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Methods used in drawing up mortality projections

Mortality projections for social security programs in Canada and the United States

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Abstract

Worldwide, the 20th century brought tremendous reductions in mortality at all ages for both males and females. The reductions in mortality, combined with the aging of the baby-boomers and lower fertility rates is projected to increase the proportion of the Canadian and United States (US). populations that are above age 65 in the coming decades. This paper examines past mortality trends in Canada and the US and discusses how these trends may change over the next 75 years, thus influencing the growth of the elderly population. In addition, this paper describes the methods and assumptions used to project future mortality rates in both countries and presents country-specific results, including assumed annual rates of mortality improvement and projected life expectancies. As well, this paper discusses stochastic time-series methods that are used to help quantify the variability in the mortality rate projections.

1. Introduction

The populations of Canada and the United States are projected to age significantly over the coming decades. Increasing life expectancies, the aging of the baby boomers and lower fertility rates are the predominant factors that will contribute to the increase in the proportion of the elderly. As a result, the population at ages 65 and over is expected to increase significantly over the next 30 years. Older age groups will experience even higher rates of growth.

Prospects of longer life are viewed as a positive change for individuals and a substantial social achievement, but often lead to concern over their implications for public spending on old-age support. The projected cost of public pensions in Canada and the United States is directly linked to the expected growth in the elderly population. In turn, the growth in the elderly population depends on how current mortality is assumed to evolve over the long-term horizon. The projection of mortality thus becomes a key element of any population projection.

The purpose of this report is to present an overview of the methods and assumptions used for projecting the mortality component of the population projections which in turn are used in estimating the financial status of the Old Age Security (OAS) Program and Canada Pension Plan (CPP) in Canada as well as the Old Age, Survivors, and Disability Insurance (OASDI) program in the United States.

In Canada, the OAS pension is a monthly benefit available to most Canadians 65 years of age or older who meet certain residence and income requirements. The Canadian OAS program includes a Guaranteed Income Supplement which is a monthly benefit paid to residents of Canada who receive the basic, full or partial OAS pension and who have little or no other income. In addition, the CPP pays a monthly retirement pension to people who have worked and contributed to the CPP. The CPP also acts as an insurance plan, providing disability and survivor benefits for those who qualify. The CPP provides monthly income in case of disability and provides a monthly income to surviving spouses or common-law partners in case of death.

In the United States, the OASDI program provides monthly benefits to qualified retired and disabled workers and their dependents and to survivors of insured workers. Eligibility and benefit amounts are determined by the worker's earnings that are covered under the program. Benefits are designed to replace a portion of earnings prior to retirement, disability, or death and are paid as an earned right to workers, their families, and their survivors. There is no means test to qualify for benefits.

The methods and assumptions described in this report reflect those included in the most recent actuarial reports on each of these Canadian and US social security programs. Canada and the US use very similar methodology in making mortality projections. The mortality projections cover a long-time horizon (75 years) and place more emphasis on historical trends than on short-term trends.

2. General population mortality trends

Worldwide, the 20th century brought tremendous gains in life expectancies at all ages for both males and females. Relative to the entire period of the existence of man, the twentieth century was a time of exceptionally rapid rates of decline in mortality. Based on mortality in 1901, roughly 50% of the Canadian population and 60% of the US populations would have died before reaching age 65. Based on mortality today, less than 20% of the Canadian and US populations would die before reaching age 65. Over the last century, life expectancy at birth increased by an estimated 27.9 years in Canada and an estimated 27.4 years in the US with most of the change occurring before 1950. Life expectancy at age 65 also increased dramatically, but in contrast to life expectancy at birth, most of the change occurred after 1950.

2.1. Mortality trends in Canada

The main reason for the slowdown in the rise of life expectancy at birth is due to the fact that infant and child mortality rates have declined significantly. Vaccinations and other medical interventions, together with improved sanitation and overall quality of life have all contributed substantially to reducing infant and child mortality. As a result, younger ages have already experienced most of the increase in life expectancy they are likely to see. Since mortality in the early years of life is very low, it is more difficult to raise life expectancy at birth.

The gap between female and male life expectancies at birth increased to reach over seven years by the mid-1970s. Since then, the gap has been narrowing as males have made greater gains in life expectancy compared to females. The gap between female and male life expectancies at age 65 has also narrowed but only more recently. Most experts agree that the rapid increase in life expectancy at birth that occurred during the 20th century will not continue and that future increases in life expectancy will have to take place at older ages as opposed to younger ages.

Table 1. *Canada: Life expectancy at birth and age 65*

	Life expectancy at birth			Life expectancy at age 65		
Year	**Males**	**Females**	**Difference**	**Males**	**Females**	**Difference**
1901	51.4	51.8	0.4	14.2	14.8	0.6
1921	56.9	58.3	1.4	13.3	13.8	0.5
1931	60.0	62.1	2.1	13.0	13.7	0.7
1941	63.0	66.3	3.3	12.8	14.1	1.3
1951	66.4	70.8	4.4	13.3	15.0	1.7
1956	67.6	72.9	5.3	13.4	15.6	2.2
1961	68.4	74.2	5.8	13.5	16.1	2.6
1966	68.8	75.2	6.4	13.6	16.7	3.1
1971	69.4	76.4	7.0	13.7	17.5	3.8
1976	70.2	77.5	7.3	14.0	18.0	4.0
1981	71.9	78.9	7.0	14.6	18.8	4.2
1986	73.0	79.7	6.7	14.9	19.1	4.2
1991	74.6	80.9	6.3	15.7	19.9	4.2
1996	75.4	81.2	5.8	16.0	19.9	3.9
2001	76.9	82.0	5.1	17.0	20.5	3.5
2006*	78.2	82.7	4.5	17.7	20.9	3.2

* Estimate.

2.2. Mortality trends in the United States

Over the last century in the US, dramatic advancements were made in medicine (vaccinations and other medical interventions) and in the standard of living (improved sanitation and overall quality of life). In addition, access to medical services was greatly expanded through the Medicare and Medicaid programs for the old, frail, and disadvantaged, those who account for the vast majority of deaths in the population. As in Canada, increases in life expectancy at birth were much greater in the first part of the twentieth century due to substantial reductions in death rates at young ages.

In the US, the gap between female and male life expectancies at birth was 3.0 years in 1901. This difference increased to 6 years in the mid-1950's. From the mid-1950's through the late 1960's, male life expectancy at birth remained level, while female life expectancy at birth increased moderately, resulting in the gap between female and male life expectancies at birth reaching a peak of 7.7 years in 1970. After 1970, the gap stabilized in the 1970's and then began narrowing after 1979, as males made greater gains in life expectancy compared to females. The gap at birth reached 5.3 years in 2002.

The gap between female and male life expectancies at age 65 has also narrowed but only more recently. In 1901, the gap was less than one year, reached a little over two years in 1950, peaked at almost five years around 1975, and then decreased to around three years in 2002.

Table 2. *US: Period life expectancy at birth and age 65*

Calendar Year	Life expectancy at birth			Life expectancy at 65		
	Male	**Female**	**Difference**	**Male**	**Female**	**Difference**
1901	47.9	50.9	3.0	11.3	12.0	0.7
1921	57.3	59.3	2.0	12.2	12.8	0.6
1931	58.6	62.0	3.5	12.0	13.1	1.1
1941	61.9	66.5	4.6	12.2	13.8	1.6
1951	65.7	71.4	5.7	12.8	15.2	2.3
1956	66.7	72.9	6.2	13.0	15.7	2.6
1961	67.1	73.6	6.6	13.1	16.1	3.0
1966	66.7	73.9	7.2	12.9	16.3	3.5
1971	67.4	75.1	7.7	13.1	17.1	4.0
1976	69.1	76.8	7.7	13.8	18.1	4.3
1981	70.4	77.9	7.5	14.2	18.6	4.3
1986	71.1	78.3	7.2	14.5	18.7	4.1
1991	72.0	79.0	7.0	15.2	19.2	4.0
1996	73.0	79.2	6.2	15.5	19.1	3.6
2001	74.1	79.5	5.3	16.1	19.1	3.0
2002	74.2	79.5	5.3	16.2	19.1	2.9

3. Mortality projections for social security programs in Canada

3.1. Methodology and assumptions for general population mortality projections

The methodology and assumptions used to make mortality projections that are presented in this section are taken from the 21st Actuarial Report on the Canada Pension Plan as at 31 December 2003 ("21st CPP Actuarial Report"). The "best-estimate" mortality assumptions reflect the best judgement of the Chief Actuary of the CPP as to the future pattern of mortality by age and sex of the Canadian population.

3.1.1. Annual rates of mortality improvement

The starting point for mortality rate projections are the mortality rates from the Statistics Canada publication "Life Tables, Canada, provinces and territories, 1995-1997". According to these tables, life expectancies at birth for males and females in Canada were 75.4 and 81.2 years, respectively for the period 1995-1997. The most recent 2000 to 2002 Life Tables were not yet available at the time the 21st CPP Actuarial Report was published in 2004.

The methodology used to project mortality rates into the future involves making assumptions about annual rates of mortality improvement by age and sex. Historical average annual rates of mortality improvement by age group and sex for Canada for various historical time periods are presented in Tables 3 and 4. Since annual rates of mortality improvement have varied significantly by age and sex in the past, future mortality is projected using separate annual rates of mortality improvement by age and sex.

The historical annual rates of mortality improvement presented were derived by fitting a least squares regression line to the logarithm of central death rates. The central death rate for a calendar year is defined as the ratio of the number of deaths in the year to the corresponding population as at July 1st of that year. The annual rate of mortality improvement is then derived from the slope of the fitted regression line.

Table 3. *Canada: Historical average annual rates of mortality improvement (Males)*

Age	1931 - 2001	1931 - 1966	1966 - 2001	1971-1981	1981-1991	1991 - 2001	1996 - 2001
0-14	4.2%	4.2%	4.3%	5.1%	3.8%	2.9%	2.2%
15-64	1.1%	0.7%	2.1%	1.8%	2.3%	2.6%	2.7%
65-89	0.7%	0.4%	1.2%	1.2%	1.2%	1.6%	2.6%

Table 4. *Canada: Historical average annual rates of mortality improvement (Females)*

Age	1931 - 2001	1931 - 1966	1966 - 2001	1971-1981	1981-1991	1991 - 2001	1996 - 2001
0-14	4.2%	4.4%	4.1%	5.2%	3.5%	2.7%	2.7%
15-64	2.0%	2.6%	1.7%	1.8%	1.8%	1.6%	2.0%
65-89	1.4%	1.1%	1.3%	2.0%	1.2%	0.8%	1.7%

Mortality rates for the year 2001 are projected by assuming annual rates of mortality improvement for years 2002 and thereafter. Historical trends over the last 70 years reveal that annual rates of mortality improvement for females younger than age 65 have been lower over the last 36 years (1966-2001) than they have been over the previous 36 years (1931-1966) and about the same over the two periods for ages 65 to 89. Over the last 36 years, male improvement rates for ages 15 and over have been higher than for females and this explains why the gap in life expectancy between males and females has narrowed considerably since the late 1970s.

When looking at the trends decade by decade over the last 30 years it is observed that rates of mortality improvement for both males and females have significantly decreased for ages below 15 from levels of about 5% per year in the 1970s to about 3% per year in the 1990s. For ages 15 to 64 the rates of improvement for females have been relatively stable at about 2% per year and lower than the 2.5% rate for males over the last 20 years. The rate of improvement increased significantly for males aged 15 to 64 between the 1970s and 1980s but has remained stable since then at 2.5% per year. Rates of improvements for ages 65 to 89 over the last 30 years have been decreasing for females (although some increase has been observed in the last five years) while for males the rates have been increasing higher than for females over the last 10 years.

Due to the uncertainty that exists with respect to future mortality improvements, it was assumed that annual rates of mortality improvement for the first five years of the projection period would be similar to those experienced recently. Thus, for years 2002 to 2006, annual rates of mortality improvement are assumed to vary by age and sex and are set equal to the smoothed average annual rates of mortality improvement experienced over the period 1991 to 2001.

Annual rates of mortality improvement after the first five years of the projection period reflect both long-term historical trends and an eventual reduction in the rates of improvement at older ages since it may well become more difficult to eradicate the causes of death at those ages. The slowdown in annual rates of mortality improvement after 2006 is assumed to occur linearly over a period of 20 years. The ultimate rates for years 2026 and thereafter are assumed to vary by age and sex only and not by calendar year. The ultimate rates were derived from an analysis of the experience in Canada and the US over the last century. The ultimate annual mortality improvement rates rely on the assumption that causes of death and general medical treatment in North America should not differ much in the future between the two countries and that the gap between US and Canadian mortality should reduce over the projection period.

The following describes how the ultimate rates of mortality improvement are derived by age group.

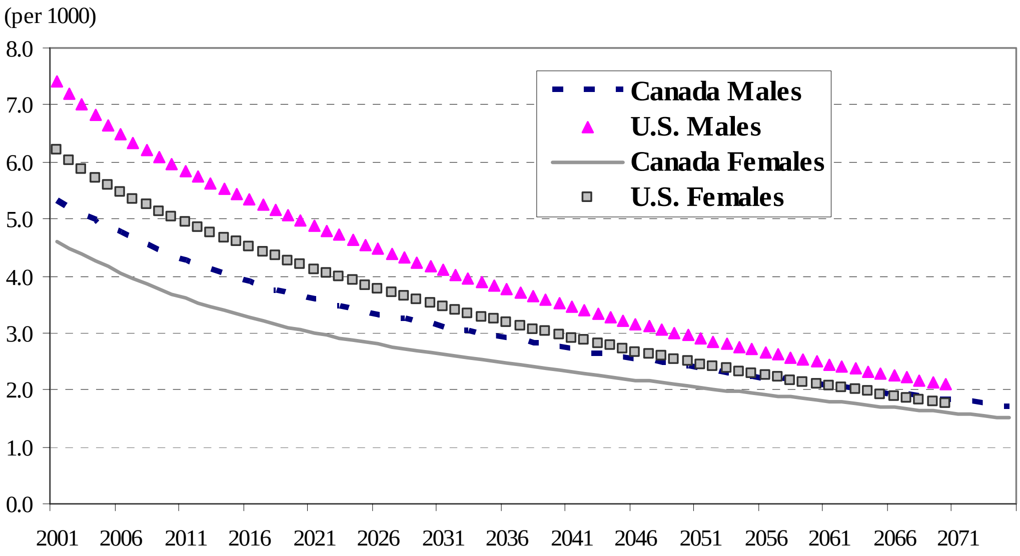
Ultimate rates of improvement from birth to age 1

Canadian mortality is lower than US mortality for the first year of life. Under the assumption that Canadian and US mortality will converge over time, it is assumed that the ultimate annual rate of mortality improvement is 1.35% for males and 1.25% for females. These rates are lower than the ultimate rate of 1.7% for males and females assumed in the 2003 OASDI Trustees Report. As a result, the gap between Canadian and US mortality is projected to reduce over time.

