations of cities/fire affected areas. VSL for individuals is likely to vary widely based on age, affluence, and attitudes. For example, older people may be equally more willing to spend more on preventive measures because they may believe they have fewer remaining years, or to spend less for the same reason! COI could help arrive at medical expenses for an average person during a wildfire season.

PIECING TOGETHER A FRAMEWORK FOR CATASTROPHE RISKS TO LIFE AND HEALTH

Catastrophe modeling is a very sophisticated approach that combines inputs from several fields to estimate financial impacts from events. While some existing functionality of property catastrophe models can be easily extended and applied, some others are not so intuitively adaptable to a life/health insurance scenario. The traditional 4-box model for property insurance, though not exactly replicable for life and health insurance, can provide a starting point for a framework to assess the impacts of catastrophes on mortality and morbidity:

- Events can be simulated based on history and scientific research from relevant fields such as epidemiology, climate change, etc.
- Exposures are readily available in population and demographic information. Scaling market wide exposures to individual companies is a common practice in insurance that can be replicated here.
- Companies have health data of their policyholders to assess vulnerability, though this could be challenging. The task then remains to convert all this information into a financial estimate of losses. In this area, some of the measures such as VSL, COI, WTP can be incorporated to assess potential costs, while also providing useful risk assessments for underwriting and pricing. Where such measures are available at regional/city level, they can be used to estimate catastrophe loadings/margins for catastrophic events.

With more frequent events, and more studies happening in this area, more possibilities will open for catastrophe modeling in life and health.

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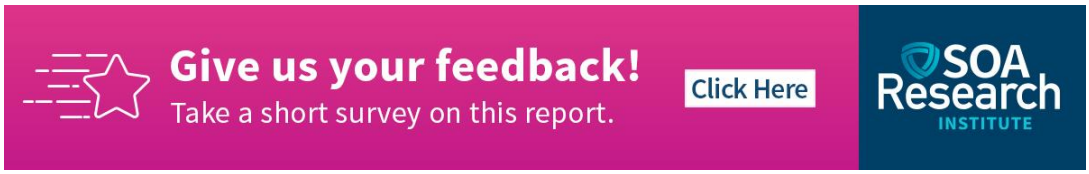

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Award Winner

Insurer Resilience to Minimize the Loss of Life and Health as a Result of Catastrophes

Gregory Whittaker, FSA, FASSA

Any views and ideas expressed in the essays are the author's alone and may not reflect the views and ideas of the Society of Actuaries, the Society of Actuaries Research Institute, Society of Actuaries members, nor the author's employer.

INTRODUCTION

According to the United States Department of Homeland Security,[1] resilience is:

> *…the ability of systems, infrastructures, government, business, and citizenry to resist, absorb, recover from, or adapt to an adverse occurrence that may cause harm, destruction, or loss of national significance, and the capacity of an organization to recognize hazards and threats and make adjustments that will improve future protection efforts and risk reduction measures.*

The purpose of this essay is to examine resilience approaches adopted by life insurance and health insurance companies in the face of adverse events such as the Los Angeles wildfires, the COVID-19 pandemic, and mass riots.

LOS ANGELES WILDFIRES

The Los Angeles wildfires of January 2025 were among the most devastating in California's history, driven by extreme drought conditions and powerful Santa Ana winds.[2] Close to 17,000 structures were destroyed or damaged, and at least 30 people lost their lives.[3] The fires forced over 200,000 residents to evacuate and with economic losses projected at $150 billion, this disaster ranks among the costliest in modern United States history.[2]

Insurers reacted in a number of ways to minimize the health impacts:

Ensuring continuity of medication and care

The California Insurance Commissioner directed health insurance companies to immediately submit emergency plans ensuring uninterrupted health care access for affected consumers. Insurers were required to allow 90-day prescription refills, suspend refill waiting periods for all drug tiers, waive delivery charges, and streamline access by removing barriers such as step therapy and prior authorizations. Insurers were required to guarantee access to medical services, replace lost medical equipment, expand network flexibility to cover out-of-network providers at in-network costs, and maintain dedicated consumer communication channels.[4]

Virtual health services

Virtual care is included in most Blue Shield of California plans with Teladoc providing 24-hour-a-day access to a doctor via phone or video, and Nursehelp 24/7^{SM} providing 24-hour-a-day advice from a registered nurse.[5] By covering telehealth, insurers ensure customers can receive timely care despite evacuations or smoke-related hazards.

