Biological Immortality Under Longevity Escape Velocity: Expected Survival Under External-Cause Mortality

Abstract

Longevity escape velocity (LEV) refers to a hypothetical condition in which biomedical progress increases an individual's remaining healthy life expectancy faster than chronological time passes. Even if ageing and age-related diseases were completely controlled, however, an individual would remain vulnerable to fatal external events, including transport accidents, occupational injuries, falls, drowning, homicide, armed conflict, natural disasters, technological failures, and other forms of trauma.

This analysis estimates the expected survival time of a biologically non-ageing individual exposed to present-day external mortality risks. A constant-hazard survival model is used as a first-order approximation. Under current global mortality conditions, the estimated annual external-cause mortality hazard is approximately 46.9–53.5 deaths per 100,000 persons. This corresponds to a mean survival time of approximately 1,900–2,100 years and a median survival time of approximately 1,300–1,500 years.

Scenario modelling indicates that the result is highly sensitive to future institutional and technological conditions. In a stable, affluent, safety-oriented society, expected survival could rise to several thousand years. In a highly advanced civilisation with very low external mortality, it could reach tens of thousands of years. Conversely, prolonged political instability, infrastructural decline, or early off-world colonisation could reduce expected survival to several hundred years or, under extreme frontier conditions, approximately one century.

The main conclusion is that biological immortality would not imply statistical immortality. Once ageing is removed, long-term survival becomes primarily a function of environmental safety, infrastructure, political stability, behavioural adaptation, and exposure to systemic risk.

---

1. Research Assumption

The analysis adopts the counterfactual assumption that LEV has reached a level sufficient to eliminate biological ageing as a cause of death. The individual does not undergo progressive senescence and does not die from ordinary age-related degeneration. This does not imply invulnerability. Death may still result from:

- transport accidents;
- occupational accidents;
- falls and traumatic injury;
- drowning;
- fires and burns;

- poisoning;
- homicide and interpersonal violence;
- armed conflict;
- natural disasters;
- technological or infrastructural failures;
- other external causes.

LEV is generally defined as the point at which biomedical progress increases remaining life expectancy by more than one year for every year that passes. The purpose of this study is not to determine whether LEV will be achieved, but to examine the actuarial consequences if biological ageing were successfully neutralised.

The central methodological implication is that the relevant quantity would no longer be conventional human life expectancy. Instead, the problem becomes one of estimating the time to death under a continuing external mortality hazard.

---

2. Mathematical Framework

2.1 Constant-hazard model

Let λ denote the annual mortality hazard from external causes. Under a constant-hazard approximation, survival follows an exponential distribution:

$$S(t) = e^{-\lambda t},$$

where:

- $S(t)$ is the probability of surviving for at least t additional years;
- λ is the annual external-cause mortality hazard;
- t is measured in years.

The expected time to death is:

$$E[T] = \frac{1}{\lambda}.$$

The median survival time is:

$$T_{50} = \frac{\ln 2}{\lambda}.$$

More generally, the time by which only a proportion p remains alive is:

$$T_p = \frac{-\ln p}{\lambda}.$$

For example, if external mortality is 50 deaths per 100,000 persons per year:

$$\lambda = \frac{50}{100\,000} = 0.0005.$$

The resulting mean survival time is:

$$E[T] = 2\,000 \text{ years},$$

while the median survival time is:

$$T_{50} \approx 1\,386 \text{ years}.$$

This does not predict that every individual would live approximately 2,000 years. It describes a probability distribution with substantial variation. Some individuals would die much earlier, while a small proportion would survive for many thousands of years.

2.2 Limitations of the constant-hazard assumption

The constant-hazard model is a simplifying approximation. In reality, risk would vary over time according to:

- geographical location;
- occupation;
- transport exposure;
- participation in dangerous activities;
- political stability;
- warfare;
- technological change;
- behavioural adaptation;
- emergency medical capabilities;
- long-term civilisational development or decline.

Nevertheless, the exponential model is useful as a transparent benchmark and permits direct comparison between alternative scenarios.

---

3. Contemporary Global External Mortality

The World Health Organization estimates approximately 4.4 million deaths annually from injuries and violence, including approximately 3.16 million deaths from unintentional injuries. Major categories include road traffic injuries, falls, drowning, burns, poisoning, suicide, homicide, and conflict-related violence.

Recent global estimates include approximately:

Cause	Approximate annual deaths
Road traffic injuries	1.19 million
Falls	684,000

Cause	Approximate annual deaths
Intentional homicide	458,000
Fatal occupational accidents	330,000
Drowning	300,000
Battle-related deaths in 2025	245,000
Burns	180,000
Natural disasters in 2024	16,753

The global population in 2025 was approximately 8.232 billion.