Table 5. *Ultimate annual rates of mortality improvement (Birth to age 1)*

	Canada	**US**
Males	1.35%	1.7%
Females	1.25%	1.7%

Chart 1. *Projected mortality rates (Birth to age 1)*



Ultimate rates of improvement for ages 1-14

Most deaths in this age group occur due to accidents and unintentional injuries, followed by cancer and congenital anomalies. Under the assumption that Canadian and US mortality will converge over time, it is assumed that the ultimate annual rate of mortality improvement is 0.95% for males and 0.85% for females. These rates are lower than the ultimate rates of 1.2% for males and 1.3% for females assumed in the 2003 OASDI Trustees Report, and as such, the gap between Canadian and US mortality is projected to reduce over time.

Table 6. *Ultimate annual rates of mortality improvement (Ages 1-14)*

	Canada	US
Males	0.95%	1.2%
Females	0.85%	1.3%

Ultimate rates of improvement for ages 15-44

For the age group 15 to 24, about three quarters of all male deaths are due to accidents and suicide. For the age group 25 to 44, cancer is the leading cause of death for females, while unintentional injuries are still the predominant cause of death for males. For females, medical breakthroughs should bring some more improvements, but mortality rates are already very low. Under the assumption that Canadian and US mortality will converge over time, it is assumed that the ultimate annual rate of mortality improvement is 0.8% for males and 0.7% for females. The rate for males is lower than the ultimate rate of 0.9% assumed in the 2003 OASDI Trustees Report while for females the rate is the same at 0.7%. The gap between Canadian and US mortality is thus projected to reduce more so for males than females.

Table 7. *Ultimate annual rates of mortality improvement (Ages 15-44)*

	Canada	US
Males	0.8%	0.9%
Females	0.7%	0.7%

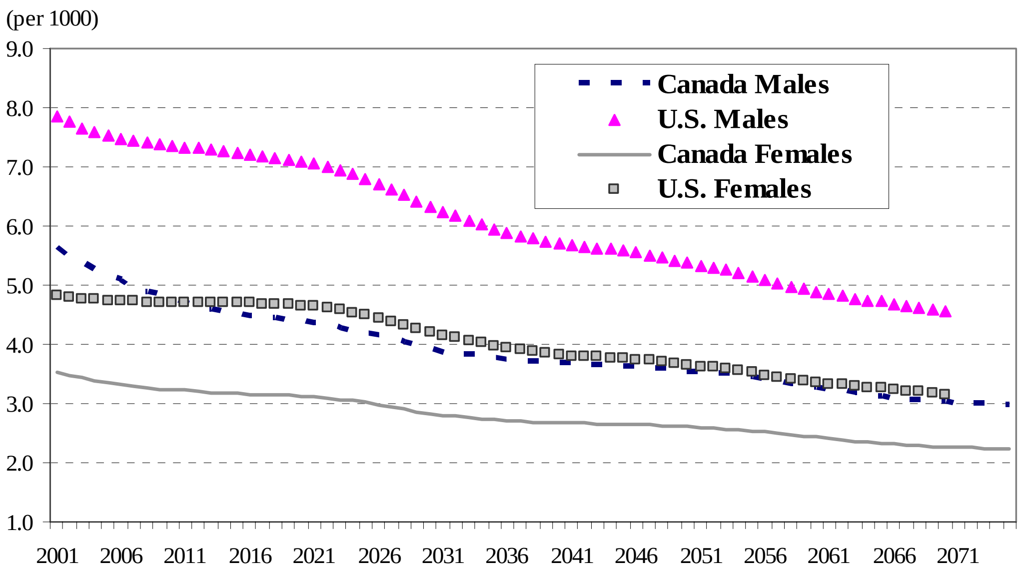
Ultimate rates of improvement for ages 45-64

Cancer is the leading cause of death for both sexes in this age group. Therefore, improvements will come mainly from medical breakthroughs. There is more room for male mortality to improve compared to female mortality because mortality rates of males are higher than for females. Assuming convergence in Canadian and US mortality, the ultimate improvement rates are set at 0.65% for males and 0.55% for females. These rates are lower than the ultimate rates of 0.8% for males and 0.7% for females assumed in the 2003 OASDI Trustees Report, and so the gap between Canadian and US mortality is projected to reduce over time.

Table 8. *Ultimate annual rates of mortality improvement (Ages 45-64)*

	Canada	US
Males	0.65%	0.8%
Females	0.55%	0.7%

Chart 2. *Projected mortality rates (Ages 45-64)*



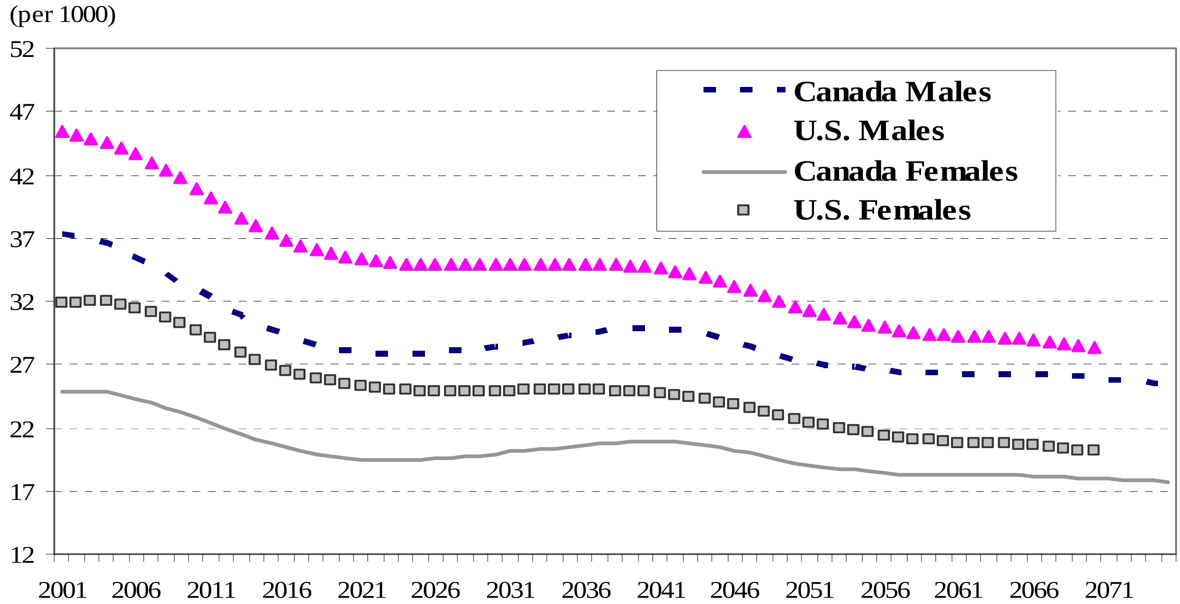
Ultimate rates of improvement for ages 65-84

For this age group, heart disease is the leading cause of death for both sexes. In this group, improvements will come mainly from medical breakthroughs and lifestyle changes. Assuming convergence in Canadian and US mortality, the ultimate improvement rates are assumed at 0.5% for males and females. These rates are lower but consistent with the 2003 OASDI Trustees Report assumption where male and female ultimate rates are set at the same level of 0.7%. As for the younger age groups, the gap between Canadian and US mortality is thus projected to reduce over time.

Table 9. *Ultimate annual rates of mortality improvement (Ages 65-84)*

	Canada	US
Males	0.5%	0.7%
Females	0.5%	0.7%

Chart 3. *Projected mortality rates (Ages 65-84)*



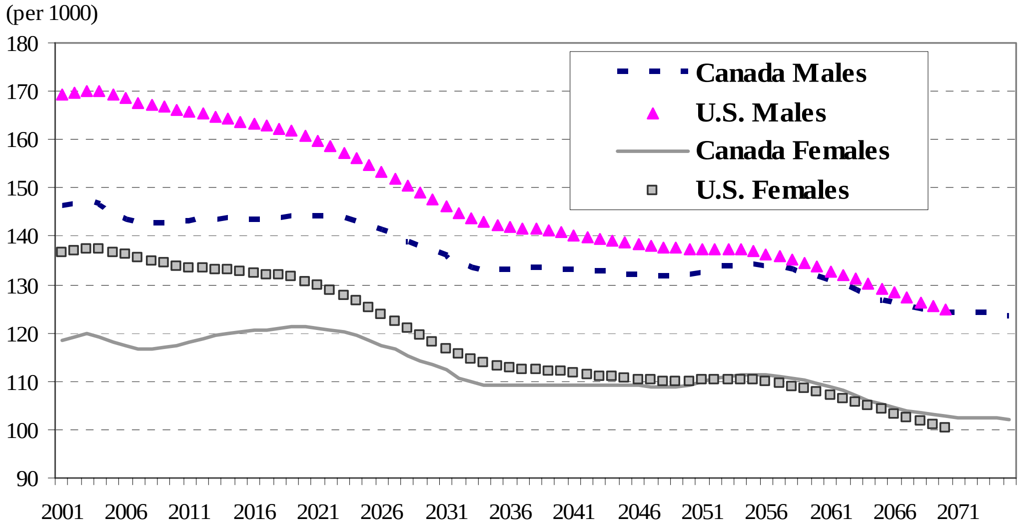
Ultimate rates of improvement for ages 85-99

For the segment of the population at the advanced ages, data quality is a major concern. Historical US death rates have been lower than Canadian death rates until recently. Assuming that Canadian and US mortality will converge over time, the ultimate improvement rates are set at 0.4% for both males and females. Although the ultimate improvement rate of 0.4% seems low compared to other ages, it is nevertheless higher than what has been experienced in the past fifteen years.

Table 10. *Ultimate annual rates of mortality improvement (Ages 85-99)*

	Canada	US
Males	0.4%	0.6%
Females	0.4%	0.6%

Chart 4. *Projected mortality rates (Ages 85-99)*



Ultimate rate of improvement for ages 100 and older

For this age group, the ultimate rate of mortality improvement is assumed at 0.25%, which is higher than what has been experienced in the past. The assumption reflects that the experience is relatively limited at those ages.

Table 11. *Ultimate annual rates of mortality improvement (Ages 100+)*

	Canada	US
Males	0.25%	0.6%
Females	0.25%	0.6%

Finally, improvement rates for years 2007 to 2025 were obtained by linear interpolation between the improvement rates of year 2006 and the ultimate improvement rates described above in respect of the period 2026 and thereafter.

Annual rates of mortality improvement are projected to decrease with age. This was judged to be consistent with historical experience. One reason for declining improvements with age is that diseases at the younger ages are, by and large, easier to overcome than those at the older ages. To eradicate the major diseases affecting the older population, including heart and respiratory diseases, cancer, stroke, diabetes and dementia will take more time, as there is still much to be learned. Table 12 summarizes the assumptions.

Table 12. *Canada: Assumed annual rates of mortality improvement*

Age	Males 2002-2006	Males 2026+	Females 2002-2006	Females 2026+
	%	%	%	%
0	2.25	1.35	2.50	1.25
1-14	3.89	0.95	3.36	0.85
15-44	3.13	0.80	1.51	0.70
45-64	2.50	0.65	1.64	0.55
65-84	1.80	0.50	1.06	0.50
85-99	0.11	0.40	0.03	0.40
100+	0.00	0.25	0.00	0.25

3.1.2. Projection results

This section presents the projected mortality rates by age and sex along with other resulting mortality measures.

Table 13 reveals that the projected mortality rates show a continuous decrease over the long term. For example, the mortality rate for a 65 year old male is expected to decline from 14.8 deaths per 1,000 people in 2004 to 7.8 deaths per 1,000 people in 2075. The gap between male and female mortality rates for a given age is also expected to decrease over the long term.

Table 13. *Canada: Mortality rates (Annual deaths per 1,000 people)*

Age	Males				Females			
	2004	2025	2050	2075	2004	2025	2050	2075
0	5.0	3.4	2.4	1.7	4.3	2.8	2.1	1.5
10	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0
20	0.8	0.5	0.4	0.3	0.3	0.2	0.2	0.2
30	0.9	0.5	0.4	0.4	0.4	0.3	0.2	0.2
40	1.5	1.0	0.8	0.7	0.9	0.7	0.6	0.5
50	3.3	2.4	2.0	1.7	2.1	1.7	1.5	1.3
60	8.8	6.0	5.1	4.3	5.5	4.2	3.7	3.2
65	14.8	10.4	9.0	7.8	8.9	7.1	6.3	5.5
70	24.4	18.0	15.9	14.0	14.3	12.0	10.6	9.3
75	39.2	30.2	26.6	23.5	23.6	19.7	17.4	15.4
80	64.3	52.8	46.6	41.1	41.3	35.2	31.1	27.4
85	104.6	94.1	84.3	75.5	73.5	68.1	61.0	54.6
90	161.8	154.0	139.3	126.0	126.9	122.1	110.5	100.0
100	368.1	357.4	330.7	306.0	309.8	300.8	278.3	257.6

Life expectancies for Canadians are assumed to continue to grow, but at a slower rate than was experienced in the 20th century. For the period 2004 to 2075, life expectancy for a male newborn is expected to increase from 77.8 years to 83.4 years. For female newborns, this increase is projected to be from 82.5 years to 86.5 years. These expectations assume no mortality improvements. If, however, future mortality improvements are included, then the increases are from 82.9 to 86.8 for males and from 86.3 to 89.7 for females over the same period. Given the continuing trend toward greater longevity, life expectancies with future mortality improvements are considered to be more realistic than without.

