Population Projection for the Denver-Boulder Standard Metropolitan Statistical Area

An Honors Thesis by

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1. Introduction

Demography is the science of analyzing vital and social statistics of human populations. It is a method of measuring the quantitative and qualitative characteristics of a given population. Quantitative characteristics deal with size and distribution while qualitative characteristics deal with their development. A quantitative demographic question might be, "What will be the population of Denver, Colorado in the year 2010?" A qualitative demographic question might be, "What is the percentage of people in Denver, Colorado who have graduated from college?"

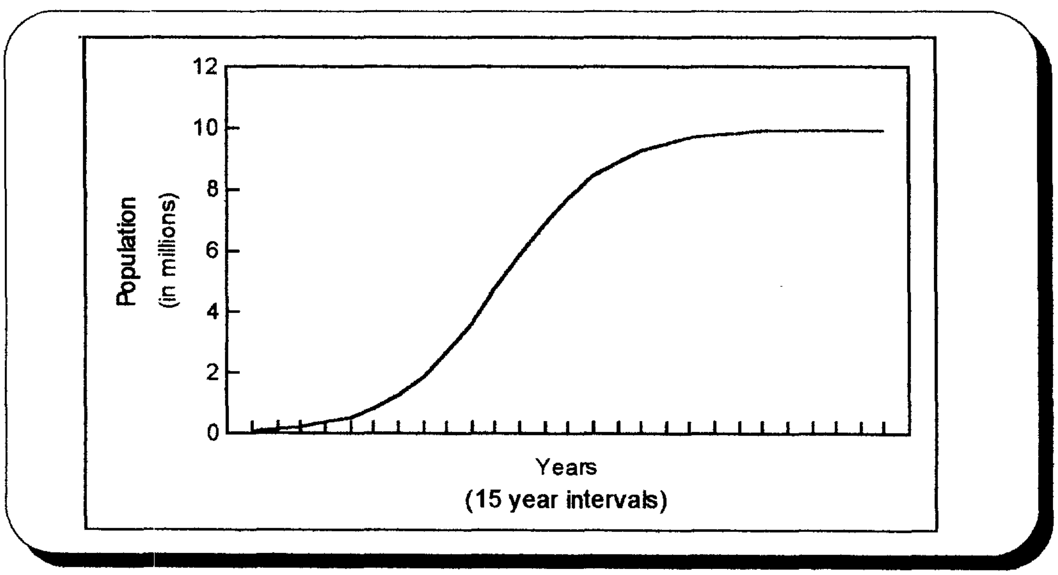
Demographic studies can provide much needed insight into the different characteristics of a population. Government organizations can use demographic statistics in many ways. The social security system and Medicare depend on the age distribution of the population. Age distribution and total population also effect the amount of traffic that uses the highway system. There are still more government funded programs that are affected by demography like the school systems and public utilities. Demography provides important information that helps the government decide what services need more or less funding. In the private sector, demography is just as important. Companies use demographics in all steps of production, from initial development all the way to marketing. Without demography it would be difficult for a company to decide what to produce and how to market the product.

In the insurance industry, demography is vitally important to the actuary. Actuaries use mortality statistics to evaluate pre-existing models and to develop new models where information was previously unavailable. The actuary might need study to death rates according to different characteristics like age, sex, race, occupation, and place of residence. Demography may also be useful in analyzing trends in mortality and other population characteristics.

Many of the problems faced by government and private organizations require a look into the future composition of a population. This look into the future population is called a projection. The increasing population in many urban areas is causing a strain on resources and the environment. A population projection can give an estimate of how the increase in a population will affect its resources and environment.

2. Models

There are two methods commonly used for population projections: the logistics curve and the component method. The logistics curve is based on the theory that all populations have a maximum size they can attain. In the early stages, a population grows slowly. As the population grows its growth rate increases until the population approaches its maximum size. As the population closes in on its maximum size its growth rate gradually slows. The growth rate decreases to zero when the population reaches its maximum size. The graph of the population's size versus time resembles an "S" which is why a logistics curve is also known as an "S" curve. Below is a sample logistic curve with an initial population of approximately 99,000 people and a limiting population of 10,000,000 million people.



The second commonly used method for population projections is the component method. According to Brown (page 8) the population can be represented by the equation

$$P(t) = P(0) + B - D + I - E$$

where P(t) is the predicted population at time t, B is the number of births in the period, D is the number of deaths in the period, I is number of immigrants in the period, and E is the number of emigrants. The component method applies age specific fertility rates, mortality rates, and immigration statistics to the current population to project the future population. This method can be quite useful in comparing different assumptions as to the changes in fertility, mortality and immigration. The logistic curve and the component method are both useful in projecting populations but each has its advantages and disadvantages.

The logistic curve has an upper limit on the size that a population can reach (Brown 163). The population will continue to grow until it eventually reaches this upper limit. The limiting size represents the largest size population that an environment can sustain. In many cases the concept of a limiting size is appropriate. One such case would be if our population was isolated so that there is no migration. If the population we are studying is a school of fish in a pond that has no outlets then there is limited space and a limited supply of food. Therefore, the school of fish could grow until their size put a strain on their environment. As the school's size approaches the limiting size of the pond either the birth rate would decrease or the death rate would increase until the number of births equaled the number of deaths. The environment would control the birth and the death rate so that if the birth rate did not decrease fast enough then the food supply might be depleted and the death rate would increase.

