Massachusetts Population Projections by Regional Planning Area

Projections Methodology

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Introduction

In 2015, with support from the Massachusetts Secretary of the Commonwealth, the UMass Donahue Institute (UMDI) published a public-use series of population projections to 2035 by age, sex, municipality, and Massachusetts regions[1].

More recently, in 2017 and 2018, UMDI worked in agreement with the Massachusetts Department of Transportation (MassDOT) to update these projections for each Municipal Planning Organization (MPO) for use in their Statewide Transportation Planning Model. For the revised population projections, UMDI worked in collaboration with a Projections Advisory Committee that included representatives from each of the Massachusetts Regional Planning Agencies, including the Metropolitan Area Planning Commission, the Central Transportation Planning Staff of the Boston Region Metropolitan Planning Organization (CTPS), and Massachusetts DOT as well as other interested stakeholders. The Advisory Group provided input on model updates including the integration of an updated launch population; decisions around which period rates to use for fertility and mortality; and model modifications for improved performance in their regions.

This methodology report details both the 2015 series projections (V2015) methods and data sources as well as the updates and changes applied to these for the 2018 vintage projections (V2018).

It is important to note that modeled projections cannot and do not purport to predict the future, but rather may serve as points of reference for planners and researchers. Like all forecasts, the UMDI projections rely upon assumptions about future trends based on past and present trends which may or may not actually persist into the future. The V2018 series employs a *status-quo* model approach to predict future population change. It assumes that recently observed trends in the components of population change, including birth, death, and migration rates, will persist in future years. It is also a demographically-based model, assuming that population change is driven by births, deaths, and the persistence of historic migration rates into the future.

[1] *Long-Term Population Projections for Massachusetts Regions and Municipalities.* UMass Donahue Institute. March 2015. http://www.donahue.umassp.edu/business-groups/economic-public-policy-research/massachusetts-population-estimates-program/population-projections

Method Overview

UMDI produces cohort-component model projections for two different geographic levels: municipalities and eight sub-state regions defined specifically for the model. These sub-state regions include the Berkshire/Franklin, Cape and Islands, Central, Greater Boston, Lower Pioneer Valley, MetroWest, Northeast, and Southeast regions. The UMDI projections are produced at five-year intervals beginning in 2015 and ending in 2040 by sex and by five-year age groups, from 0-4 through 85+.

We use a cohort-component model based on a combination of trends in fertility, mortality, and migration from 2000 through 2015. Our regional-level method makes use of American Community Survey sample data on migration rates by age and uses a gross, multi-regional approach in forecasting future levels of migration. Our municipal-level estimates rely on residual net migration rates computed from vital statistics and decennial Census data. Municipal age/sex projections are controlled to the regional projections age/sex projections and are then summed up to MPO totals by aggregating all age/sex/town cohorts that fall within the MPO. RPAs are then given the opportunity to re-distribute these regional totals within their own catchments areas. Appendix A to this report shows the geographic correspondence between municipalities and their respective UMDI model and MPO regions.

While most MPO regions in the state are modelled identically, we adjust the model to account for specific data issues in the Cape Cod and Island Regions. We also make an adjustment to the 2015 base population distribution in the Greater Boston region due to specific concerns related to college students in the region. These variations are discussed in further detail in the Technical Discussion of Methods and Assumption section of this report.

Technical Discussion of Methods and Assumptions

This section provides a technical description of the process used to develop 1) sub-state regional and 2) municipal-level population projections. While both levels of projections are prepared using a cohort-component method, the major methodological difference is in the way migration is modeled: the municipal-level estimates (also referred to as Minor Civil Divisions, or MCDs) rely on residual net migration rates computed from vital statistics, while the sub-state regional projections use gross domestic migration rates based on the American Community Survey Public Use Microdata (ACS PUMS). MCD projections are controlled to projections developed for eight sub-state regions in order to smooth out variations due to data quality issues at the MCD level and ensure more consistent and accurate projections at higher-level geographies. These controlled MCD projections are then be re-aggregated to MPO regions and provided to RPAs for customized distribution. In the final population projections published by MassDOT, some Regional Planning Agencies maintained the original town-level age/sex projections prepared by UMDI to create the MPO projections, while others redistributed these according to specific emergent economic developments or planning initiatives in their regions.