Life expectancies have considerably increased over the last 25 years, and this is reflected in the projected growth in the near term. Thereafter, there is a projected slowdown in life expectancy growth consistent with the low rates of improvement in mortality assumed for years 2026 and thereafter. It is also expected that the gap in life expectancies between females and males will continue to narrow over time; however, it is not anticipated that this gap will altogether disappear.

A comparison between life expectancies with and without mortality improvements after the specific years is presented in Tables 14 and 15. Table 14 shows the projected life expectancies at various ages for selected years, assuming no mortality improvements after the specific years, while Table 15 shows the same life expectancies, but with all mortality improvements included. The historical and projected evolution of life expectancies at birth for males and females, with mortality and without mortality improvements after the specific years, is displayed in Chart 5, and a similar evolution at age 65 is displayed in Chart 6.

Mortality improvements have more of an impact on increasing expected lifetimes at younger ages than at older ages, since the improvement factors decrease with age. For instance, by 2075, mortality improvements lead to more than a 3-year increase in expected lifetimes for both male and female newborns, compared to those without such improvements (that is, 86.8 minus 83.4, or 3.4 years for males and 89.7 minus 86.5, or 3.2 years for females). At age 30, this increase falls to 2 years for both sexes, and by age 85, it falls to 0.1 year.

Table 14. *Canada: Life expectancies, without improvements after the year shown**

	Males				Females			
Age	**2004**	**2025**	**2050**	**2075**	**2004**	**2025**	**2050**	**2075**
0	77.8	80.7	82.0	83.4	82.5	84.1	85.3	86.5
10	68.3	71.0	72.3	73.6	73.0	74.4	75.6	76.7
20	58.5	61.1	62.4	63.7	63.1	64.5	65.6	66.7
30	48.9	51.4	52.7	53.9	53.3	54.7	55.8	56.8
40	39.4	41.7	42.9	44.1	43.5	44.9	45.9	47.0
50	30.1	32.3	33.4	34.5	34.0	35.3	36.3	37.3
60	21.4	23.3	24.3	25.3	25.0	26.1	27.1	28.0
65	17.5	19.1	20.0	20.9	20.8	21.7	22.6	23.5
70	13.9	15.2	16.0	16.8	16.8	17.6	18.4	19.2
75	10.8	11.7	12.4	13.1	13.1	13.8	14.5	15.2
80	8.0	8.6	9.2	9.8	9.8	10.3	10.9	11.5
85	5.9	6.1	6.6	7.1	7.1	7.3	7.8	8.3

* These are calendar year life expectancies based on the mortality rates of the given attained year.

Table 15. *Canada: Life expectancies, with improvements after the year shown***

Age	Males 2004	Males 2025	Males 2050	Males 2075	Females 2004	Females 2025	Females 2050	Females 2075
0	82.9	84.2	85.5	86.8	86.3	87.4	88.6	89.7
10	72.9	74.0	75.3	76.5	76.3	77.3	78.4	79.5
20	62.5	63.7	64.9	66.2	66.0	66.9	68.1	69.1
30	52.3	53.4	54.7	55.9	55.7	56.6	57.7	58.8
40	42.1	43.3	44.5	45.6	45.4	46.4	47.5	48.6
50	32.2	33.4	34.5	35.6	35.4	36.4	37.5	38.5
60	22.7	24.0	25.0	26.0	25.9	26.8	27.8	28.8
65	18.4	19.6	20.5	21.4	21.4	22.3	23.2	24.1
70	14.5	15.5	16.4	17.2	17.2	18.0	18.8	19.7
75	11.0	11.9	12.7	13.4	13.3	14.0	14.8	15.5
80	8.1	8.8	9.4	10.0	9.9	10.4	11.1	11.7
85	5.9	6.2	6.7	7.2	7.1	7.4	7.9	8.4

** These are cohort life expectancies that take into account future improvements in mortality and therefore differ from calendar year life expectancies, which are based on the mortality rates of the given attained year.

Chart 5. *Canada: Male and female life expectancy at birth*

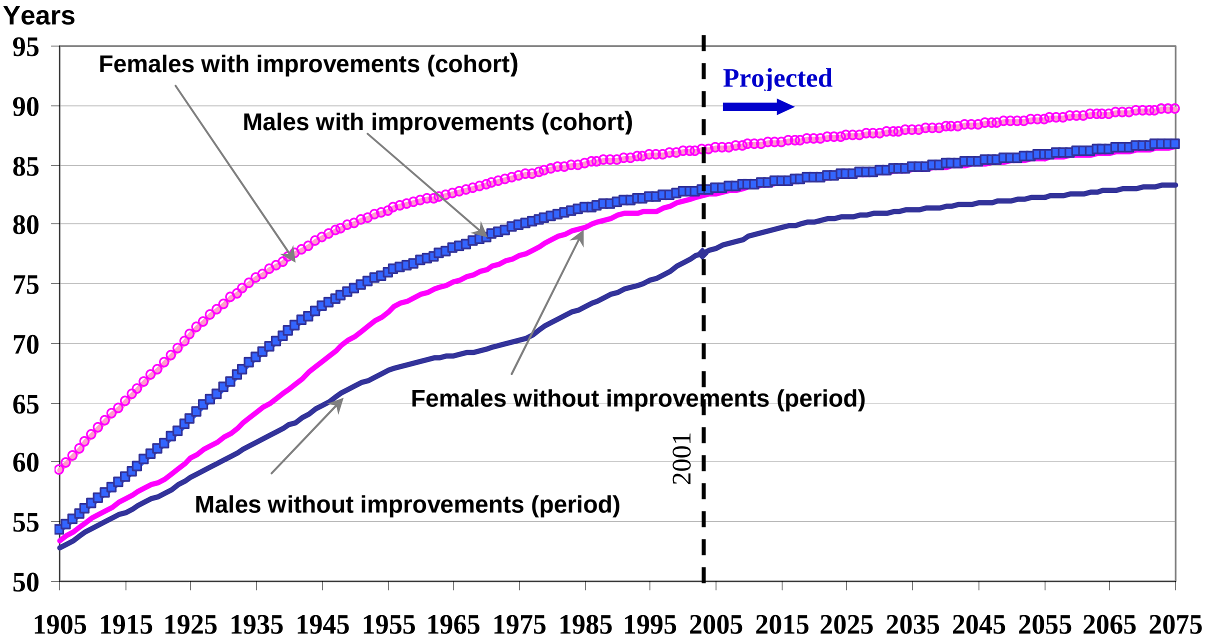
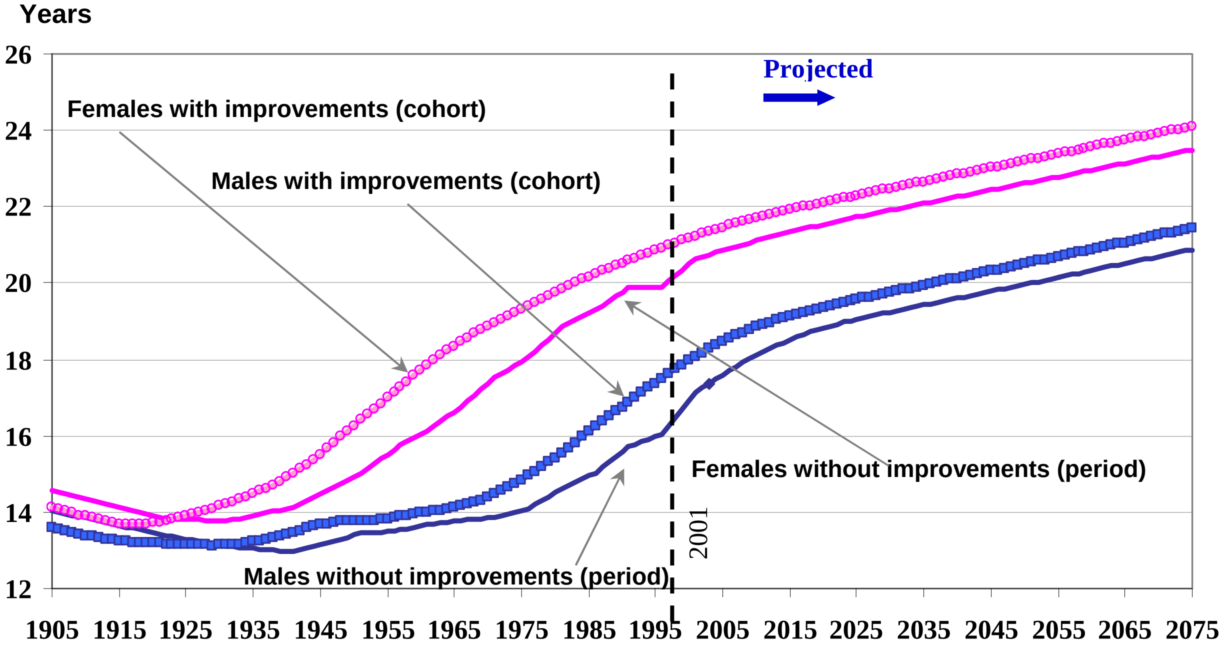
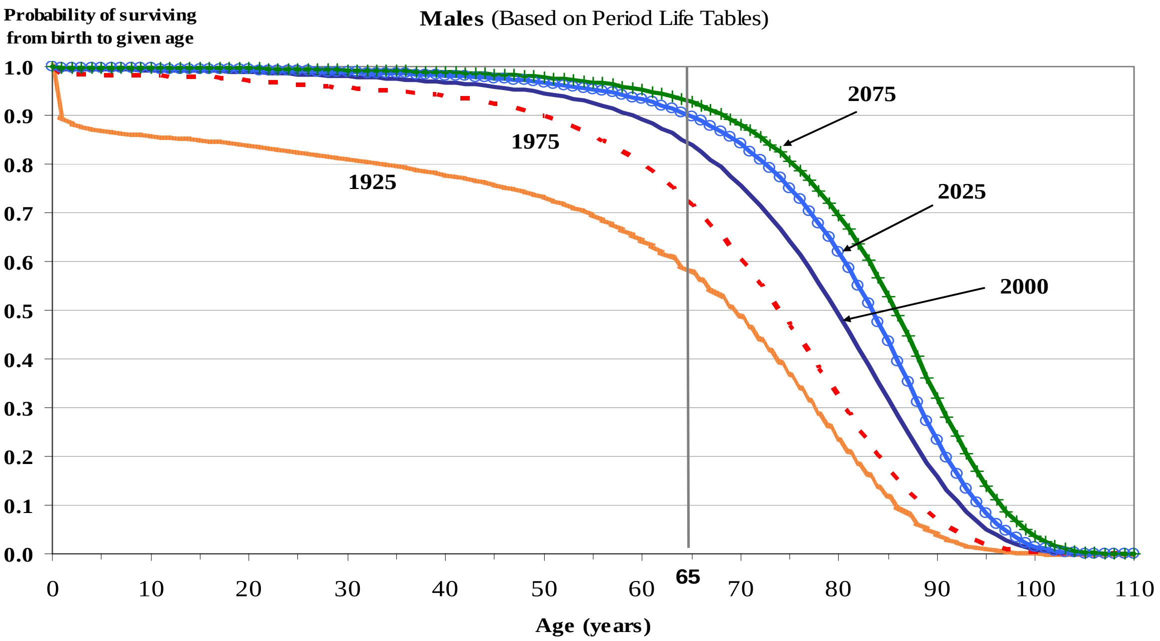


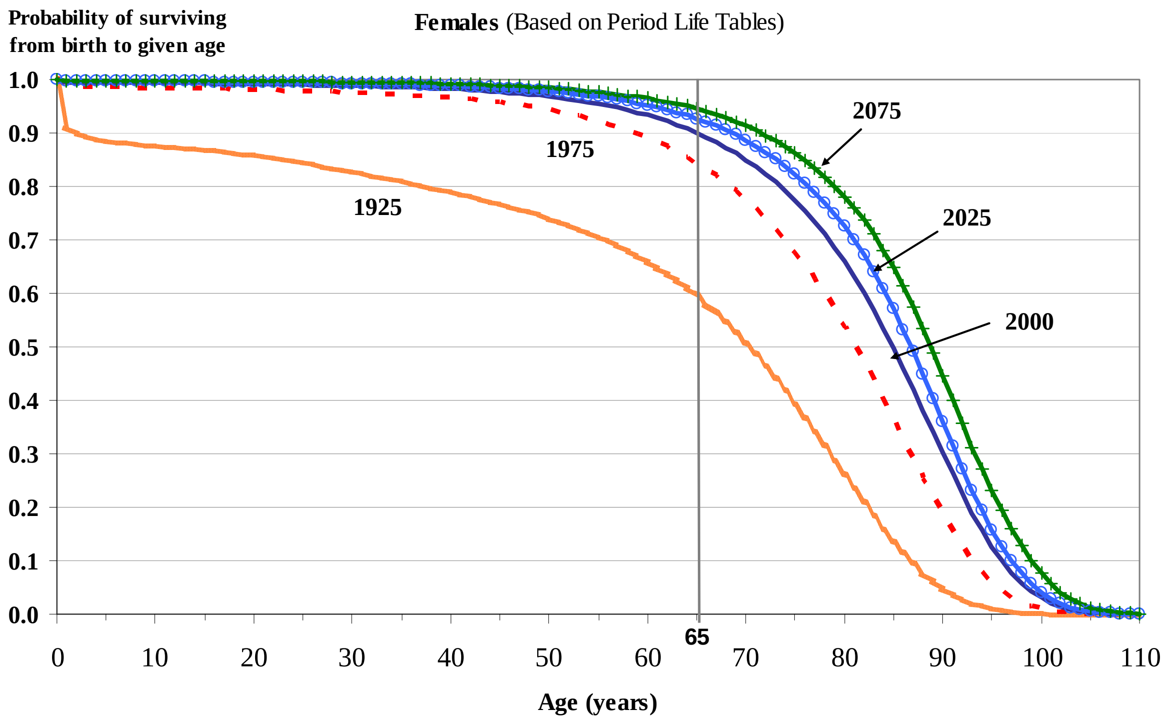
Chart 6. *Canada: Male and female life expectancy at age 65*



The low probabilities of a newborn reaching a very advanced age can be seen by the survival curves at birth as illustrated in Chart 7. A survival curve at birth represents the probability of a newborn reaching a given age. The "squaring" of the survival curves over time from 1925 to 2075 is the result of expected lifetimes increasing and the maximum age that can be attained being about 120 years. Note from the following two graphs that the probability of surviving from birth to ages beyond 110 is practically zero.