Another advantage of the logistic curve is that fertility, mortality, and migration statistics are unnecessary to project a population. The logistic curve can be fitted to a population with just three past population counts that are equally spaced. The limiting size of the population as well as the other parameters of the logistic curve are easily estimated from these numbers. According to Brown (page 165) the logistic curve equation for a population can be written as follows

$$P(t) = \frac{1}{A + Be^{-kt}}$$

where $\frac{1}{A}$ is the limiting population size, t is the time since the first population count, and B and k are parameters estimated from the population counts.

A disadvantage of the logistic curve becomes apparent when it is fitted to different sets of population counts. The parameters for the logistic curve may vary dramatically depending on which years are used for the population count. If the logistic curve is not a perfect fit for the population then a decision has to be made as to which population counts will give the best results. Choosing the population values adds a degree of prior opinion to the projection that may affect the outcome of the projection.

Unlike the logistic curve, the component method can be used to model the affects of changing fertility, mortality, and immigration statistics. Projecting populations is a difficult process because there are so many variables that need to be accounted for. Small changes in fertility, mortality, or immigration alone can cause significant changes in the size and composition of a population in the future. When small changes in each of these characteristics are compounded the results are astonishing. A population with a decreasing mortality would normally be expected to grow but if that population has a low fertility rate the population might stay the same size or decrease in size.

Whether the population stays the same size or decreases in size the composition of the population will change. Unless a population's fertility rate is significantly greater than a rate sufficient to replace the population, lower mortality will cause the population to age. A high fertility rate may result in more than a growing population, it may also result in a younger population. Immigration may also have a varying affect on future populations. A net immigration will contribute to a larger population, and the age distribution of the immigrants may compound the contribution. A high rate of immigration may be enough to offset the affects of low fertility and cause a population to increase.

An obvious drawback to the component method is the large amount of information that is necessary to project a population. Projecting a population may become a tedious process if simplifying assumptions are not adopted. Mortality, fertility, and immigration change from year to year in a dynamic population. To account for these yearly changes would require complex trend analysis techniques. Even the most complex trend analysis techniques cannot predict the future with great accuracy. The most that can be hoped for is a range in which the true values will likely fall. Most projections are not meant to accurately project an exact future population but to illustrate a possible population size and distribution given a set of assumptions. These assumptions can be set without spending a great deal of time and effort doing trend analysis.

Finding reliable information on mortality, fertility, and immigration for a small population may be difficult. Information for some small populations may not even be available. Collecting information takes a great deal of resources, and it is not economical to collect information for every small population. The information that is collected for small populations may not be very reliable. The smaller the population the greater the chance for large fluctuations in mortality, fertility, and immigration. A population for example with five females aged 30 might not experience any deaths in one year which would imply a mortality rate of zero. If this group experienced one death the mortality rate for that year would be one in five or 0.20 which could be as much as 300 times larger than the actual mortality rate. The same problem exists for fertility and immigration statistics. These fluctuations are less pronounced in larger populations because of the law of large numbers. According to the Grolier Multimedia Encyclopedia the law of large numbers states that, "The average of the outcomes of independent repetitions of a chance phenomenon must approach the EXPECTED VALUE of the outcome as the number of repetitions increases without limit, or approaches infinity."

3. Projections Using the Component Method

The following is an explanation of the derivation of the Leslie matrix as found in Introduction to the Mathematics of Demography, Robert Brown, pages 168-170.

As stated earlier the component method for projecting populations uses the equation

$$P(t) = P(0) + B - D + I - E$$

where P(t) is the predicted population at time t, B is the number of births in the period, D is the number of deaths in the period, I is number of immigrants in the period, and E is the number of emigrants. The component method can be applied using a matrix called the Leslie matrix.

Assume we have a population count on July 1, z and wish to estimate the population count on July 1, z+5. Our data is split by age and sex and is grouped in quinqennial, or five year age intervals. We can represent the population of each quinquennial age interval with the symbol ${}_5C_0^Z$, ${}_5C_5^Z$, ..., ${}_5C_{95}^Z$, up to our maximum age, where the first subscript signifies the length of the interval, the second subscript signifies the lower bound of the interval, and Z is the year. The symbol ${}_5C_0^Z$ includes all ages up to but not including age five and similarly for the other population counts.

The first step in projecting the future population is to account for survivorship over the five year interval by "aging" the population. This is done by applying mortality information from an appropriate recent sex-specific life table. Using information from the life table the quinquennial age group can be "aged" using the following equation

$${}_5C_5^{Z+5} = {}_5C_0^Z \times \frac{{}_5L_5}{{}_5L_0}$$

and in general

$${}_5C_{x+5}^{Z+5} = {}_5C_x^Z \times \frac{{}_5L_{x+5}}{{}_5L_x}$$

where ${}_5L_x$ is the total expected number of years lived between ages x to x+5 by survivors of the initial cohort. If we temporarily ignore migration we now have an estimate of the population age five and over.