Flexibility on claims and premiums

Wildfire response plans often include leniency in administrative requirements to aid recovery. Insurers have extended deadlines for approvals, claims, and payments in affected areas. For example, some insurers may temporarily waive the usual preauthorization requirements and give extra time for claims filing. In addition, some insurers granted grace periods for premium payments for members facing wildfire-related financial hardship. These accommodations are a resilience tactic to prevent policy lapses and alleviate stress on customers until the crisis passes.

Mental health support

Some health insurers opened crisis counseling hotlines, and some insurers offered a free 24-hour crisis line for anyone affected by the Los Angeles wildfires irrespective of insured status.[6] Such initiatives help communities cope with stress, grief, and respiratory anxieties. Extending mental health support and guidance on issues such as smoke inhalation not only assists recovery but strengthens customer trust and engagement during disasters.

COVID-19 PANDEMIC

The COVID-19 pandemic emerged in Wuhan, China in late 2019 and rapidly escalated into a global health crisis. Declared a Public Health Emergency of International Concern by the World Health Organization (WHO) on Jan. 30, 2020[7] and a pandemic on March 11, 2020,[8] the virus spread globally, leading to widespread morbidity, mortality, and socio-economic disruption. Characterized primarily by respiratory symptoms, COVID-19 has varied in severity, disproportionately affecting the elderly and those with pre-existing conditions.[9] Governments worldwide implemented public health interventions such as lockdowns, travel restrictions, and vaccination campaigns to contain transmission.[10] As of mid-2023, the WHO declared that COVID-19 was no longer a public health emergency, although it remains a global health concern with ongoing vaccination and monitoring efforts.[11]

Remote monitoring and early intervention

A novel approach by Discovery Health (South Africa) was to identify high-risk customers and equip them with pulse oximeters for at-home monitoring of blood oxygen during COVID-19. This proactive program enabled early detection of silent hypoxia and timely care, significantly reducing severe outcomes. Over 7,500 members received oximeters, and the cohort saw 27% lower hospital admissions and a 38% lower fatality rate compared to similar groups.[12] By leveraging simple technology and data analytics to monitor patients remotely, the insurer mitigated health risks and improved survival.

Goodwill benefits

Singapore's leading life and health insurers, including AIA Singapore, Etiqa, DBS (via Chubb), and Manulife introduced complimentary COVID-19 protection for policyholders.[13] For example, Manulife allocated S$1 million to offer S$1,500 upon diagnosis, an additional S$2,000 for hospital stays beyond five days, and a S$30,000 death benefit to be paid on top of the death benefit from the customer's existing policy. These goodwill benefits were aimed at enhancing financial protection and customer trust. By absorbing pandemic risk and paying ex-gratia benefits, insurers demonstrated resilience through customer-centric innovation.

Mitigation of lapse rates

The Reinsurance Group of America outlined five pragmatic strategies to reduce policy lapse rates amid the COVID-19 pandemic:[14] (1) Consumer relief, such as premium deferrals, grace-period extensions, benefit suspensions, and coverage reductions; (2) Incentives to maintain coverage, such as wellness perks, telemedicine, loyalty rewards, or retailer discounts; (3) Disincentives against lapses, including policy clauses with penalties or claw-backs and

conditional penalties that can be waived upon policy reinstatement; (4) Front-loading premiums, encouraging annual or single-premium payments with discounts and optional later conversion to monthly plans; and (5) Minimizing process friction, like removing wet signatures, promoting automatic renewals, and streamlining digital interactions via apps or messaging platforms. These approaches, coupled with advanced lapse-risk modeling, early-warning systems, proactive retention teams, channel optimization, and competitive product benchmarking, form a comprehensive persistency framework for insurers.

Telehealth expansion

During the COVID-19 pandemic, Nigeria adopted several innovative insurance-related responses, particularly through AXA Mansard, which played a leading role.[15] The company provided free life insurance coverage to frontline medical professionals in major Nigerian cities and launched a telemedicine partnership with Tremendoc, enabling Nigerians to access virtual consultations and prescriptions while adhering to social distancing protocols. Additionally, AXA Mansard leveraged its relationship with Nigeria's largest women's business network, WimBiz, to offer webinars on health, wellness, and financial literacy, expanding women's awareness of how insurance can mitigate personal and business risks. These initiatives exemplify how Nigeria's insurance sector embraced technology and gender-sensitive outreach to address pandemic-related challenges.