Chart 7. *Canada: Survival curves at birth*





As indicated in the graphs by the intersection of the vertical lines at age 65 with the survival curves, the probability of reaching age 65 increased substantially in the past. Based on period life tables of 1925, males had a probability of 58% of reaching age 65. By 2000, this figure had increased to 85%, and by 2075 it is projected to reach 93%. For females, the probability of reaching age 65 was 60%, increased to 91% by 2000, and is projected to reach 95% by 2075. In general, probabilities of surviving to older ages have increased over the last century and this trend is expected to continue at a slower pace.

Another perspective on viewing the aging of the population is to consider the median age at death and the proportion of deaths over time (see Tables 16 and 17). It is projected that deaths resulting from those aged 85 and older will eventually comprise the largest proportion of deaths compared to the younger age groups shown, as the proportions of younger age groups decline. By 2075, over 57% of all deaths will result from those aged 85 and older. Correspondingly, the median age at death for both sexes is projected to increase well above age 85 by 2075.

Table 16. *Canada: Median age at death*

Year	Males	Females
1925	71	72
1950	74	78
1975	75	83
2000	81	86
2025	85	88
2050	86	89
2075	87	90

Table 17. *Canada: Distribution of deaths, number and proportion*

Calendar year/ Age group	Deaths					Proportion of deaths (%)				
	0-64	65-74	75-84	85+	Total	0-64	65-74	75-84	85+	Total
1925	72,000	15,400	14,300	5,700	107,400	67.0	14.3	13.3	5.3	100.0
1950	58,400	28,000	26,000	11,400	123,700	47.2	22.6	21.0	9.2	100.0
1975	61,200	37,500	41,000	27,200	167,000	36.7	22.4	24.6	16.3	100.0
2000	48,700	43,300	66,500	59,600	218,100	22.3	19.9	30.5	27.3	100.0
2025	45,300	63,500	102,100	122,300	333,200	13.6	19.1	30.7	36.7	100.0
2050	40,000	61,100	131,600	276,600	509,400	7.9	12.0	25.8	54.3	100.0
2075	35,800	54,500	136,200	303,500	530,100	6.8	10.3	25.7	57.3	100.0

It is also interesting to consider over time the range of ages in which a given percentage of deaths are expected to occur. For instance, Table 18 shows the progression over time of the age range in which 70% of deaths are expected to occur. The historical large gains in life expectancy can be seen from this table. Based on period life tables of 1925, about 70% of males could expect to die between the ages of 17 and 83; that is, 15% of males died prematurely before age 17 while 15% who were the strongest died after age 83. By 2000, this range had both moved forward and narrowed to an age range of 65 to 91. A similar shift and narrowing in range can be seen for females. Again, this trend is expected to continue in the future, but at a slower pace compared to the past.

Table 18. *Canada: Evolution of age range in which given percentage of deaths occur*

Year	Male range			Female range		
	15%	70%	15%	15%	70%	15%
1925	(0-16)	(17-83)	(84+)	(0-23)	(24-84)	(85+)
1950	(0-49)	(50-85)	(86+)	(0-55)	(56-87)	(88+)
1975	(0-55)	(56-86)	(87+)	(0-63)	(64-91)	(92+)
2000	(0-64)	(65-91)	(92+)	(0-70)	(71-94)	(95+)
2025	(0-68)	(69-92)	(93+)	(0-72)	(73-95)	(96+)
2050	(0-70)	(71-94)	(95+)	(0-73)	(74-96)	(97+)
2075	(0-71)	(72-95)	(96+)	(0-75)	(76-97)	(98+)

Although life expectancies are projected to increase in the future, it is plausible that health and environmental factors may counteract the degree of this increase. The rising incidence of obesity in both children and adults and the ensuing risk of related complications later on in life, such as diabetes and heart disease, could act to reduce future projected gains in life expectancy. The threat of worldwide pandemics resulting from more virulent forms of infectious diseases is also a reality, which could impact longevity.

3.2. Stochastic process

A new methodology has been developed for determining the evolution, as well as volatility, of mortality rates. The mortality rates will be analyzed using a stochastic time series model. In a stochastic process, random variation is present, which is generally based on fluctuations observed in historical data, compared to a fitted model, for a selected period prior to the current year being modeled. A stochastic time series model may include the variable's prior-period values, prior-period error terms, and a random error term. The distribution of potential outcomes comes from a large number of simulations, each with random variation in the variables. Variable states at a particular point in time are not described by unique values, but rather by probability distributions, increasing the information available relative to the deterministic model.

Annual historical mortality rates are calculated for 40 age-sex groups (under 1, 1-4, 5-9, 10-14,…80-84, 85-89, 90+; male and female) for the period 1926-2003 as the ratio of annual deaths to the population for each age-sex group. Data for the annual numbers of deaths and the Canadian population were obtained from Statistics Canada. The first year of data available for the analysis is 1926.

The time series model selected to reproduce the annual mortality rates is a log ARIMA (0, 1, 0), which is the difference of consecutive logged terms. This model was selected because the resulting series after logging and differencing consecutive terms is stationary and an analysis of the fit statistics, including R2, for all age-sex groups indicate that this model provides a very close fit to the actual data. Other time series models were tested, but none provided as good a fit as the log ARIMA(0, 1, 0). In fact, the R2 value for all but one age-sex group was above 0.9. As well, the use of the log transformation eliminates the need for a lower bound of zero, since logged mortality rates will always remain positive.

The general form of the equation used is:

$$\ln(Y_{k,t}) = \ln(Y_{k,t-1}) + \mu_k + \varepsilon_{k,t}$$

Thus,

$$Y_{k,t} = Y_{k,t-1} e^{\mu_k} e^{\varepsilon_{k,t}}$$

where: $Y_{k,t} =$ number of deaths per 1000 for group k in year t

$\mu_k =$ the mean of the transformed series (i.e. logged and differenced series)

$\varepsilon_{k,t} =$ a random error for group k in year t

Although the mortality rates of one group are not dependent upon the mortality rates of other groups, there is certainly a degree of correlation among groups. This correlation must continue to be reflected in the projected rates and is done so by correlating the error terms of the 40 age-sex groups using Cholesky decomposition.

Random error terms with the Uniform(0,1) distribution are generated using a random number generator. In order to reflect correlation between these error terms, they must be transformed to a Normal(0, $\mathbf{V}$) distribution, where $\mathbf{V}$ is the variance-covariance matrix of residuals, the differences between the actual historical data points and the estimated data points (using the chosen ARIMA model). The random error terms are first converted to a

Normal (0,1) distribution. The final step is to convert the standard normal error terms to a multivariate normal distribution with variance covariance matrix **V**. Cholesky Decomposition is used to decompose the matrix **V** into a lower triangle matrix **L** such that $\mathbf{V} = \mathbf{LL^T}$. As an example, let us consider a case where it is necessary to correlate the error terms of three variables, denoted x, y and z. Let the variance covariance matrix **V** be the following matrix:

$$\mathbf{V} = \begin{bmatrix} 36 & -36 & 18 \\ -36 & 117 & -72 \\ 18 & -72 & 189 \end{bmatrix} \quad \text{where} \quad \mathbf{V} = \begin{bmatrix} \sigma_X^2 & \sigma_{XY} & \sigma_{XZ} \\ \sigma_{YX} & \sigma_Y^2 & \sigma_{YZ} \\ \sigma_{ZX} & \sigma_{ZY} & \sigma_Z^2 \end{bmatrix}$$

Then, **V** is decomposed into the lower triangle matrix **L** such that $\mathbf{V} = \mathbf{LL^T}$,

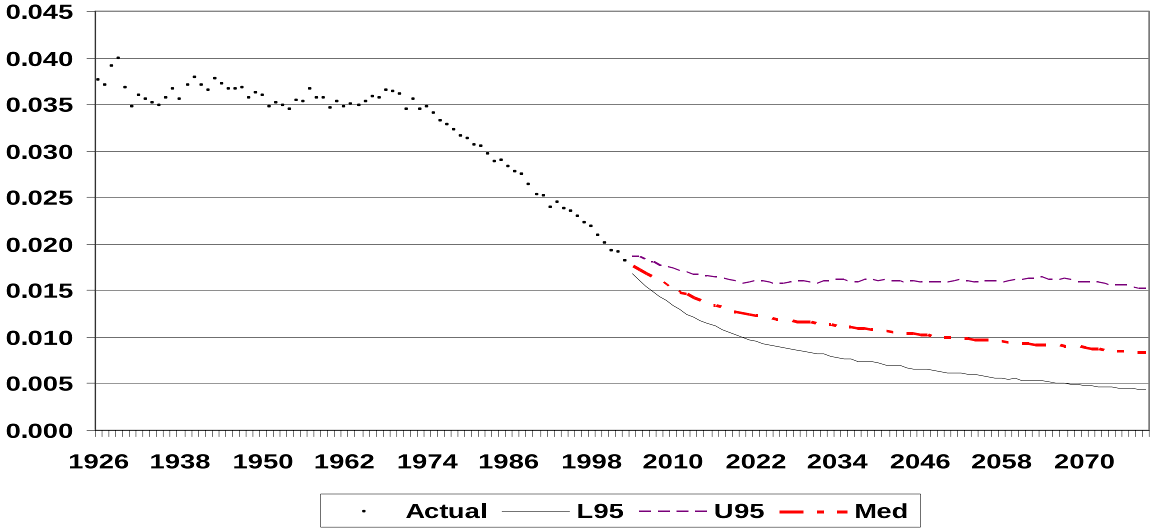
$$\text{where } \mathbf{L} = \begin{bmatrix} 6 & 0 & 0 \\ -6 & 9 & 0 \\ 3 & -6 & 12 \end{bmatrix} \quad \text{and} \quad \mathbf{L^T} = \begin{bmatrix} 6 & -6 & 3 \\ 0 & 9 & -6 \\ 0 & 0 & 12 \end{bmatrix}$$

By multiplying the Cholesky matrix **L** by the Normal(0,1) vector of error terms, $\vec{\varepsilon}$, we obtain a vector of correlated error terms, $\mathbf{L}\vec{\varepsilon}$, with the required multivariate normal distribution. These error terms are then used in the projection of future mortality rates.

Once the equation has been determined and the Cholesky Decomposition has been performed, future mortality rates are projected for each age-sex group 75 years into the future for 1,000 scenarios. The resulting mortality rate is the median mortality rate over all 1,000 scenarios. In addition, 95% confidence intervals are calculated to create awareness about the range of possible mortality rates.

The graph below shows the historical and projected mortality rates for males in the age range 65-69. The middle line represents the median mortality rates of the 1,000 scenarios run, while the lines above and below represent the bounds of the 95% confidence interval.

Chart 8. *Canada: Mortality rates, male age 65-69 (1926-2079)*



Having projected mortality rates for each age-sex group, the next step is to convert those values into mortality improvement factors. The equation used for this purpose is:

$$MIR_{k,t} = (MR_{k,t} \div MR_{k,t-1}) - 1$$

where $MIR_{k,t}$ = mortality improvement factor for group k at time t

$MR_{k,t}$ = mortality rate for group k at time t

Mortality improvement factors are calculated for each age-sex group 75 years into the future for all 1,000 scenarios. The results tend to show that mortality improvement rates are rather constant over the projection period with little fluctuation.

It must be taken into consideration that an ARIMA model can not explicitly represent a stochastic process with a time-varying mean displacement. However, historical mortality data does exhibit time-varying mean displacement. The purpose of differencing the logged mortality rates is to eliminate this displacement and transform the data such that the mean is stationary. It's possible that this transformation may not completely eliminate the time-varying mean displacement, which would lead to understating the degree of uncertainty in the simulated probability distributions of the mortality rates.

As well, when projecting future mortality rates, it may not be prudent to rely solely on historical experience. During the twentieth century, structural changes in mortality patterns have lessened the validity of historical experience compared to the recent past and emerging patterns. Thus, the use of judgement may be necessary in determining appropriate mortality improvement factors.

Therefore, the next step is to incorporate some judgment into the process. The evolution of a 15 year moving average of historical improvement rates is analyzed through time and then compared to the mortality improvement factors produced by the model in order to finalize the best-estimate mortality improvement factors for each age group.

Next, the best-estimate mortality improvement factors determined above are applied to the 2001 Canada Life Table (CLT) in order to establish the best-estimate mortality rates for the future. Finally, a stochastic process is used to project 1,000 future mortality rate paths that are centered around this best-estimate. The life expectancy for each of the 1,000 paths is then calculated and the best-estimate life expectancy is equal to the median of the 1,000 life expectancies. The tables below show the best-estimate life expectancy at ages 0 and 65 as compared to the values from CPP 21, as well as the 95% confidence interval of these life expectancies.