Our next step is to get an estimate of the quinquennial age group ${}_5C_0^{Z+5}$ for the female population. Two things must be done to estimate the population of the quinquennial age group. First, we must estimate the number of live births in the five-year interval and then we must account for their survivorship of the newborns in that interval. Age-and-sex specific fertility rates are applied to the current female population to estimate the number of live female births. The age-and-sex specific fertility rates are denoted by the symbol ${}_5f_x^{f,Z}$, where the first subscript signifies the length of the interval, the second subscript signifies the lower bound of the age, and the exponent signifies that it is a female fertility rate for year *Z*. Age-and-sex specific fertility rates are calculated by dividing the number of female births in an interval by the number of females alive in the interval.

$${}_5f_x^{f,Z} = \frac{B^{f,Z}}{{}_5F_x(Z)},$$

where $B^{f,Z}$ is the number of live female births in five year interval beginning with year Z and ${}_5F_x(Z)$ is the mid-year population between ages x and $x+5$.

Next we must apply these fertility rates to the population to estimate the number of live female births. This is not as straight forward as it sounds. It would be incorrect to simply multiply the age-and-sex specific fertility rate, ${}_5f_{20}^{f,Z}$, by the corresponding age group, ${}_5C_{20}^{Z}$. The age group ${}_5C_{20}^{Z}$ would experience both ${}_5f_{20}^{f,Z}$ fertility and ${}_5f_{25}^{f,Z}$ fertility for those who live past age 25 in the interval. If we assume the experience is distributed uniformly, then our estimate for the number of live female births would be ${}_5C_{20}^{Z}(\frac{1}{2}\times{}_5f_{20}^{f,Z}+\frac{1}{2}\times\frac{{}_5L_{25}}{{}_5L_{20}}\times{}_5f_{25}^{f,Z})$ each year. This number is multiplied by 5 to obtain the estimate for the 5-year period. To get an estimate of the number of newborn females who survive to $Z+5$ we must multiply by $\frac{{}_5L_0}{5\times l_0}$, using an appropriate female life table. Therefore the number of live female births contributed to ${}_5C_0^{Z+5}$ by ${}_5C_{20}^{Z}$ is given by

$$5\times{}_5C_{20}^{Z}\times\frac{{}_5L_0}{5\times l_0}(\frac{1}{2}\times{}_5f_{20}^{f,Z}+\frac{1}{2}\times\frac{{}_5L_{25}}{{}_5L_{20}}\times{}_5f_{25}^{f,Z})$$

$$={}_5C_{20}^{Z}\times\frac{{}_5L_0}{l_0}(\frac{1}{2}\times{}_5f_{20}^{f,Z}+\frac{1}{2}\times\frac{{}_5L_{25}}{{}_5L_{20}}\times{}_5f_{25}^{f,Z})$$

In general this equation would be

$${}_5C_x^{Z}\times\frac{{}_5L_0}{l_0}(\frac{1}{2}\times{}_5f_x^{f,Z}+\frac{1}{2}\times\frac{{}_5L_{x+5}}{{}_5L_x}\times{}_5f_{x+5}^{f,Z})$$

We combine the factors for survivorship with the factors for fertility-and-survivorship to create a female sex-specific square matrix of the following form

$$M=\begin{bmatrix} 0 & \frac{{}_5L_0}{l_0}(0+\frac{1}{2}\times\frac{{}_5L_{10}}{{}_5L_5}\times{}_5f_{10}^{f,Z}) & \frac{{}_5L_0}{l_0}(\frac{1}{2}\times{}_5f_{10}^{f,Z}+\frac{1}{2}\times\frac{{}_5L_{15}}{{}_5L_{10}}\times{}_5f_{15}^{f,Z}) & \cdots \\ \frac{{}_5L_5}{{}_5L_0} & 0 & 0 & \cdots \\ 0 & \frac{{}_5L_{10}}{{}_5L_5} & 0 & \cdots \\ 0 & 0 & \frac{{}_5L_{15}}{{}_5L_{10}} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \end{bmatrix}$$

This matrix is called a Leslie matrix. The dimension of the matrix depends on the highest age attainable by the population. The matrix only need be expanded as long as ${}_5L_x$ is greater than zero. Multiplying the vector containing the age groups, ${}_5C_{x+5}^{Z+5}$, by the Leslie matrix gives an estimate of the population five years in the future.

4. Numbers

4.1 Introduction

The numbers necessary to project a population are not always easy to find and may not be in a form that is easily manipulated. While working on my projections, I made many assumptions and approximations. These assumptions and approximations are listed below along with my reasoning for using them.