MASS RIOTS

The July 2021 riots in South Africa, mainly affecting the provinces of KwaZulu-Natal and Gauteng, were the most violent unrest in the country's democratic history, triggered by the incarceration of former President Jacob Zuma. The violence, which occurred between July 8 and 17, left at least 354 people dead, thousands injured, and communities fractured. Critical infrastructure was attacked, shopping malls and warehouses looted, and essential supply chains disrupted. The South African economy suffered losses estimated at several billion dollars.[16] The unrest severely disrupted COVID-19 services, including the delivery of treatment and vaccines, particularly in KwaZulu-Natal.

Several insurers implemented novel resilience measures following the unrest:

Hollard

Recognizing the need for long-term social rebuilding, in April 2022 Hollard launched "Hollard ChangeMaker"—a world-first program allowing policyholders to earn back part of their life insurance premiums by volunteering for vetted community causes.[17] The ChangeMaker initiative logs participants' volunteer hours and rebates up to 20% of premiums for a pilot group of Hollard life policyholders. The goal is to harness citizen action to heal communities and promote social cohesion after the unrest.

Metropolitan (Momentum Group)

Metropolitan Life (part of the Momentum Group) launched a community development initiative in the wake of the unrest to bolster food security and livelihoods.[18] In October 2021 it rolled out "Metropolitan Collective Shapers"—an agricultural entrepreneurship training program for unemployed youth. The nine-week course covers agri-business fundamentals (for example, vegetable and avocado production, permaculture) and includes post-course mentoring to help young farmers start businesses. Metropolitan's CEO explained that instead of one-off donations, this initiative "gives people the tools to create long-lasting and sustainable opportunities." By tapping into existing farming skills and passions in rural communities, the program aims to build generational knowledge, boost food production, and strengthen community resilience after the riots.

Sanlam

The Sanlam Group used its Enterprise & Supplier Development (ESD) program to shield local businesses from the unrest's impact.[19] Sanlam's foundation rapidly extended grants and coaching to small and micro enterprises (SMEs) in the areas hardest hit by the riots. By late 2021, the ESD program increased funding in its COVID-19 relief grant to keep businesses afloat. As Sanlam reported, its COVID-19 relief grant "played a crucial role in keeping businesses buoyant" even when revenues collapsed. Overall, Sanlam's support aimed to preserve jobs and help entrepreneurs emerge stronger from the unrest by cutting costs, diversifying income streams, and accelerating digital transformation.

CONCLUSION

Through interventions like virtual care, remote monitoring, crisis mental health services, policy flexibility, community rebuilding, and support for vulnerable populations, insurers have gone beyond traditional risk pooling to actively mitigate harm, promote continuity of care, and foster social stability. These case studies demonstrate that resilience is not only about operational continuity, but about proactively safeguarding human wellbeing in times of crisis—an evolving imperative in an age of increasingly complex systemic shocks.

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About The Society of Actuaries Research Institute

Serving as the research arm of the Society of Actuaries (SOA), the SOA Research Institute provides objective, data-driven research bringing together tried and true practices and future-focused approaches to address societal challenges and your business needs. The Institute provides trusted knowledge, extensive experience and new technologies to help effectively identify, predict and manage risks.

Representing the thousands of actuaries who help conduct critical research, the SOA Research Institute provides clarity and solutions on risks and societal challenges. The Institute connects actuaries, academics, employers, the insurance industry, regulators, research partners, foundations and research institutions, sponsors and non-governmental organizations, building an effective network which provides support, knowledge and expertise regarding the management of risk to benefit the industry and the public.

Managed by experienced actuaries and research experts from a broad range of industries, the SOA Research Institute creates, funds, develops and distributes research to elevate actuaries as leaders in measuring and managing risk. These efforts include studies, essay collections, webcasts, research papers, survey reports, and original research on topics impacting society.

Harnessing its peer-reviewed research, leading-edge technologies, new data tools and innovative practices, the Institute seeks to understand the underlying causes of risk and the possible outcomes. The Institute develops objective research spanning a variety of topics with its strategic research programs: aging and retirement; actuarial innovation and technology; mortality and longevity; diversity, equity and inclusion; health care cost trends; and catastrophe and climate risk. The Institute has a large volume of topical research available, including an expanding collection of international and market-specific research, experience studies, models and timely research.

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