Table 19. *Life expectancies for Canada, without improvements after the year shown*

		CPP21	Stochastic process	Lower 95% CI	Upper 95% CI
Male, age 0	2005	78.0	77.4	76.8	78.0
	2025	80.7	80.4	78.1	82.5
	2050	82.0	82.0	77.9	85.6
	2075	83.4	83.3	77.9	87.5
Male, age 65	2005	17.6	17.5	17.0	18.0
	2025	19.1	19.3	17.3	21.1
	2050	20.0	20.5	17.1	23.5
	2075	20.9	21.5	17.1	25.0
Female, age 0	2005	82.6	82.2	81.6	82.7
	2025	84.1	83.9	80.7	86.5
	2050	85.3	85.2	79.8	89.3
	2075	86.5	86.3	78.8	91.2
Female, age 65	2005	20.9	20.8	20.2	21.2
	2025	21.7	21.9	19.0	24.3
	2050	22.6	22.9	18.0	26.3
	2075	23.5	23.8	17.6	28.0

Table 20. *Life expectancies for Canada, with improvements after the year shown*

		CPP21	Stochastic process	Lower 95% CI	Upper 95% CI
Male, age 0	2005	83.0	83.0	78.1	87.0
	2025	84.2	84.4	78.7	88.4
	2050	85.5	85.5	80.4	89.5
	2075	86.8	87.0	82.1	90.2
Male, age 65	2005	18.5	18.6	17.0	20.0
	2025	19.6	19.9	17.1	22.3
	2050	20.5	21.1	16.9	24.2
	2075	21.4	22.1	17.3	25.5
Female, age 0	2005	86.4	86.2	79.5	90.8
	2025	87.4	87.3	79.8	92.0
	2050	88.6	88.4	81.3	92.7
	2075	89.7	89.5	83.0	93.2
Female, age 65	2005	21.5	21.5	19.2	23.5
	2025	22.3	22.5	18.4	25.5
	2050	23.2	23.5	17.7	27.5
	2075	24.1	24.4	17.4	28.5

4. Mortality projections for social insurance programs in the United States

4.1. Methodology and assumptions for general population mortality projections

The methodology and assumptions presented for the US are based on the intermediate projections of the 2006 Annual Report of the Board of Trustees.[1] These intermediate projections reflect the Trustees' best estimates of future experience.

The methodology used to project mortality rates into the future involves making assumptions about annual rates of mortality improvement by age, sex, and cause of death. The initial step in making this projection is to calculate historical average annual rates of mortality improvement by age, sex, and cause of death. These historical average annual rates are used as a guide in determining the assumed ultimate annual rate of mortality improvements. Additional details about the methodology are found in Actuarial Study Number 120, located at the following internet site: *http://www.ssa.gov/OACT/NOTES/s2000s.html*.

4.1.1. Historical annual rates of mortality improvement and starting values

For the US, the base year for the mortality projections is 2002. For this year and all other historical years, rates are initially calculated using deaths from the National Center for Health Statistics and resident population counts from the US Bureau of Census. For years since 1968, numbers of deaths and participants from the Medicare programs are used to determine mortality rates for ages 65 and older. Instead of using the measured mortality rates for the last single year of data (calendar year 2002) as the starting point from which mortality projections are made, starting levels of mortality rates are calculated to be consistent with the trend inherent in the last 12 years of available data, 1991 through 2002. This procedure reduces the impact of sometimes-wide swings in annual data on the starting level for the mortality projection.

Annual rates of mortality improvement are calculated as is done in Canada. The rates of improvement are derived by fitting a least squares regression line to the logarithm of central death rates. The central death rate for a calendar year is defined as the ratio of the number of deaths in the year to the corresponding population as at July 1st of that year. The annual rate of mortality improvement is then derived from the slope of the fitted regression line.[2]

Average annual rates of mortality improvement in the US for various historical time periods are presented by age group for males in Table 21 and for females in Table 22. The time periods are selected on the basis of similar annual rates of improvement throughout the period.

[1] The 2006 Trustees report is located at the following internet site: http://www.ssa.gov/OACT/TR/TR06/index.html

[2] The average annual rate of mortality improvement is equal to the complement of the exponential of the slope of the least squares regression line through the logarithm of the central death rates.

Table 21. *US: Historical average annual rates of mortality improvement (Males)*

Age	1900-2002	1900-1936	1936-1954	1954-1968	1968-1982	1982-2002
0-14	3.3%	2.9%	4.8%	1.7%	4.3%	2.9%
15-64	1.3%	1.0%	1.9%	-0.2%	2.3%	1.5%
65+	0.6%	0.2%	1.2%	-0.4%	1.5%	0.8%
All ages	0.9%	0.7%	1.6%	-0.2%	1.8%	1.0%

Note: *All rates of improvement shown reflect age-sex adjustment to the distribution of the 2000 United States population.*

Table 22. *US: Historical average annual rates of mortality improvement (Females)*

Age	1900-2002	1900-1936	1936-1954	1954-1968	1968-1982	1982-2002
0-14	3.3%	3.1%	5.1%	1.7%	4.2%	2.6%
15-64	1.6%	1.2%	3.5%	0.6%	2.2%	0.9%
65+	0.8%	0.3%	1.8%	0.7%	2.1%	0.1%
All ages	1.2%	0.8%	2.4%	0.7%	2.2%	0.3%

Note: *All rates of improvement shown reflect age-sex adjustment to the distribution of the 2000 United States population.*

During the period 1900-1936, annual mortality reduction averaged about 0.7% for males and 0.8% for females. During the following period, 1936-1954, there was more rapid reduction (with the help of antibiotics and other advances in medicine), averaging 1.6% per year for males and 2.4% per year for females. The period 1954-1968 saw a much slower reduction of 0.7% per year for females and an *increase* of 0.2% per year for males. From 1968 through 1982, rapid reduction in mortality surged (with the help of Medicare and Medicaid), averaging 1.8% for males and 2.2% for females, annually. From 1982 to 2002, more moderate reduction in mortality returned, averaging 1.0% per year for males and 0.3% for females.

For the period 1982-2002, the average annual rate of improvement for females was considerably less than that for males. For all other periods mentioned above, the opposite is true, i.e., the average annual rate of improvement for males is less than that for females. Even with normal year-to-year variation, it is clear that, from the beginning of the past century, improvement was generally greater for females until about 1980. But it is also clear that female improvement was generally less than or equal to that for males beginning about 1980.

The tables above show that average annual rates of improvement over the period 1900-2002 are greater for younger ages. The average annual rate is over 3% for the age group 0-14 and declines for each succeeding older age group, reaching less than 1% for the age group 65 and older. For the age group 65 and over, the rate of improvement experienced during 1900-2002 averaged 0.6% for males and 0.8 for females, while the rate of improvement during 1982 2002 averaged 0.8% for males and only 0.1 for females. Thus, while the average rate of improvement for males in the most recent 20 years was slightly higher than for the entire 1900-2002 period, the average rate of improvement for females in the most recent period was dramatically lower than for the entire 1900-2002 period.

Past reduction in mortality has varied greatly by cause of death. In assessing past experience and future possible improvement in mortality, we believe it is useful to understand the variations in mortality by cause of death. For the period 1979-2002, average annual reductions in central death rates by age group and sex for six major groups of causes of death are analyzed. For rates that combine all ages and both sexes, the largest reductions, at slightly over 2.1% per year, were in the categories of Vascular Disease and Heart Disease. Averaging about 0.9% reduction per year was Violence. Cancer averaged a decrease of about 0.1% per year. The categories of Respiratory Diseases, Diabetes Mellitus and Other Causes, averaged *increases* ranging from 1.1 to just over 2.2% per year.

4.1.2. Assumed future rates of mortality reduction

Ultimate annual percentage reductions in central death rates by sex, age group, and seven causes of death are assumed to apply for years starting with 2030. Annual reductions by age, sex, and cause from the starting year of the projections (2002) to 2005 are assumed to equal the average annual reductions observed for the period 1982-2002.[3] For years after 2005, the reductions in central death rates are assumed to change rapidly from initial levels, equal to the average annual reductions observed for the period 1982-2002, to the assumed ultimate rates of reduction for years 2030 and later.

The ultimate annual percentage reductions in central death rates by age and sex (all causes combined) are shown in Table 23. The ultimate annual percentage reductions are determined based on historical trends and consideration of many factors which affect mortality. Expected rates of improvement in mortality by cause of death are considered in selecting ultimate mortality improvement assumptions. While these rates by cause of death have not effectively “controlled” the outcome for assumptions reflecting all causes combined, they serve as an important basis for analysis relative to past trends and for assessment of reasonableness of future assumptions.

Table 23. *US: Assumed average annual rates of mortality improvement*

	Male		**Female**	
Age	**2002-2030**	**2030-2080**	**2002-2030**	**2030-2080**
Under age 15	1.89%	1.54%	1.85%	1.57%
Ages 15 - 49	0.93%	0.86%	0.73%	0.73%
Ages 50 - 64	1.12%	0.82%	0.87%	0.72%
Ages 65 - 84	0.90%	0.72%	0.68%	0.68%
Ages 85 and older	0.49%	0.62%	0.43%	0.61%

Because reductions in mortality have differed widely by age in the past, the ultimate reductions in death rates have been selected to vary by age group. Historically, reductions have been very rapid at the youngest ages while reductions at the highest ages, ages 85 and over, have been very slow. Assumptions have reflected for many years the belief that neither of these extremes will persist indefinitely into the future. The assumptions have reflected slower improvement at the youngest ages than evidenced over the past century and faster improvement at the highest ages (85 and over) than experienced historically.

[3] The current methodology bases the starting level of decline in mortality on the average rate of decline over the past 20 years. Additionally, if the average rate of reduction for a particular cause age-sex group during the period 1982-2002 is negative, then 75% of that average rate is assumed.

Extrapolation of the average trends experienced for the past century (or for any other period) to project future mortality presumes that there will be a constancy to these rates in the future that has not occurred in the past. We believe it is crucial to study not only the differing historical rates of decline for various periods, but also the conditions that contributed to these variations. Only after considering how future conditions will differ from the past can we speculate about future mortality improvement.

A number of extremely important developments have contributed to the generally rapid general rate of mortality improvement during the past century. These developments include:

- access to primary medical care for the general population (in particular, the access due to Medicare and Medicaid health coverage for the elderly, disabled, and poor);
- discovery of and general availability of antibiotics and immunizations;
- clean water supply and waste removal; and
- the rapid rate of growth in the general standard of living.

Each of these developments is expected to make a substantially smaller contribution to annual rates of mortality improvement in the future. The diminishing effect of these factors has already been in evidence since 1982.

Future reductions in mortality will depend upon such factors as:

- The development and application of new diagnostic, surgical, and life-sustaining techniques.
- The presence of environmental pollutants.
- Changes in amount and type of physical activity.
- Improvements in nutrition.
- The incidence of violence and suicide.
- The isolation and treatment of causes of disease.
- The emergence of new forms of disease.
- The evolution of existing forms of disease.
- Improvements in prenatal care.
- The prevalence of obesity.
- The prevalence of cigarette smoking.
- The misuse of drugs (including alcohol).
- The extent to which people assume responsibility for their own health.
- Education regarding health.
- Changes in our perception of the value of life.

In reviewing the above list, future progress for some factors seems questionable when recent statistics are considered. Recent National Center for Health Statistics (NCHS) releases have reported a substantial increase in the prevalence of obesity and diabetes, decreased environmental air quality, and an increase in negative side effects from invasive surgical procedures. On the other hand, there is good basis for speculation that there will be substantial breakthroughs in advancing medical technology and treatment in the future. The extent to which such new technologies will have purely positive effects (like improved sanitation) versus mixed effects (as in the case of chemotherapy) will determine their potential for improving mortality. A final consideration, however, is the ability and willingness of our society to pay for the development of new treatments and technologies, and to provide these to the population as a whole. A comparison of the basis for past improvement in mortality with the expected basis for future improvement suggests to us that future improvement for ages under 65 is likely to continue, but at a slower rate than experienced during the extraordinary period of the last century. It seems more reasonable, however, to expect the rate of mortality improvement for the age group 65 and older for the next 75 years to be close to that experienced over the last century.

Education and income are factors that are well correlated with mortality differences in the population. More education and higher income are associated with lower mortality. It is not entirely clear whether this correlation is largely due to the benefits of higher income and education, or to the “selection” of more advantaged (and thus healthier) individuals in gaining access to the best education and job opportunities. If the former factor is important, then increasing education and income for the population as a whole may provide some further benefits, but substantially less than in the past.

Finally, we must consider that improvements in mortality and extension of longevity through the last century were relatively unconstrained by limitations of senescence and gradual deterioration of body systems. While we do not subscribe to the notion that there is a fixed limit for human longevity, it is true that average human lifespan has improved more than the maximum observed lifespan. This suggests that even with continue technological advances, the inherent limitations of the physical body and the mind to endure successfully much past 110 years will gradually result in a decelerating force of mortality improvement. This maximum observed lifespan can be expected to continue increasing, but only at a very modest pace.

4.1.3. Projection results

This section presents the projected central death rates by age and sex. In addition, resulting life expectancies and other mortality measures are included.

The projected central death rates in Table 24 show a continuous decrease over the projection period. For example, the central death rate for males ages 65-69 is expected to decline from 22.0 deaths per 1,000 people in 2006 to 12.7 deaths per 1,000 people in 2075. Over the period 2006 to 2075, the age for which central death rates are expected to decline the most, by 71%, is age 0. For age groups 65-69 and 70-74, the expected decline over this period is 42% for males and 37% for females. The age groups that are expected to have the smallest declines, (around 33%) over this period are the oldest age groups.