4.2 Mortality

The mortality for my projection was taken from a 1979-1981 Colorado life table produced by the National Center for Health Statistics. The life table contained values of L_x for females in Colorado. For my projection I used values of ${}_5L_x$ which can be calculated from the L_x values by summing the values of L_x for x to $x+4$. To simplify my projections I used the same mortality throughout my projection. Mortality is expected to slowly improve over time. In an *Alternative Projection of the U.S. Population* by Dennis A. Ahlburg and James W. Vaupel they state that, "Mortality rates over the past quarter of a century have been declining at a rate of 1% or 2% per year." Over time this small improvement every year can add up. Future mortality improvements are difficult to estimate. There is also a possibility that mortality will become worse. In a worst case scenario, AIDS or a large scale war could have a dramatic affect on the population. By using the same mortality throughout my projection, I made a necessary compromise between accuracy and simplicity. The result of this compromise by itself is an understatement of the future population.

4.3 Fertility

Fertility information for the Denver-Boulder area was difficult to come by. I was unable to find age-and-sex specific fertility rates for the Denver-Boulder area so I had to calculate them myself. All the birth related numbers came from different years of the National Center for Health Statistics: *Vital Statistics of the United States*, Natality. The total number of live births for each quinquennial age group was estimated by averaging the births over the 5-year interval of 1980-84. I multiplied these numbers by the percentage of live births that were female which was approximately 48.7% to obtain an estimate of the number of live female births for each quinquennial age group. I used the population counts from the 1980 census of population for the mid-year female population. The initial estimate of the age-and-sex specific fertility rates were calculated by dividing the estimate of the live births by the estimate for the mid-year female population. This estimate will overstate the fertility rates if the population is growing and underestimates the fertility if the population is declining. Below is a table containing the number of births in the Denver-Boulder area for the years 1980 to 1984.

Births (year)

Age(x)	F(x)	1980	1981	1982	1983	1984	Ave.
0..4	57401	0	0	0	0	0	0
5..9	57538	0	0	0	0	0	0
10..14	62183	36	37	38	50	38	39.8
15..19	71094	3304	3348	3326	3125	2989	3218.4
20..24	82661	8338	8741	9157	8843	8671	8750.0
25..29	88771	8945	9320	9832	10051	10064	9642.4
30..34	78483	5021	5479	5927	6201	6559	5837.4
35..39	56520	1097	1226	1531	1727	1948	1505.8
40..44	44806	120	149	146	205	208	165.6
45..49	39995	9	6	7	9	7	7.6
50..54	38545	0	0	0	0	0	0

The resulting fertility rates were lower than expected. One statistic that is used in Demography to measure the growth of a population is the total fertility rate. The total fertility rate (TFR) is calculated by summing all the age specific fertility rates. Note that the age specific fertility rates include both male and female births. A TFR of about 2.1 is necessary for a constant population size. My estimate of the TFR was well below 2.1. I increased the TFR from 1.83 to 1.95 to account for a possible increase in fertility in the future and to partially offset the understatement due to mortality. Some common theories about fertility say that fertility runs in cycles. An example of these cycles is the "Baby Boom" that occurred after World War II and the baby bust that followed several years later. During the "Baby Boom" total fertility rates climbed above 3. For my projection I kept fertility constant. Over the last century the total fertility rate has declined except for the period following the two World Wars. Unless there is another war or an event of similar magnitude, I expect the fertility rates to remain fairly constant or decline. The table below contains the numbers used for the age-and-sex specific fertility rates.

Age(x)	F(x)	B(x)	total fert.	female fert.	adj. fert.
0..4	57401	0	0	0	0
5..9	57538	0	0	0	0
10..14	62183	39.8	0.00064	0.000312	0.000333
15..19	71094	3218.4	0.045270	0.022052	0.023544
20..24	82661	8750.0	0.105854	0.051565	0.055053
25..29	88771	9642.4	0.108621	0.052913	0.056492
30..34	78483	5837.4	0.074378	0.036232	0.038682
35..39	56520	1505.8	0.026642	0.012978	0.013856
40..44	44806	165.6	0.003696	0.001800	0.001922
45..49	39995	7.6	0.000190	0.000093	0.000099
50..54	38545	0	0	0	0
		TFR= 1.826453		New TFR = 1.95	

4.4 Migration

Migration was the most difficult characteristic of the population to estimate. My initial attempt at estimating migration was to include a migration factor in the "aging" factor. This migration factor would imply that migration is a linear function of population. Migration did not seem to be a function of population because past migration fluctuated heavily. The official Bureau of the Census projection estimates migration separately and adds the estimates after fertility and mortality statistics are applied. I decided to use this method so that migration would not be a function of population. I found an estimate for the net migration from 1990 to 2020 for Colorado in the Bureau of the Census, Current Population Reports, *Population Projection for States*. The Bureau of the Census estimate for net migration was 160,000 immigrants. Between 1990 and 2020 there are six 5-year periods so I divided this net immigration by six to estimate the migration for a 5-year interval and then by two to estimate the female portion. The next step was to determine a reasonable estimate of how many of these immigrants would move to the Denver-Boulder area. The Denver-Boulder area constitutes roughly two thirds of the population of Colorado and is growing. Multiplying by two thirds would result in a net migration of about 9,000 females for each 5-year period. I increased this number to 11,000 because the Denver-Boulder area has seen considerable immigration in the past.