These figures indicate that routine, recurrent hazards dominate contemporary external mortality. Road transport, falls, violence, drowning, and occupational injuries are quantitatively more important than spectacular but relatively rare disasters.

3.1 The ageing-related component of present injury mortality

Present-day external mortality statistics are not fully transferable to a biologically non-ageing population. A substantial proportion of deaths classified as accidental are associated with age-related frailty.

Falls are particularly important. Older adults experience the highest risk of fatal falls, and global estimates indicate that more than 555,000 fall-related deaths among older adults occurred in 2021. If biological ageing, sarcopenia, osteoporosis, neurological decline, and frailty were eliminated, a considerable part of current fall mortality would probably disappear.

Road traffic mortality differs in this respect. Road injuries are already a major cause of death among children and young adults. Eliminating ageing would therefore not remove most transport-related risk.

Consequently, present global external mortality may overestimate the hazard for a permanently young and physiologically robust individual, particularly regarding falls. At the same time, it provides a reasonable initial benchmark for transport, violence, occupational injury, drowning, and other non-age-dependent hazards.

---

4. Contemporary Benchmark Estimates

Two benchmark definitions are useful.

4.1 Narrow external-cause benchmark

The narrow benchmark includes:

- 3.16 million unintentional injury deaths;

- 458,000 intentional homicides;
- 245,000 battle-related deaths.

Total:

$$3.863 \text{ million deaths annually.}$$

Dividing by a global population of 8.232 billion gives:

$$\lambda \approx 0.000469,$$

or approximately:

$$46.9 \text{ deaths per } 100\,000 \text{ persons annually.}$$

4.2 Broad injury-and-violence benchmark

The broader benchmark uses the WHO estimate of 4.4 million annual deaths from injuries and violence. This category also includes suicide and other intentional injury mortality.

The corresponding mortality rate is:

$$53.5 \text{ deaths per } 100\,000 \text{ persons annually.}$$

4.3 Resulting survival estimates

Benchmark	Annual mortality hazard	Mean time to death	Median survival
Narrow external benchmark	46.9 per 100,000	approximately 2,131 years	approximately 1,478 years
Broad injury-and-violence benchmark	53.5 per 100,000	approximately 1,871 years	approximately 1,296 years

Under current global conditions, a biologically non-ageing individual would therefore have an expected survival time of approximately **1,900–2,100 years**.

The median is lower than the mean because the exponential survival distribution has a long upper tail. Approximately half of the population would die before roughly 1,300–1,500 years, while a smaller proportion would survive for considerably longer.

---

5. Long-Horizon Survival Under Present Conditions

Using the narrow benchmark of 46.9 deaths per 100,000 annually:

$$\lambda = 0.000469.$$

The probability of surviving for t years is:

$$S(t) = e^{-0.000469t}.$$

This produces the following estimates:

Additional survival period	Probability of survival
100 years	95.4%
500 years	79.1%
1,000 years	62.6%
1,478 years	50.0%
4,910 years	approximately 10.0%
9,820 years	approximately 1.0%
10,000 years	approximately 0.9%

The result is simultaneously very large and clearly finite. Removing ageing would shift typical survival from decades to millennia, but it would not produce indefinite survival if present external risks remained unchanged.

---

6. Relationship Between Annual Hazard and Expected Survival

The inverse relationship between mortality hazard and expected survival is particularly important over millennial timescales.

Annual external mortality	Mean survival	Median survival
5 per 100,000	20,000 years	13,863 years
10 per 100,000	10,000 years	6,931 years
20 per 100,000	5,000 years	3,466 years
50 per 100,000	2,000 years	1,386 years
100 per 100,000	1,000 years	693 years
300 per 100,000	333 years	231 years
1,000 per 100,000	100 years	69 years

A relatively small annual hazard becomes decisive when compounded over thousands of years. For example, a mortality rate of only 10 per 100,000 annually still implies that most individuals would eventually die within several thousand years.

7. Scenario Analysis

The following scenarios combine present empirical data with modelled assumptions concerning future safety, technological development, institutional stability, behavioural change, and exposure to frontier conditions.

The first two benchmarks are directly based on contemporary mortality estimates. The remaining scenarios are hypothetical ranges calibrated against present differences between safe and unsafe societies, occupational fatality rates, conflict mortality, disaster trends, and plausible future environments.

---

8. Scenario A: Continuation of Present Global Conditions

Assumptions

- Biological ageing is eliminated.
- Global external mortality remains close to its present level.
- Transport, occupational, violent, and disaster risks do not change fundamentally.
- No permanent global collapse or major safety revolution occurs.