Table 24. *US: Central death rates by age group, sex and calendar year*

(per thousand)								
Sex and age group	Male				Female			
	2006	**2025**	**2050**	**2075**	**2006**	**2025**	**2050**	**2075**
0	6.7	4.6	3.0	1.9	5.6	3.8	2.5	1.6
1-4	0.3	0.2	0.2	0.1	0.2	0.2	0.1	0.1
5-9	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
10-14	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
15-19	0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.2
20-24	1.3	1.1	0.9	0.7	0.4	0.4	0.3	0.3
25-29	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3
30-34	1.3	1.1	0.9	0.7	0.7	0.6	0.5	0.4
35-39	1.9	1.6	1.3	1.0	1.2	1.0	0.9	0.7
40-44	2.9	2.5	2.0	1.6	1.8	1.6	1.3	1.1
45-49	4.3	3.6	2.9	2.3	2.5	2.1	1.7	1.5
50-54	5.9	4.8	3.8	3.1	3.5	3.0	2.5	2.1
55-59	8.8	7.1	5.7	4.7	5.7	4.8	3.9	3.3
60-64	13.8	11.2	9.0	7.4	9.1	7.8	6.4	5.4
65-69	22.0	18.3	15.1	12.7	14.8	13.0	10.9	9.3
70-74	35.0	29.3	24.2	20.4	23.7	20.9	17.4	14.9
75-79	55.0	46.1	37.8	31.9	38.1	33.4	27.6	23.5
80-84	90.6	77.0	62.8	52.6	64.9	56.6	46.1	38.8
85-89	153.6	137.4	116.4	100.2	113.7	103.1	87.7	75.9
90-94	251.5	229.5	193.9	166.7	197.3	180.9	152.9	131.7

Life expectancy is the average number of remaining years expected prior to death. Life expectancies in the United States are presented in two different forms – *period life expectancies* in Tables 25 and *cohort life expectancies* in Table 26. Period life expectancy is calculated for a given year using the expected death rates at each age for that year. Thus, it *does not* reflect the life expectancy for actual cohorts of individuals. Instead, it is a useful statistic for summarizing the death rates over all ages for a given year. On the other hand, cohort life expectancy *does* reflect the life expectancy for an actual cohort of individuals. It is calculated using death rates from the series of years in which the cohort will actually reach each succeeding age.

Table 25 shows that period life expectancies at age 0 in the United States are projected to continue growing, but at a much slower rate than was experienced since 1940. Life expectancy at age 0 for males was 61.4 years in 1940, is expected to be 75.0 years in 2006, and is projected to reach 81.4 years in 2075. For females, life expectancy at age 0 is projected to increase from 65.7 years in 1940 to 79.7 years in 2006 and to 84.8 years in 2075.

For age 60, period life expectancies in the United States are also projected to continue to grow, but at a rate slightly less than that experienced since 1940. Life expectancy at age 60 for males was 14.8 years in 1940, is expected to be 20.1 years in 2006, and is projected to reach 24.4 years in 2075. For females, life expectancy at age 60 is projected to increase from 16.8 years in 1940 to 23.1 years in 2006 and to 26.9 years in 2075.

Assumed mortality improvements have more of an impact on increasing expected lifetimes at younger age than at older ages, since the improvement factors decrease with age. For instance, from 2006 to 2075, assumed mortality improvements lead to more than a 5-year increase in life expectancy at age 0 for both male and female. However, at age 60, this increase falls to about 4 years for both sexes, and by age 85, it falls to less than 2 years.

Table 25. *US: Period life expectancies*

	Male				Female			
Age	**2006**	**2025**	**2050**	**2075**	**2006**	**2025**	**2050**	**2075**
0	75.0	77.1	79.4	81.4	79.7	81.2	83.1	84.8
10	65.6	67.5	69.7	71.6	70.2	71.6	73.4	75.0
20	55.9	57.8	59.9	61.8	60.4	61.7	63.5	65.1
30	46.5	48.3	50.4	52.2	50.6	51.9	53.7	55.3
40	37.2	38.9	40.9	42.6	41.1	42.3	44.1	45.6
50	28.4	30.0	31.8	33.3	31.8	33.0	34.6	36.1
60	20.1	21.5	23.0	24.4	23.1	24.1	25.6	26.9
70	13.0	14.0	15.3	16.4	15.3	16.1	17.4	18.5
85	5.2	5.6	6.2	6.9	6.3	6.7	7.4	8.1

Table 26 shows, on a cohort basis, life expectancies at selected ages, by sex and year of birth. If life expectancy is calculated on a cohort basis, based on the annual death rates by age of individuals born in selected calendar years, then the life expectancy of newborns born in 2006 is projected to be 80.7 for males and 84.6 for females. For newborns born in 2075, life expectancies are projected to be 85.6 for males and 88.6 for females.

Table 26. *US: Cohort life expectancies for selected years of birth*

	Male				Female			
Age	**2006**	**2025**	**2050**	**2075**	**2006**	**2025**	**2050**	**2075**
0	80.7	82.2	84.0	85.6	84.6	85.9	87.4	88.6
10	71.3	72.7	74.4	75.8	75.1	76.3	77.6	78.8
20	61.6	63.0	64.6	66.0	65.3	66.4	67.7	68.9
30	52.2	53.5	55.0	56.3	55.5	56.6	57.9	59.1
40	42.7	43.9	45.4	46.6	45.9	46.9	48.2	49.3
50	33.6	34.7	36.0	37.2	36.5	37.5	38.7	39.7
60	24.9	25.8	27.0	28.0	27.4	28.3	29.4	30.4
70	17.0	17.8	18.7	19.6	19.1	19.9	20.8	21.7
85	7.5	7.9	8.6	9.1	8.8	9.3	9.9	10.5

Comparisons between period and cohort life expectancies are shown in Charts 9 and 10. Historical and projected life expectancies at age 0 for males and females are displayed in Chart 9. In addition, a similar display at age 65 is provided in Chart 10. For the cohort lines in Chart 10, *year* indicated on the horizontal axis refers to the year of attaining age 65.

Cohort life expectancy at a particular age for a specific year is based on death rates for that age in the specific year and for each higher age in each succeeding year. Life expectancies on a cohort basis tend to fluctuate less from year to year than do period-based life expectancies because of sudden and temporary events, such as a flu epidemic, which may affect the entire population, for a brief period of one or two years, but affect only one or two years of mortality experience for each of the cohorts alive during the period. Therefore, cohort life expectancies are more useful in analyzing subtle and gradual generational trends in mortality.

Chart 9. *US: Male and female life expectancy at birth*

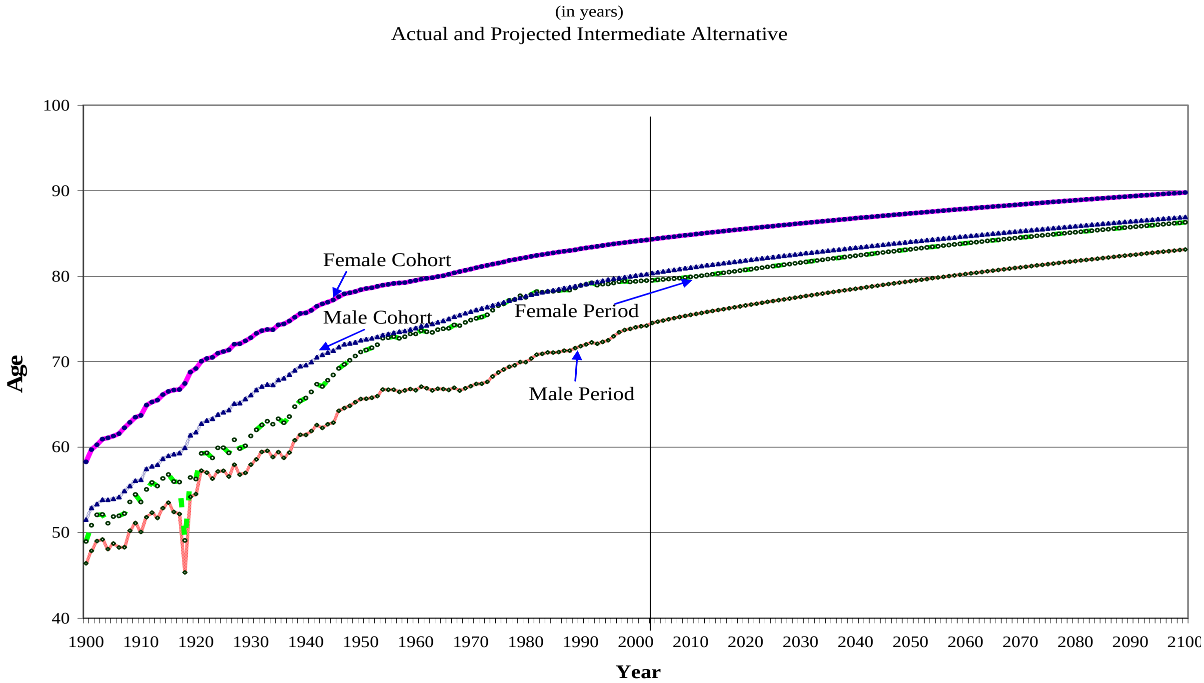
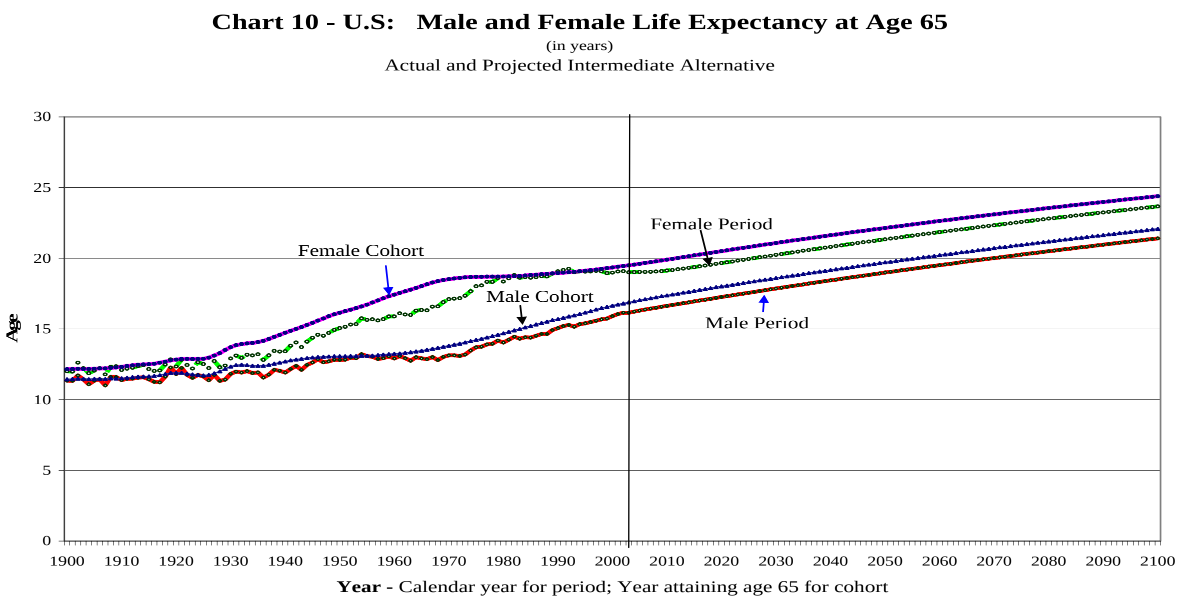


Chart 10. *US: Male and female life expectancy at age 65*



Charts 11 and 12 present the population survival curves based on period life tables for selected calendar years. Great strides were made in the twentieth century toward eliminating the hazards to survival which existed at the very young ages in the early 1900's. Little additional improvement to survival rates is possible at these young ages. Survival rates at the older ages are projected to continue to improve steadily.

Although the shape of the survivorship curve has become somewhat more rectangular (less diagonal) through time, it appears that little additional rectangularization will occur because survival rates are already so high at the young ages and are expected to continue increasing at older ages. The so-called "curve squaring" concept, though appealing to many, simply cannot be supported by the mathematics of mortality. The age at which the survivorship curve comes close to zero, through the compounding of single-year probabilities of survival, increased greatly during the twentieth century and will continue to increase, as further strides are made against degenerative diseases. That mortality rates are found to continue to decline, at every age for which adequate data are available, demonstrates that no absolute limit to the biological life span for humans has yet been reached, and that such a limit is unlikely to exist.

As indicated in the graphs by the intersection of the vertical lines at age 65 with the survival curves, the probability of reaching age 65 increased substantially over the past century. For the calendar year 1900, males had a 37% probability of reaching age 65. By 2000, this probability had increased to 78%, and by 2100 it is projected to reach 91%. For females, the probability of reaching age 65 using 1900 mortality data was 41%. This probability increased to 87% by 2000, and is projected to reach 94% by 2100. In general, probabilities of surviving to older ages have increased over the last century and this trend is expected to continue at a slower pace.