The next decision was to find a way to distribute these 11,000 immigrants into quinquennial age groups. The Bureau of the Census used three different assumptions for the number and distribution of immigrants in their projections. The overall distribution of the immigrants in their low estimate seemed to roughly match the distribution of the actual number of immigrants for the period of 1975 to 1980 in the Denver-Boulder area according to the U.S. Bureau of the Census report on *Geographic Mobility for Metropolitan Areas*. The greatest immigration occurred between ages 25 to 29 in both the census projection and the actual numbers for the Denver-Boulder area. The immigration also decreased as ages increased in distance from this peak with a net emigration at older ages. I scaled their low estimates down to give a total immigration of 11,000 so that it would fit my estimate of net immigration. These immigrants were added after each application of the Leslie matrix. The following is a table of the immigration statistics used in my projections.

Immigration	**1975 to 1980 male and female**	**Census low projection for females**	**My estimate for females**
Age 0..4	0	6,800	1,149
5..9	4,500	7,500	1,267
10..14	3,343	8,200	1,386
15..19	2,733	5,400	912
20..24	19,005	7,800	1,318
25..29	25,134	16,200	2,737
30..34	Ages 30 to 44=	7,900	1,335
35..39	15,257	4,800	811
40..44		2,700	456
45..49	Ages 45 to 64=	2,000	338
50..54	-2,406	1,500	253
55..59		900	152
60..64		-500	-84
65..69	Ages 65 and	100	17
70..74	over=	-1,400	-237
75..79	70	-1,400	-237
80..84		-1,400	-237
85..89		-1,400	-237
90..94		-500	-84
95..99		-100	-17
100..104		0	0
105..109		0	0
Total	**67,636**	**65,100**	**11,000**

4.5 Baseline Population

Finally, we need a place to start our population projection. Our starting place is the actual population during the year that our projection starts, which is also known as the baseline population. Every ten years the Bureau of the Census counts the population by sending surveys through the mail to everyone in the United States and in some cases going door to door to collect information. The Bureau of the Census reports the population for every county in the United States. The following is a table of the female population of the Denver-Boulder area for the 1980 census count.

Age	Population
Under 5 years	57,401
5 to 9 years	57,538
10 to 14 years	62,183
15 to 19 years	71,094
20 to 24 years	82,661
25 to 34 years	167,254
35 to 44 years	101,326
45 to 54 years	78,540
55 to 64 years	66,347
65 to 74 years	43,384
75 years and over	33,830
Total	**821,558**

Note that not all the age groups are in 5-year intervals. Quinquennial age groups are necessary to project a population using a Leslie matrix so I needed a method to split the age groups that were not quinquennial. Initially I was going to use earlier census counts that reported the groups in quinquennial age groups and "age" the groups. I did not use this method because I had no way to keep track of migration. For the age groups included in the interval 25 to 64 years I used a ratio of the distribution of the population in the state of Colorado. The ages between 25 and 64 were grouped in 10-year intervals. I will use the age group 25 to 34 to illustrate specifically how I split these groups. There were 167,254 females age 25 to 34 in the Denver-Boulder area in 1980. According to the U.S. Bureau of the Census, *Statistical Abstract of the United States* there were 569,000 people age 25 to 34 in Colorado in 1980. Of these 569,000 people, 302,000 were age 25 to 29 while the remaining 267,000 were age 30 to 34. I divided the number of people in Colorado who were age 25 to 29 by the number of people who were age 25 to 34 to obtain an estimate of the fraction of the 25 to 34 age group in the Denver-Boulder area who were age 24 to 29. I multiplied this fraction by the number of people in the Denver-Boulder area who were age 25 to 34 to obtain an estimate of how many people were age 25 to 29. Again, this method was used to split all the 10-year age groups from age 25 to 64.

The Bureau of the Census, *Statistical Abstract of the United States* did not have any information on the distribution of the population age 65 and over. Splitting the population age 65 and over did not require as much accuracy as the younger age groups because they do not contribute to fertility. I calculated fractions using values of ${}_nL_x$ from the Colorado Life Table to split the remaining group into quinquennial age groups. The fraction used to find the age group 65 to 69 was calculated by dividing ${}_5L_{65}$ by ${}_{10}L_{65}$. This fraction was multiplied by the 10-year age group for ages 65 to 74 to obtain the estimated number of females age 65 to 69. Similarly, the fraction for the age group 70 to 74 is ${}_5L_{70}$ divided by ${}_{10}L_{65}$. The general relationship for the remaining age groups is

$$\frac{{}_5L_x}{T_{75}}$$

where T_{75} is the total expected number of years lived beyond age 75 by the initial cohort. In our specific case T_{75} is the same as ${}_{35}L_{75}$ because the age limit of the projection is 110. The following table contains the population of the Denver-Boulder area in quinquennial age groups using the preceding methods to split nonquinquennial age groups.