Estimated hazard

$$46.9\text{–}53.5 \text{ deaths per } 100\,000 \text{ annually.}$$

Results

- Mean survival: approximately 1,900–2,100 years.
- Median survival: approximately 1,300–1,500 years.
- Probability of surviving 1,000 years: approximately 59–63%.

This is the most direct answer to the question of how long a biologically non-ageing individual would live if only ageing were removed and the surrounding world remained broadly similar to the present.

The scenario is mathematically useful but historically unlikely over very long periods. Civilisations, technologies, political systems, and risk profiles rarely remain unchanged for millennia.

---

9. Scenario B: Stable, Affluent, and Highly Cautious Society

Assumptions

- Residence in a wealthy and politically stable jurisdiction.
- High-quality infrastructure and emergency medicine.
- Avoidance of war zones and violent regions.
- No high-risk occupation.
- Reduced exposure to private driving and dangerous transport.

- Strong personal risk management.
- Elimination of age-related frailty and most geriatric fall mortality.
- Continued but not revolutionary technological improvement.

The European Union provides a partial contemporary reference point. Its standardised mortality rate from accidents was approximately 35.6 per 100,000, while mortality from assault was approximately 0.7 per 100,000. These figures still include age-related falls and other mortality associated with biological ageing.

A biologically young, risk-averse individual in a stable society could therefore plausibly experience a lower hazard than the present population average.

Modelled hazard

$$15\text{–}25 \text{ deaths per } 100\,000 \text{ annually.}$$

Results

Measure	Estimated range
Mean survival	4,000–6,700 years
Median survival	2,773–4,621 years
Probability of surviving 1,000 years	77.9–86.1%

In this scenario, individual behaviour becomes significant. A person expecting potentially unlimited biological life would have much stronger incentives to avoid motorcycles, dangerous sports, violent locations, hazardous occupations, and unnecessary transport exposure.

However, individual caution could not eliminate systemic hazards such as war, major infrastructure failures, or large-scale political collapse.

---

10. Scenario C: Technologically Optimistic Mature Civilisation

Assumptions

- Highly automated transport.
- Extensive use of autonomous safety systems.
- Improved building and infrastructure standards.
- Advanced predictive maintenance.
- Strong occupational automation.
- Rapid emergency response.
- Improved weather and disaster prediction.
- Low homicide and conflict rates.
- Long-term institutional continuity.
- Widespread behavioural adaptation to extremely long expected lifespans.

This trajectory has some empirical basis. Global road mortality has declined modestly relative to 2010, while disaster mortality declined substantially between the 2005–2014 and 2014–2023 periods. A technologically mature civilisation might continue these trends far beyond present levels.

Modelled hazard

$$5\text{–}10 \text{ deaths per } 100\,000 \text{ annually.}$$

Results

Measure	Estimated range
Mean survival	10,000–20,000 years
Median survival	6,931–13,863 years
Probability of surviving 1,000 years	90.5–95.1%

Under these conditions, a non-ageing individual could plausibly survive for tens of thousands of years. Nevertheless, even an annual hazard of 5 per 100,000 eventually produces substantial cumulative mortality.

At the lower bound:

$$S(10\,000) = e^{-0.5} \approx 60.7\%.$$

At the upper bound:

$$S(10\,000) = e^{-1} \approx 36.8\%.$$

Thus, even a very safe civilisation would not automatically produce permanent individual survival.

---

11. Scenario D: Prolonged Instability and Partial Civilisational Decline

Assumptions

- Deteriorating infrastructure.
- Reduced enforcement of safety standards.
- Political fragmentation.
- More frequent regional wars.
- Greater criminal violence.
- Disruption of supply chains and emergency services.
- Increased use of improvised technology.
- Declining quality of medical and rescue systems.
- Recurrent periods of migration and displacement.

Conflict mortality can increase rapidly. Approximately 245,000 battle-related deaths were recorded globally in 2025, making it one of the most violent years since the end of the Cold War. Present-day occupational data also show that some occupations exceed 100 fatalities per 100,000 workers annually.

Modelled hazard

$$100\text{–}300 \text{ deaths per } 100\,000 \text{ annually.}$$

Results

Measure	Estimated range
Mean survival	333–1,000 years
Median survival	231–693 years
Probability of surviving 1,000 years	5.0–36.8%

In this scenario, biological immortality would still increase lifespan substantially relative to present human life, but the benefit would be limited by environmental danger.

The result illustrates that LEV would be most valuable in a stable civilisation. If institutions and infrastructure deteriorated, external mortality could become the principal constraint on lifespan.