Chart 11. *US: Population survival curves - Male*

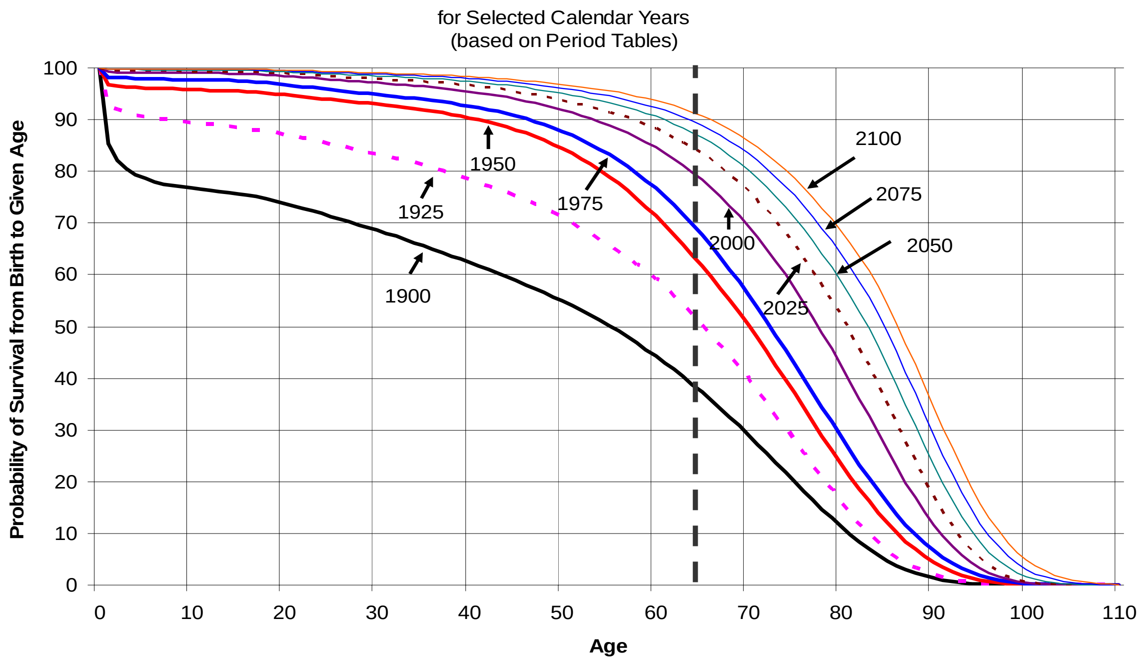


Chart 12. *US Population survival curves - Female*

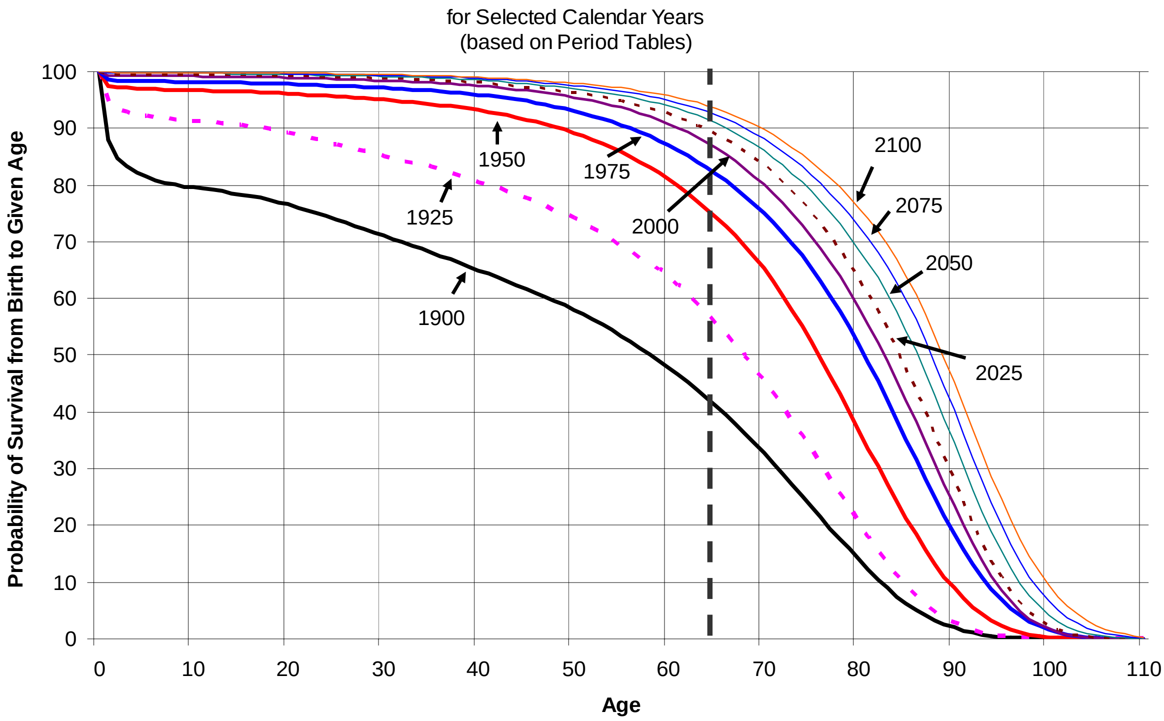
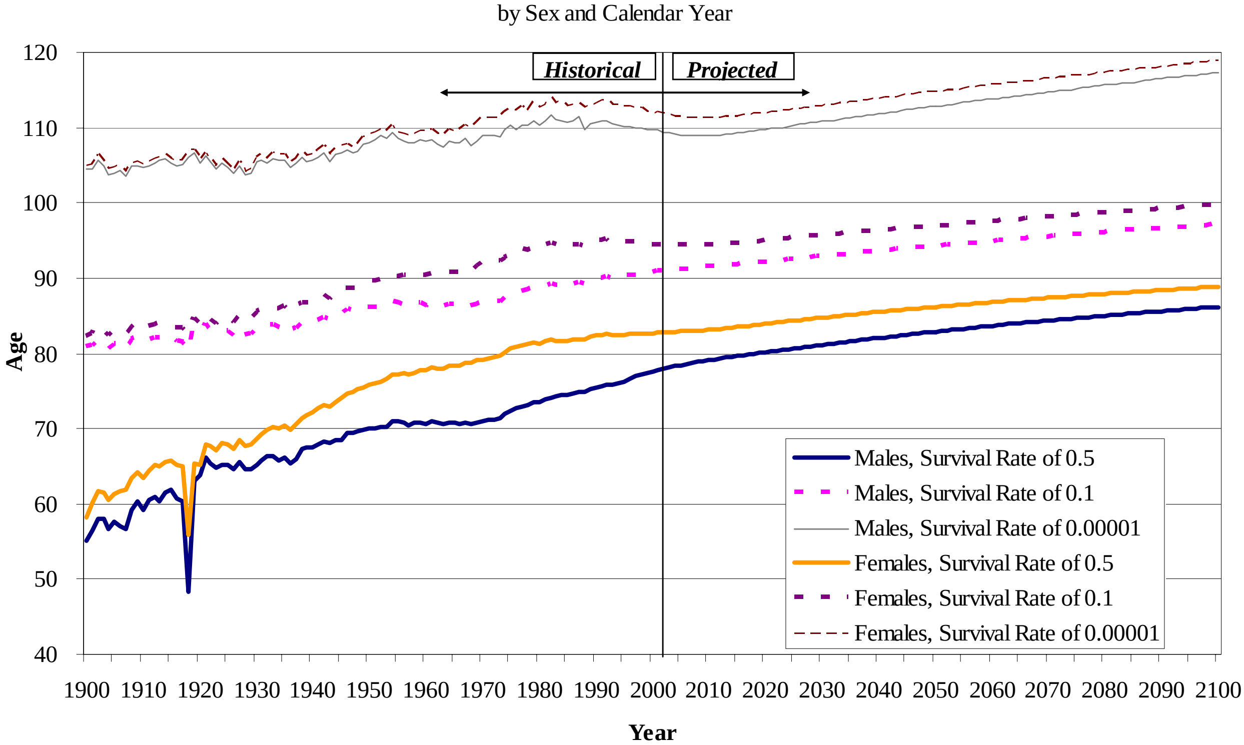


Chart 13 presents the age for three selected survival rates, by sex and calendar year on a period basis. The median age at death is indicated by the age at which the survival rate equals 0.5. The median age increased 22.7 years, from 55.2 years for males in 1900 to 77.9 in 2002. For females the increase was 24.7 years, from 58.2 years in 1900 to 82.9 years in 2002. Increases in the median age at death between 2002 and 2100 are projected to be 8.3 years for males and 6.0 years for females.

For the survival rate equal to 0.1, the corresponding age for males increased 10.1 years from 80.9 years in 1900 to 91.0 years in 2002, while for females it increased about 12.2 years from 82.3 years to 94.5 years. From 2002 to 2100, the age for males is expected to increase by 6.2 years and for females by 5.2 years.

Historical data are used in calculating mortality rates up to about age 95. After that age, the probability of dying is assumed to gradually increase for each succeeding higher age. Based on this methodology, the age corresponding to a survival rate equal to 0.00001 is determined. This age for males increased from 104.4 years in 1900 to 109.4 years in 2002, while for females it increased from 104.9 years to 111.9 years. These results are in opposition to the widely held belief that the age attained by the oldest survivors in the population had risen little, if at all, during the twentieth century. The extreme old age, where the survival rate equals 0.00001, increased very little from 1900 through 1930. However, this age increased rapidly between 1930 and 1954, and again between 1963 and 1982. Since 1982, this age has decreased for both males and females. For the period 2002-2100, this extreme old age is projected to increase by 7.9 years and for females by 7.0 years.

Chart 13. *US: Age for selected survival rates*



4.2. Stochastic modeling

It is important to provide policymakers with a sense of the range of variation in the financial projections that might occur if the intermediate assumptions are not realized. Traditionally, additional estimates using a low cost and a high cost set of specified assumptions are provided to reflect the presence of uncertainty. The set of assumptions chosen for the low cost estimates produce a much more *favorable financial effect* for the program. That is, mortality rates are generally higher than those assumed under the intermediate set of assumptions. Similarly, the set of assumptions chosen for the high cost produce a much more *unfavorable* financial effect. Under the high cost set of assumptions, mortality rates are generally lower than those assumed under the intermediate set of assumptions. These additional estimates provide a range of possible outcomes for the projections. However, they provide no indication of the probability that actual future experience will be inside or outside the range of these estimates. Thus, we rely on the results of a model, based on stochastic modeling techniques, to estimate a probability distribution of future mortality outcomes. It should be noted that this model is subject to further development. Future improvements and refinements are expected to be more likely to expand rather than reduce the indicated range of uncertainty.

All of the following descriptions pertaining to the stochastic process are based on the 2004 Annual Report of the Board of Trustees. Additional details concerning this process are found in Actuarial Study Number 117, located at the following internet site: http://www.ssa.gov/OACT/NOTES/s2000s.html.

4.2.1. Specifics of the stochastic process

Central death rates were calculated for 42 age-sex groups (under 1, 1-4, 5-9, 10-14, ..., 85-89, 90-94, and 95+; male and female) for each year in the period 1900 through 2000. From these data, annual rates of decline were calculated. Using time-series analysis for the data over the entire historical period, an equation was selected for projecting annual rates of decline in the central death rate for each age-sex group. The selected equation uses the variation in the annual rates of decline observed during the historical period to estimate the future variation. The general form of the equation is:

$$MR_{k,t} = MR_{k,t}^{TR} + \varphi_k mr_{k,t\text{-}1} + \varepsilon_{k,t}$$

In this equation,

- $MR_{k,t}$ represents the annual rate of decrease in the central death rate for group *k* in year *t*;
- $MR_{k,t}^{TR}$ represents the projected annual rate of decrease from the central death rate for group *k* in year *t* that was assumed under the intermediate assumptions;
- $mr_{k,t}$ represents the *deviation* of the annual rate of decrease from that assumed under the intermediate assumptions for group *k* in year *t-1 (the prior year)*; and
- $\varepsilon_{k,t}$ represents the random error for group *k* in year *t*.

In order to achieve consistency amount the 42 projection annual rates of decline, a Cholesky decomposition was then performed using the residuals from the 42 fitted equations. The Cholesky matrix used was 42 x 42 with the age groups in ascending order with alternating male and female groups.

4.2.2. Results of the stochastic process

Tables 27 and 28 compare the resulting period life expectancies at birth from the 2004 Annual Report with those from the stochastic modeling process. The tables compare the value of the life expectancies in 2078, the increase from 2004 to 2078 in the resulting life expectancies (75-year increase), and the increase from 2029 to 2078 in the resulting life expectancies (50-year increase). The upper limit of the 90% confidence interval in 2078 is nearly equal to that assumed for the high cost set of assumptions (85.8 vs. 85.9 years for males, and 89.5 vs. 89.2 years for females). Additionally, the lower limit is only slightly less than that assumed for the low cost set of assumptions (77.5 vs. 78.0 years for males, and 81.6 vs. 82.1 years for females).

Table 27. *US: Male period life expectancies at birth (in years)*

	Intermediate assumptions trustees report	Stochastic process: Median	Low Cost assumptions trustees report	High cost assumptions trustees Report	Confidence intervals based on stochastic process					
					95%		90%		80%	
Value in 2078	81.4	81.8	78.0	85.9	76.5	86.6	77.5	85.8	78.6	84.9
75-year increase	6.9	7.4	3.6	11.3	2.9	11.3	3.7	10.6	4.7	9.8
Final 50-year increase	4.1	4.4	2.2	6.8	2.8	6.4	3.1	6.0	3.4	5.5

Table 28. *US: Female period life expectancies at birth (in years)*

	Intermediate assumptions trustees report	Stochastic process: Median	Low cost assumptions trustees report	High cost assumptions trustees report	Confidence intervals based on stochastic process					
					95%		90%		80%	
Value in 2078	85.2	85.4	82.1	89.2	80.9	90.4	81.6	89.5	82.4	88.6
75-year increase	5.6	5.9	2.6	9.6	2.1	10.2	2.7	9.5	3.4	8.7
Final 50-year increase	3.6	3.8	1.8	5.9	2.0	6.2	2.3	5.8	2.6	5.3

Charts 14 and 15 present the period life expectancies at birth for males and females throughout the entire historical and projection periods.