Age	Population
Under 5 years	57,401
5 to 9 years	57,538
10 to 14 years	62,183
15 to 19 years	71,094
20 to 24 years	82,661
25 to 29 years	88,771
30 to 34 years	78,483
35 to 39 years	56,520
40 to 44 years	44,806
45 to 49 years	39,995
50 to 54 years	38,545
55 to 59 years	36,505
60 to 64 years	29,842
65 to 69 years	22,703
70 to 74 years	20,681
75 to 79 years	12,972
80 to 84 years	10,057
85 to 89 years	6,465
90 to 94 years	3,098
95 to 99 years	993
100 to 104 years	210
105 to 109 years	35
Total	**821,558**

4.6 The Leslie Matrix

Now that we have calculated all the preliminary numbers we must combine them to form a Leslie matrix. Using the above numbers our Leslie matrix starts on page 18 and continues onto page 19.

4.7 Projections

Once we have the Leslie matrix we are ready to project the population. For each five year period that we want to project the population, we must multiply the baseline population by the Leslie matrix and then add the migration estimates. Below is a table containing the baseline population along with the 1990 population according to my projections and projections for every thirty year period thereafter.

Population	1980	1990	2020	2050	2080
Age 0..4	57,401	71,357	69,008	69,674	71,051
5..9	57,538	75,594	70,585	70,918	72,065
10..14	62,183	59,892	70,030	71,776	73,155
15..19	71,094	59,665	67,616	71,449	73,473
20..24	82,661	64,079	67,558	71,651	74,064
25..29	88,771	74,685	73,047	74,490	76,336
30..34	78,483	86,179	79,206	76,892	77,548
35..39	56,520	90,199	82,703	77,783	78,110
40..44	44,806	78,830	65,955	75,856	77,560
45..49	39,995	56,291	64,580	72,276	75,985
50..54	38,545	44,112	66,829	70,149	74,052
55..59	36,505	38,647	72,737	71,211	72,556
60..64	29,842	36,113	79,145	72,885	70,806
65..69	22,703	32,972	77,635	71,264	67,083
70..74	20,681	25,384	61,758	51,721	59,440
75..79	12,972	17,348	37,962	43,583	48,802
80..84	10,057	13,371	23,075	35,233	37,009
85..89	6,465	6,076	13,024	25,069	24,529
90..94	3,098	2,900	5,992	13,576	12,473
95..99	993	949	1,839	4,517	4,135
100..104	210	206	327	833	693
105..109	35	35	43	99	115
Total	**821,558**	**934,884**	**1,150,654**	**1,192,905**	**1,221,040**

0	0.000823	0.058853	0.193522	0.274251	0.233303	0.12839	0.038442	0.004903	0.000238	0
0.998038	0	0	0	0	0	0	0	0	0	0
0	0.99915	0	0	0	0	0	0	0	0	0
0	0	0.997917	0	0	0	0	0	0	0	0
0	0	0	0.996747	0	0	0	0	0	0	0
0	0	0	0	0.996765	0	0	0	0	0	0
0	0	0	0	0	0.996628	0	0	0	0	0
0	0	0	0	0	0	0.995335	0	0	0	0
0	0	0	0	0	0	0	0.992975	0	0	0
0	0	0	0	0	0	0	0	0.988932	0	0
0	0	0	0	0	0	0	0	0	0.982322	0
0	0	0	0	0	0	0	0	0	0	0.97354
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