---

12. Scenario E: Early Off-World Colonisation and Frontier Exposure

Assumptions

- Settlement on the Moon, Mars, orbital habitats, or other technically hostile environments.
- Dependence on artificial life-support systems.
- High-risk launch and transport operations.
- Radiation exposure.
- Limited emergency medical capacity.
- Isolation and delayed rescue.
- Small, non-self-sufficient settlements.
- Potential resource conflicts.
- Frequent maintenance and construction in hazardous environments.
- Possibility of catastrophic habitat failure.

Contemporary high-risk occupations provide only a lower-bound analogy. In the United States, commercial fishing and logging have recorded fatality rates approaching or exceeding approximately 90–110 deaths per 100,000 workers annually.

Early off-world settlements could be considerably more hazardous because a single technical failure could simultaneously expose many individuals to vacuum, radiation, toxic atmospheres, fire, or loss of life support.

Modelled hazard

$$300\text{–}1\,000 \text{ deaths per } 100\,000 \text{ annually}.$$

This corresponds to annual individual mortality between 0.3% and 1%.

Results

Measure	Estimated range
Mean survival	100–333 years
Median survival	69–231 years
Probability of surviving 1,000 years	approximately 0.005–5.0%

At a 1% annual hazard:

$$E[T] = 100 \text{ years},$$

and:

$$T_{50} \approx 69 \text{ years}.$$

In other words, biological non-ageing would provide little actuarial benefit if the individual continuously inhabited an environment with a persistent 1% annual fatality risk.

A frontier population could therefore possess biological immortality while exhibiting observed lifespans similar to those of present-day humans.

---

13. Comparative Scenario Results

Scenario	Annual external hazard	Mean survival	Median survival	Probability of surviving 1,000 years
Present world: narrow benchmark	46.9 per 100,000	2,131 years	1,478 years	62.6%
Present world: broad benchmark	53.5 per 100,000	1,871 years	1,296 years	58.6%
Stable, affluent, highly cautious society	15–25 per 100,000	4,000–6,700 years	2,773–4,621 years	77.9–86.1%
Technologically mature civilisation	5–10 per 100,000	10,000–20,000 years	6,931–13,863 years	90.5–95.1%

Scenario	Annual external hazard	Mean survival	Median survival	Probability of surviving 1,000 years
Prolonged instability and partial decline	100–300 per 100,000	333–1,000 years	231–693 years	5.0–36.8%
Early off-world frontier environment	300–1,000 per 100,000	100–333 years	69–231 years	approximately 0.005–5.0%

14. Survival Probabilities Across Longer Horizons

The following table applies representative hazard values to several long-term horizons.

Scenario	Hazard per 100,000/year	Survive 100 years	Survive 1,000 years	Survive 10,000 years	Survive 100,000 years
Highly advanced safety regime	5	99.5%	95.1%	60.7%	0.67%
Optimistic mature civilisation	10	99.0%	90.5%	36.8%	0.0045%
Stable and cautious society	20	98.0%	81.9%	13.5%	effectively zero
Present global benchmark	46.9	95.4%	62.6%	0.92%	effectively zero
Prolonged instability	100	90.5%	36.8%	0.0045%	effectively zero
Severe dystopian environment	300	74.1%	5.0%	effectively zero	effectively zero
Extreme frontier environment	1,000	36.8%	0.0045%	effectively zero	effectively zero

These calculations show that survival over 100,000 years would require hazards far below even the optimistic scenarios presented here. A biologically immortal individual would need not only negligible ageing but also an extraordinarily safe and durable civilisation.

15. Interpretation

15.1 Biological immortality is not actuarial immortality

The elimination of ageing changes the scale of life expectancy but does not eliminate mortality. Under present conditions, death would typically occur after millennia rather than decades.

The individual would remain subject to cumulative risk. Even very small annual probabilities become substantial over sufficiently long periods.

15.2 Civilisational conditions become part of longevity medicine

Once ageing is controlled, the main determinants of lifespan would increasingly include:

- transport safety;
- infrastructure reliability;
- occupational safety;
- crime and homicide rates;
- war prevention;
- disaster preparedness;
- emergency medicine;
- political stability;
- technological reliability;
- personal risk behaviour.

In this sense, institutions and infrastructure would become functional components of longevity.

15.3 Individual risk exposure would produce very large differences

Two biologically identical non-ageing individuals could have radically different expected survival times.

One individual living in a stable, automated, low-violence society might have an expected survival of 10,000 years or more. Another working in a dangerous frontier settlement or living through prolonged social collapse might have an expected survival of only 100–300 years.