Regional-Level Methods and Assumptions

Summary

This section describes the process and data used to develop the regional population projections. These projections were developed separately for eight Massachusetts regions, although each region was produced following the same framework, with some variations applied to the Cape and Island and Greater Boston regions. The methodology describing how the regional projections were used to estimate municipal population projections follows in Part B of this section.

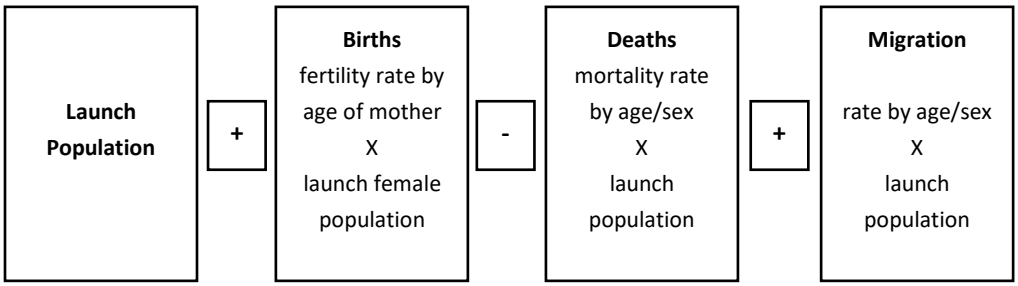
Our regional projections are based on a demographic accounting framework for modeling population change, commonly referred to as a cohort-component model. The cohort-component method recognizes that there are only four ways that a region's population can change from one time period to the next. It can add residents through either births or in-migration, or it can lose residents through deaths or out-migration. In our regional-level model, we further divide migration by whether domestic or international, and use separate estimation methods for each.

The cohort-component approach also accounts for population change associated with the aging of the population. The current age profile is a strong predictor of future population levels, growth and decline and can differ greatly from one region to another. For example, the Greater Boston region has a high concentration of residents in their twenties and early thirties, while the Cape and Islands have large shares of near and post-retirement age residents. Furthermore, the likelihood of birth, death, and in- and out-migration all vary by age. Because fertility rates are highest among women in their twenties and early thirties, a place that is anticipating a large number of women coming into their twenties and thirties in the next decade will likely experience more births. Similarly, mortality rates are notably higher for persons 70-years and older, such that an area with a large concentration of elderly residents will experience more deaths in decades to come.

Developing a cohort-component model involves estimating rates of change for each separate component and age-sex cohort (i.e. age-specific fertility rates, survival rates, and in- and out-migration rates) - typically based on recent trends. It then applies these rates to the current age profile in order to predict the likely number of births, deaths, and migrants in the coming years. The changes are added to or subtracted from the current population, with the resulting population aged forward by a set number of years (five years, in our case). The result is a prediction of the anticipated number of people in each cohort X years in the future. This prediction becomes the new starting baseline for estimating change due to each component an additional X years in the future. The process is repeated through several iterations until the final target projection year has been reached.

Figure 1. Cohort Component Method

For each age/sex/geography cohort:

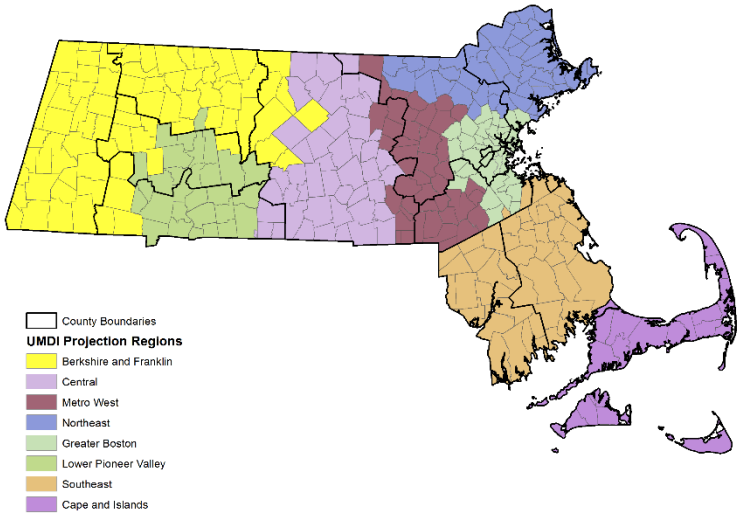


Regional definitions

A preliminary step in generating our regional projections was to determine the boundaries for each of our study areas. We use the definitions for the MassBenchmarks regions as a starting point. The Benchmarks regions were designed by the UMass Donahue Institute to approximate functional regional economies (sets of communities with roughly similar characteristics in terms of overall demographic characteristics, industry structure, and commuting patterns). These Benchmarks regions constitute a widely accepted standard among policy officials and analysts statewide that meet common perceptions of distinct regional economies in Massachusetts.