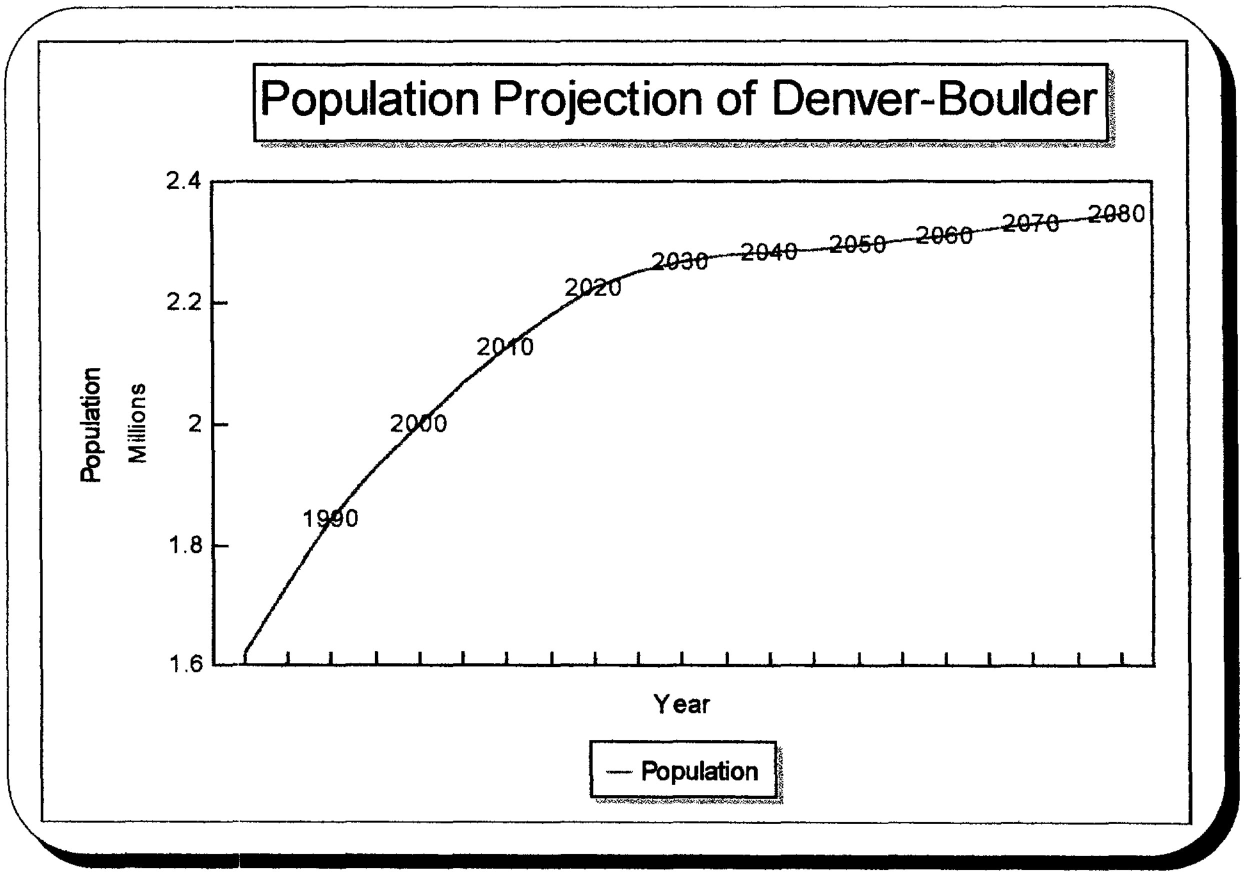
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0.960736	0	0	0	0	0	0	0	0	0	0
0	0.941913	0	0	0	0	0	0	0	0	0
0	0	0.910946	0	0	0	0	0	0	0	0
0	0	0	0.86011	0	0	0	0	0	0	0
0	0	0	0	0.775298	0	0	0	0	0	0
0	0	0	0	0	0.642788	0	0	0	0	0
0	0	0	0	0	0	0.479187	0	0	0	0
0	0	0	0	0	0	0	0.320434	0	0	0
0	0	0	0	0	0	0	0	0.211256	0	0
0	0	0	0	0	0	0	0	0	0.167847	0

The preceding chart contained projections for the female population. The total population including males could be estimated by doubling the female population. This would not be a good estimate if we wanted to estimate the total population by age group. If we want to calculate the population including males as well as female for each age group we could multiply each age group by a ratio of the total population to the female population for each age group using the baseline population. In the early years these ratios should be slightly above two because there are typically more male births than female births. Due to higher mortality in males, females outnumber males at later ages so these ratios can be expected to decrease and eventually dip below two. Below is a chart containing projections that include males and females.

Male and Female

Population	**1980**	**1990**	**2020**	**2050**	**2080**
Age 0..4	117,274	145,787	140,988	142,349	145,162
5..9	117,552	154,441	144,207	144,888	147,231
10..14	126,570	121,907	142,542	146,096	148,903
15..19	145,202	121,859	138,099	145,927	150,061
20..24	164,822	127,770	134,707	142,869	147,680
25..29	179,077	150,661	147,357	150,268	153,992
30..34	158,323	173,848	159,782	155,114	156,437
35..39	113,318	180,841	165,812	155,948	156,604
40..44	89,832	158,047	132,234	152,085	155,501
45..49	79,169	111,427	127,835	143,069	150,410
50..54	76,299	87,319	132,286	138,858	146,584
55..59	69,933	74,037	139,343	136,420	138,997
60..64	57,169	69,182	151,619	139,627	135,644
65..69	39,645	57,578	135,571	124,446	117,145
70..74	36,115	44,327	107,846	90,319	103,798
75..79	19,403	25,949	56,783	65,190	72,997
80..84	15,043	20,000	34,515	52,701	55,357
85..89	9,670	9,088	19,481	37,498	36,690
90..94	4,634	4,338	8,963	20,307	18,657
95..99	1,485	1,419	2,751	6,756	6,185
100..104	314	308	489	1,246	1,037
105..109	52	52	64	148	172
Total	**1,620,902**	**1,840,187**	**2,223,275**	**2,292,126**	**2,345,243**

The following is a graph of the projections for the total population. Note that the growth of the population slows between 2020 and 2030. This slower growth can be attributed to the "Baby Boom" experiencing higher mortality due to old age.



5. Analysis

5.1 Growth rates

The results of my projection show that the population of the Denver-Boulder area will grow throughout the next century. The Denver-Boulder area will experience the fastest growth over the next 30 years. This rapid growth can be attributed to the fertility of the "Baby Boom" generation. The number of newborns will increase over the next decade because the "Baby Boom" generation is in their child bearing years. As the "Baby Boom" generation ages and leaves their child bearing years the growth rate will decrease dramatically as can be seen in projections for the years 2020 through 2050. Eventually the population growth will approach a steady percentage increase. The following table contains growth rates for selected 30-year periods and the total percentage increase during the period.