The relevant quantity would therefore not be a single universal lifespan but an exposure-dependent survival distribution.

15.4 Behaviour would probably change

Present mortality rates reflect people who generally expect to live for several decades. A person expecting thousands of years might behave differently.

Potential adaptations include:

- avoiding high-risk sports;
- avoiding motorcycles and other dangerous transport;

- preferring autonomous transport;
- refusing hazardous occupations;
- relocating away from unstable regions;
- investing heavily in protective technology;
- maintaining redundant residences and evacuation options;
- avoiding unnecessary exposure to conflict and disaster zones.

Such behavioural adaptation could reduce individual hazard below the population average. However, it could not remove systemic or civilisation-wide threats.

---

16. Major Sources of Uncertainty

16.1 Classification uncertainty

External-cause mortality categories overlap. Occupational deaths may also be recorded under transport, falls, burns, or poisoning. Conflict deaths may be counted differently by different institutions.

The categories should therefore not be mechanically added without considering potential overlap.

16.2 Age-standardisation

Current mortality data describe ageing populations. They contain substantial mortality associated with frailty, especially from falls. Applying these rates directly to permanently young individuals may overstate risk.

16.3 Time-varying hazard

The assumption of a constant mortality hazard over thousands of years is unlikely to hold. Future hazards may decline gradually, increase during crises, or alternate between long safe periods and short catastrophic episodes.

16.4 Correlated and systemic risk

The exponential model assumes largely independent individual risk. It does not adequately represent rare events capable of killing large fractions of a population simultaneously, such as:

- global nuclear war;
- severe pandemics not controlled by LEV medicine;
- major asteroid impacts;
- catastrophic technological failures;
- collapse of artificial habitats;
- global infrastructure failure;
- human extinction events.

Such events could dominate survival over extremely long horizons even when ordinary annual accident rates were very low.

16.5 Unknown future technologies

Advanced technologies could reduce ordinary mortality while creating new failure modes. Artificial intelligence, autonomous weapons, molecular manufacturing, synthetic biology, geoengineering, or large-scale space infrastructure could either lower or increase the total hazard.

---

17. Conclusions

Under the assumption that longevity escape velocity eliminates biological ageing but does not protect against external causes of death, the expected survival time can be estimated using contemporary injury and violence mortality.

At the present global external-cause mortality rate, a biologically non-ageing human would have:

- an expected survival time of approximately **1,900–2,100 years**;
- a median survival time of approximately **1,300–1,500 years**;
- approximately a **59–63% probability of surviving 1,000 years**;
- approximately a **1% probability of surviving around 10,000 years**.

The result varies substantially across future scenarios:

- **Stable and cautious society:** approximately 4,000–6,700 years mean survival.
- **Technologically mature civilisation:** approximately 10,000–20,000 years.
- **Prolonged instability or partial collapse:** approximately 333–1,000 years.
- **Early off-world frontier conditions:** approximately 100–333 years.

The most defensible single estimate, assuming present global external mortality remains constant, is therefore approximately:

$$\boxed{2\,000 \text{ years}}$$

This estimate should not be interpreted as a biological limit. It is an actuarial consequence of current environmental risk.

The broader conclusion is that after the elimination of ageing, lifespan would depend less on biology and more on the quality, safety, and long-term stability of civilisation.

Principal Data Sources

1. de Grey, A. D. N. J. “Escape Velocity: Why the Prospect of Extreme Human Life Extension Matters Now.” *PLoS Biology*, 2004.

2. World Health Organization. *Injuries and Violence: Fact Sheet*.

3. World Health Organization. *Global Status Report on Road Safety 2023*.

4. World Health Organization. *Falls: Fact Sheet*.

5. World Health Organization. *Global Status Report on Drowning Prevention*.

6. World Health Organization. *Burns: Fact Sheet*.

7. United Nations Office on Drugs and Crime. *Global Study on Homicide 2023*.

8. Peace Research Institute Oslo and Uppsala Conflict Data Program. *Conflict Trends: A Global Overview, 1946–2025*.

9. United Nations Population Fund. *World Population 2025*.

10. International Labour Organization. Global estimates of fatal occupational accidents and work-related mortality.

11. Centre for Research on the Epidemiology of Disasters. *EM-DAT: 2024 Disasters in Numbers*.

12. United Nations Office for Disaster Risk Reduction. Sendai Framework monitoring data on disaster mortality.

13. Eurostat. *Accidents and Injuries Statistics*.

14. United States Bureau of Labor Statistics. *Census of Fatal Occupational Injuries, 2024*.

15. Chen, Y., et al. “Global, Regional, and National Burden of Falls Among Older Adults.” 2025.