Chart 14. *US: Male period life expectancies at birth, calendar years 1900-2078*

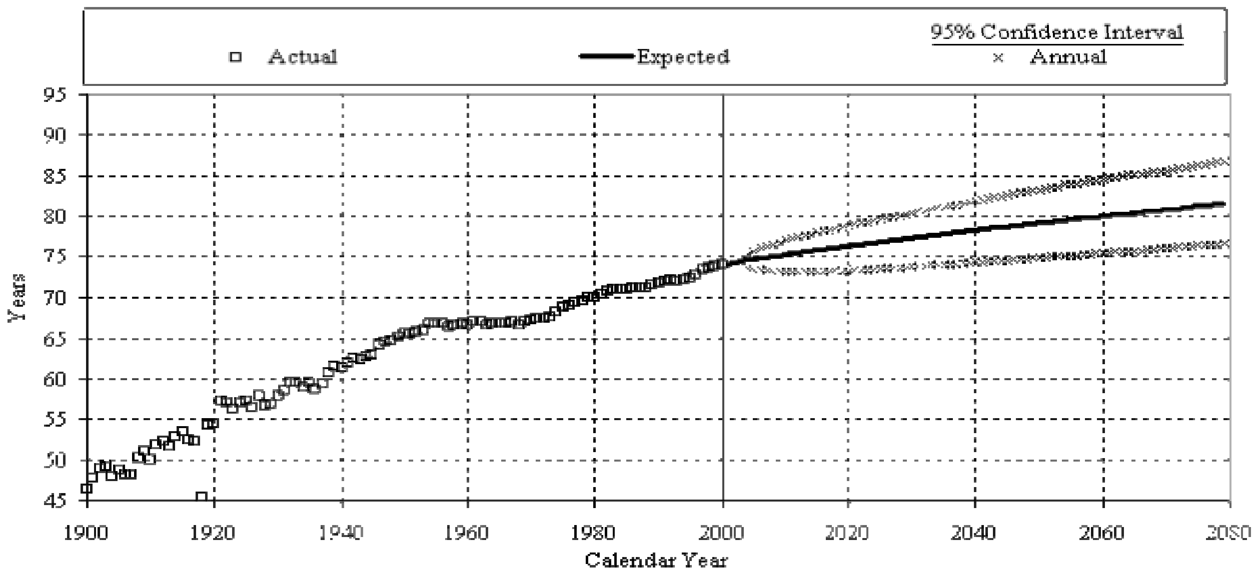
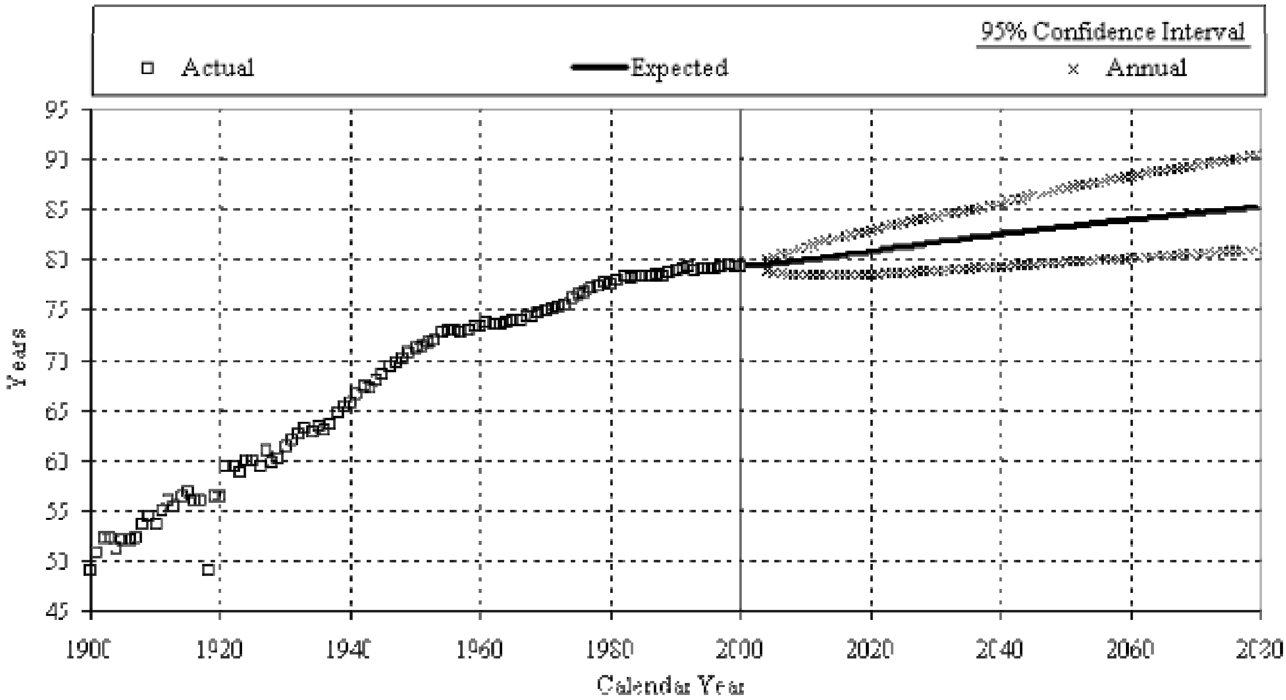


Chart 15. *US: Female period life expectancies at birth, calendar years 1900-2078*



Tables 29 and 30 compare the resulting period life expectancies at age 65 from the 2004 Annual Report with those from the stochastic modeling process. The values shown in these tables are analogous to those shown for life expectancy at birth analogous. The upper limit of the 80% confidence interval in 2078 is close to that assumed for the high cost set of assumptions (23.2 vs. 23.6 years for males, and 26.3 vs. 26.1 years for females) while the lower limit is slightly larger than that assumed for the low cost set of assumptions (18.4 vs. 17.7 years for males, and 20.7 vs. 20.3 years for females).

Table 29. *US: Male period life expectancies at age 65*

	Intermediate assumptions trustees report	Stochastic process: Median	Low cost assumptions trustees report	High cost assumptions trustees report	Confidence intervals based on stochastic process					
					95%		90%		80%	
Value in 2078	20.3	20.6	17.7	23.6	17.2	24.8	17.7	24.0	18.4	23.2
75-year increase	4.2	4.5	1.7	7.5	1.6	8.3	2.0	7.6	2.6	6.8
Final 50-year increase	2.7	2.9	1.1	4.8	1.4	5.1	1.6	4.6	1.9	4.2

Table 30. *US: Female period life expectancies at age 65*

	Intermediate assumptions trustees report	Stochastic process: Median	Low cost assumptions trustees report	High cost assumptions trustees report	Confidence intervals based on stochastic process					
					95%		90%		80%	
Value in 2078	22.8	23.3	20.3	26.1	19.4	28.1	19.9	27.3	20.7	26.3
75-year increase	3.9	4.3	1.4	7.1	0.9	8.6	1.4	7.9	2.1	7.0
Final 50-year increase	2.6	2.9	1.1	4.6	1.2	5.3	1.4	5.0	1.8	4.4

Charts 16 and 17 present the period life expectancies at age 65 for males and females throughout the entire historical and projection periods.

Chart 16. *US: Male period life expectancies at age 65, calendar years 1900-2078*

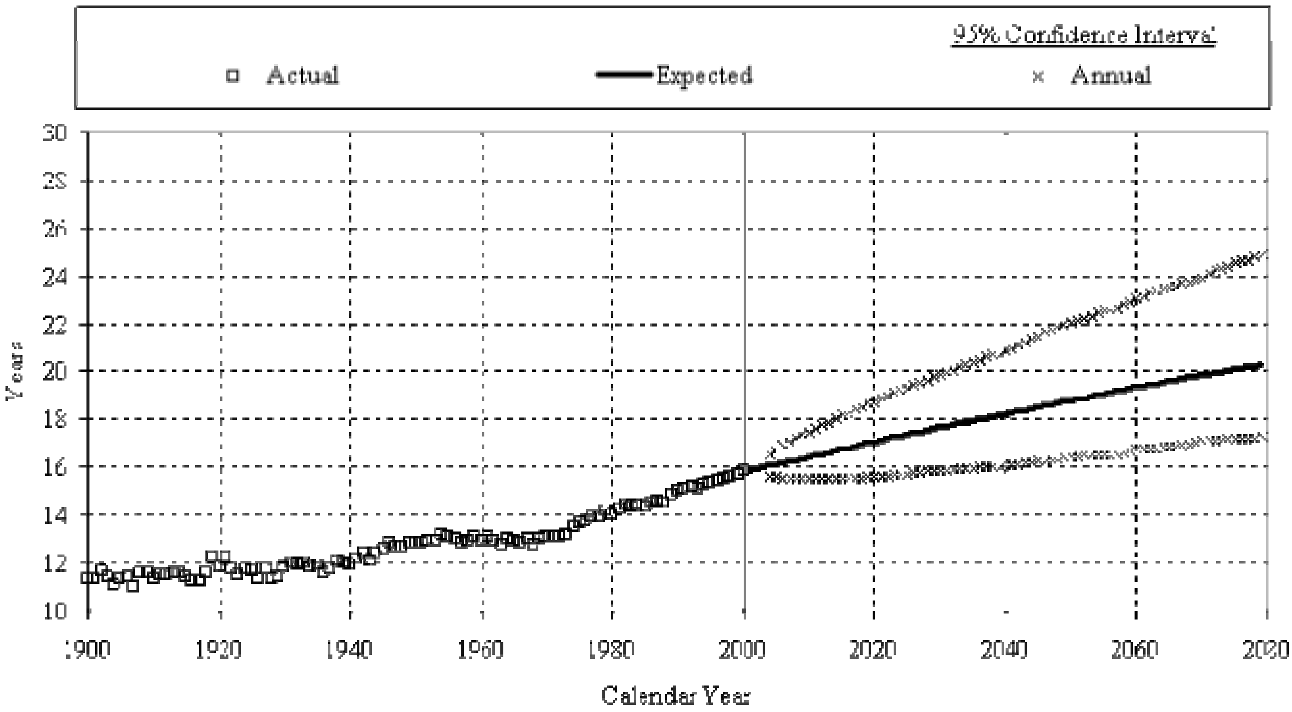
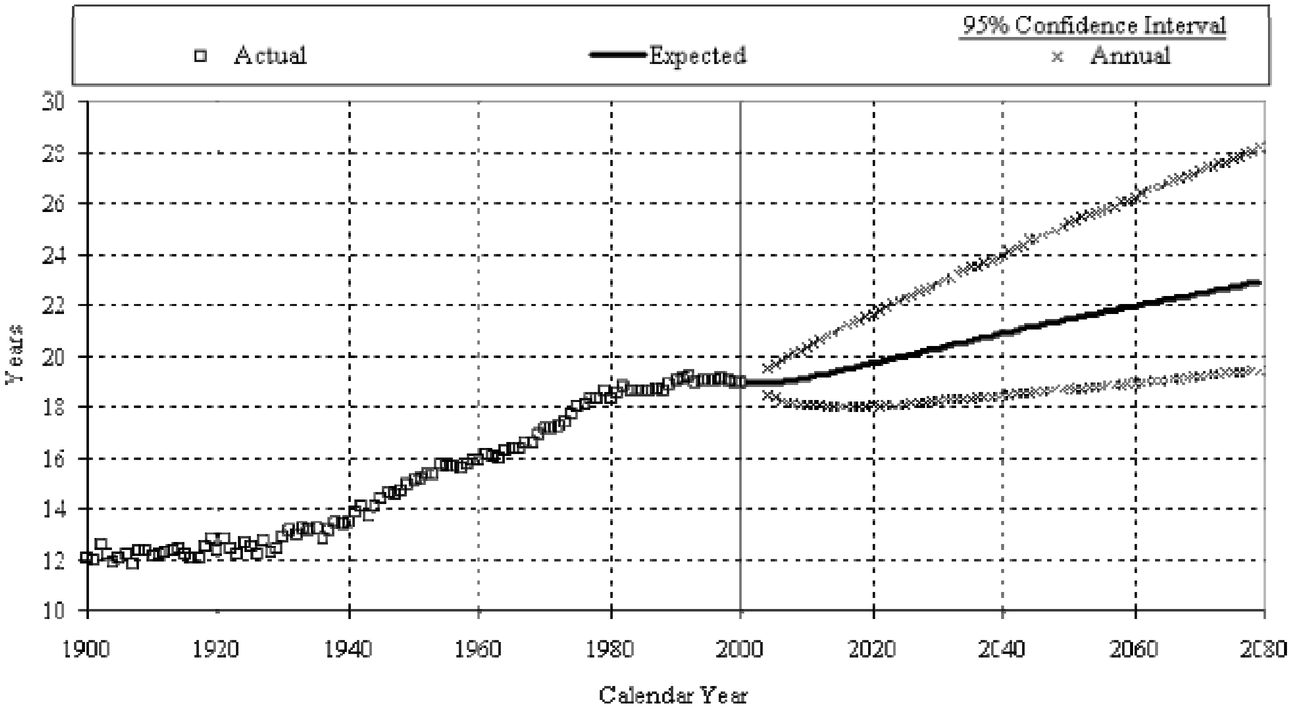


Chart 17. *US: Female period life expectancies at age 65, calendar years 1900-2078*



5. Conclusion

Mortality in Canada and the US declined significantly in the 20th century at all ages and for both males and females. In fact, in the last century, life expectancy at birth increased by an estimated 27.9 years in Canada and 27.4 years in the US In both countries, female life expectancies have exceeded male life expectancies; however the gap between the two has varied over time. In Canada, the gap between female and male life expectancies at birth reached its peak of just over seven years in the mid-1970s. Since then, the gap has narrowed, reaching 5.1 years in 2001, due to males experiencing greater improvements in mortality than females. In the US, the gap between female and male life expectancies at birth peaked at 7.7 years in 1970. The gap has since narrowed and was 5.3 years in 2002.

In the 21st CPP Actuarial Report, the ultimate mortality improvement factors for years 2026 and thereafter vary by age and sex and were derived from an analysis of experience in Canada and the US over the last century. The ultimate annual mortality improvement rates rely on the assumption that causes of death and general medical treatment in North America should not differ much in the future between the two countries and that the gap between US and Canadian mortality should reduce over the projection period. It is also expected that the gap in life expectancies between females and males will continue to narrow over time; however, it is not anticipated that this gap will completely disappear.

In both Canada and the US, mortality is assumed to continue to decline throughout the 75-year projection period. In Canada, the growth in life expectancies is expected to be at a slower rate than was experienced in the 20th century. In the US, future mortality improvement for ages below 65 is expected to continue, but at a slower rate than was experienced during the 20th century. However, for ages 65 and above, future mortality improvement is expected to be close to that experienced over the last century.

Finally, methodologies involving stochastic time series models have been developed in both Canada and the United States for illustrating the evolution, as well as volatility, of mortality rates. The main advantage of a stochastic projection is that it provides a reasonable quantification of the range of uncertainty around the central (best estimate) projection. In particular, the stochastic modeling results from the United States show that the low-cost and high-cost sets of assumptions capture a reasonable range of variability.