Population Growth Rates

Ages	Geometric Growth Rate	Percent increase
1990 to 2020	0.63%	20.82%
2020 to 2050	0.10%	3.10%
2050 to 2080	0.08%	2.32%

5.2 Dependency ratios

A dependence ratio measures the dependence of one age group on another age group in a population. Dependency ratios are useful statistics for measuring the effectiveness of government funded retirement plans. In the United States, people rely on three sources for their retirement income. These three sources are government sponsored sources, employer sponsored plans, and personal savings. Of these three sources the government sponsored sources are the most dependent on the age distribution of the population. Most government sponsored retirement plans are funded on a pay-as-you-go basis. A pay-as-you-go funded retirement plan uses funds acquired from those who are currently working to pay for the benefits of those who are retired. Pay-as-you-go funded retirement plans are very sensitive to the age distribution of the population. The strain on the working portion of a population to fund retirement benefits increases as the distribution of the population ages. One statistic used to measure this strain is the age dependency ratio. According to Brown (pager 192), the age dependency ratio is the number of people over 65 divided by the number of people age 20 to 64. In most cases, an increasing age dependency ratio signifies a strain on the working portion of the population.

Another important dependency ratio found in Brown (page 194) measures the strain on the working portion of a population by those who are not old enough to work. This dependency ratio is call the youth dependency ratio and is calculated by dividing the number of people under 20 by the number of people age 20 to 64. The youth dependency ratio is used to measure the burden placed on the population for providing education. The following table contains both the age and youth dependency ratios for my projection along with the expenditure dependency ratios. The expenditure dependency ratio is similar to the total dependency ratio except that it is calculated using the assumption that supporting the elderly costs three times as much as supporting the young (Brown 203).

Population Numbers

	Ages			Dependency ratios			
Year	0..19	20..64	65+	Youth	Aged	Total	Expenditure
1980	506,598	823,120	126,362	0.615461	0.153516	0.768977	1.07600836
1990	543,994	1,005,362	163,060	0.541093	0.16219	0.703283	1.02766281
2020	565,836	1,156,269	366,463	0.489364	0.316935	0.806299	1.44016981
2050	579,259	1,171,388	398,610	0.494507	0.340288	0.834795	1.51537203
2080	591,357	1,194,169	412,037	0.495203	0.34504	0.840244	1.5303249

The dependency ratios show that the population of the Denver-Boulder area is aging. There is an increase in the aged dependency ratio from 1990 to 2020 of about 93%. The aging population also contributes to an increasing total dependency ratio and expenditure dependency ratio. Over the same period the youth dependency ratio is decreasing. This decrease is attributable to the low fertility rates. These dependency ratios show that the Denver-Boulder area could experience a strain in the future providing for the elderly.

6. Final Remarks

Demography is used to measure both quantitative and qualitative characteristics of a population. My thesis dealt mainly with the quantitative measures of the Denver-Boulder area although I did touch upon a few qualitative measures. I focused on the quantitative measures of the Denver-Boulder area because they relate to my current studies better than the qualitative measures.

One result of my projection is that the population of the Denver-Boulder area is going to continue to grow. We are currently in the middle of a large growth period. Eventually we can expect the growth rate to slow. A more important result of my projection is that the distribution of the population will age. An aging population puts a large strain on society. The elderly require significantly more medical attention than the youth. Since the elderly are past their productive years, a large part of the burden for providing medical attention falls on the working aged population. The "Baby Boom" generation will approach retirement age in a couple of decades. The current system for providing benefits for the elderly may not be equipped to handle the strain of a group as large as the "Baby Boom" generation. It may be necessary to change the Social Security system to deal with the aging population.

In my projection the population of the Denver-Boulder area increased and the trend seems to be a continued increase. Eventually the population would reach a point where it started to decrease if we were to ignore migration. This statement is also true of the United States population. According to the U.S. Bureau of the Census, *Projections for the Population of the*

United States, by Age, Sex, and Race: 1983 to 2080, if immigration was to decrease the population would eventually decrease after the "Baby Boom" generation passes away. It is not always possible to blame one statistic for a trend that relies on several statistics but in this case immigration is responsible for the continued growth. By severely limiting the number of immigrants allowed into the country we can solve many of the problems in the United States and in the world.

The question is how will limiting the number of immigrants into the United States solve any world problems. The people of the United States are the largest consumers of natural resources and polluters in the world yet we are not one of the largest countries. If we were to limit our immigration and therefore slow the growth and eventually cause a decline in our population the world's environment would benefit. By allowing our population to grow we are contributing to the death of our planet. If we closed our doors to immigrants we would be forcing them to stay in their original countries where they will quite possibly be less of a burden to the planet. Many of these immigrants come to the United States to escape substandard conditions in their native countries. Instead of absorbing these immigrants we could help them to improve the conditions of their countries.

If the population continues to increase we will eventually run out of space and resources. I am not suggesting that population mandates be imposed. Eventually the population will either hit the limit that the Earth can sustain or people will decide to have fewer children. In either case, the key will be to use our resources more efficiently and take care of our environment because there is only one Earth.

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