Overview

Reliability theory **developed a part from the mainstream of probability and statistics. It was originally a tool to help nineteenth century maritime insurance and life insurance companies compute profitable rates to charge their customers. Even today, the terms "failure rate" and "hazard rate" are often used interchangeably.**

The failure of mechanical devices such as ships, trains, and cars, is similar in many ways to the life or death of biological organisms. Statistical models appropriate for any of these topics are generically called "time-to-event" models. Death or failure is called an "event", and the goal is to project or forecast the rate of events for a given population or the probability of an event for an individual.

When reliability is considered from the perspective of the consumer of a technology or service, actual reliability measures may differ dramatically from perceived reliability. One bad experience can be magnified in the mind of the customer, inflating the perceived unreliability of the product. One plane crash where hundreds of passengers die will immediately instill fear in a large percentage of the flying consumer population, regardless of actual reliability data about the safety of air travel.

Reliability theory allows researchers to predict the age-related failure kinetics for a system of given architecture (reliability structure) and given reliability of its components. Applications of reliability-theory approach to the problem of biological aging and species longevity lead to the following conclusions:

1. Redundancy is a key of the notion for understanding aging and the systemic nature of aging in particular. Systems, which are redundant in numbers of irreplaceable elements, do deteriorate (i.e., are aging) over time, even if they are built of non-aging elements.
2. Paradoxically, the apparent aging rate or expression of aging (measured as relative differences in failure rates between compared age groups) is *higher* for systems with higher redundancy levels.

3. Redundancy exhaustion over the life course explains the observed 'compensation law of mortality' (mortality convergence at later life, when death rates are becoming relatively similar at advanced ages for different populations of the same biological species), as well as the observed late-life mortality deceleration, leveling-off, and mortality plateaus.

4. Living organisms seem to be formed with a high initial load of damage (HIDL hypothesis), and therefore their lifespan and aging patterns may be sensitive to early-life conditions that determine this initial damage load during early development. The idea of early-life programming of aging and longevity may have important practical implications for developing early-life interventions promoting health and longevity.

5. Reliability theory explains why mortality rates increase exponentially with age (the Gompertz law) in many species, by taking into account the initial flaws (defects) in newly formed systems. It also explains why organisms "prefer" to die according to the Gompertz law, while technical devices usually fail according to the Weibull (power) law. The Gompertz and the Weibull laws are just special cases of this more general failure law.

6. Reliability theory helps evolutionary theories to explain how the age of onset of deleterious mutations could be postponed during evolution, which could be easily achieved by a simple increase in initial redundancy levels. From the reliability perspective, the increase in initial redundancy levels is the simplest way to improve survival at particularly early reproductive ages (with gains fading at older ages). This matches exactly with the higher fitness priority of early

reproductive ages emphasized by evolutionary theories. Evolutionary and reliability ideas also help in understanding why organisms seem to "choose" a simple but short-term solution of the survival problem through enhancing the systems' redundancy, instead of a more permanent but complicated solution based on rigorous repair (with the potential of achieving negligible senescence). Thus there are promising opportunities for merging the reliability and evolutionary theories of aging.

Overall, the reliability theory provides a parsimonious explanation for many important aging-related phenomena and suggests a number of interesting testable predictions. Therefore, reliability theory seems to be a promising approach for developing a comprehensive theory of aging and longevity integrating mathematical methods with specific biological knowledge and evolutionary ideas.