We then compared the Benchmarks regions to the boundaries of Public Use Micro-Sample Areas, also known as PUMAs. PUMAs are the smallest geographic units used by the U.S. Census Bureau for reporting data taken from the detailed (micro) records of the American Community Survey (ACS) – our primary source of migration data. PUMA boundaries are defined so that they include no fewer the 100,000 persons, and thus their physical size varies greatly between densely settled urban and sparsely settled rural areas. And although PUMAs do not typically match county boundaries, in Massachusetts individual PUMAs can be grouped together to form regions whose outer boundaries match aggregated groups of individual municipalities. This critically important feature allows us to match Census micro-data with other Census data and State vital statistics estimates we obtained at the municipal level (i.e. births and deaths). We performed our regional grouping using Geographic Information System mapping software. The resulting study regions are presented in Figure 2 and are cross-walked to municipalities in Appendix A to this report.

Figure 2. UMDI Projection Regions



Estimating the components of change

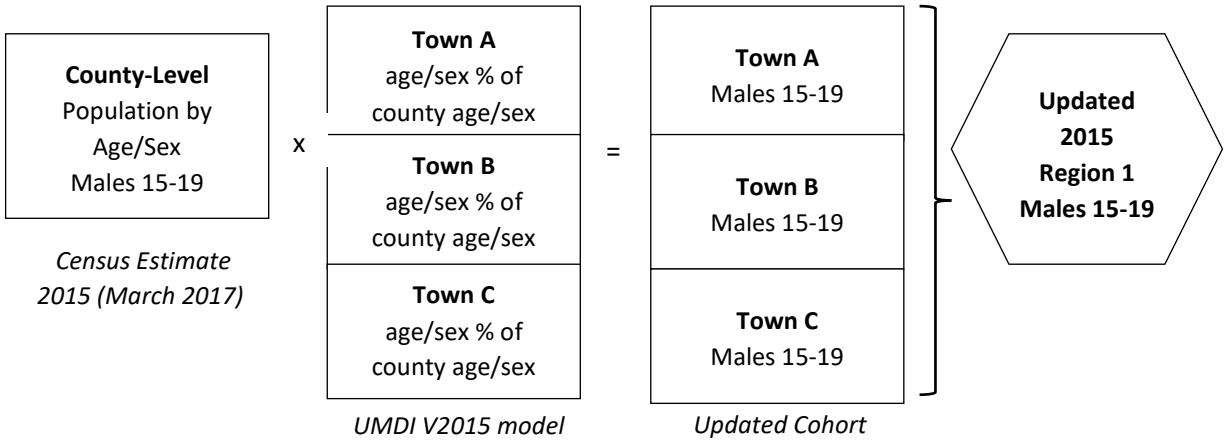
Determining the launch year and cohort classes

We begin by classifying the composition of resident population into discrete cohorts by age and sex. Following standard practice, in the 2015 vintage series, we used five year age cohorts (e.g. 0- 4 years old, 5- 9,… 80-84, and 85-and older) and developed separate profiles for males and females, based on information provided in the 100% Count (SF 1) file of the 2010 Decennial Census of Population to serve as the starting point (i.e. launch year) for generating forecasts.

In the current vintage 2018 (V2018) series for the MassDOT project, we instead launch the projections from the year 2015, to better capture the rapid growth experienced in Massachusetts following the last Census. Population counts or estimates by age, sex and municipality are not produced by the Census Bureau in non-decennial years, although they do produce estimates by age, sex, and county. Therefore, to estimate the needed 2015 “launch” cohorts by age, sex, and municipality, we take the UMDI V2015 projected populations by age, sex, and municipality for 2015 and control these to the most current U.S.

Census Bureau estimates of the 2015 population by age, sex, and county.[2] Specifically, we control each age/sex/MCD cohort within a county to its corresponding age/sex/county cohort total. For example, if a town included 10% of a county's age/sex cohort in the UMDI V2015 projected population for 2015, it is assigned 10% of the Census Bureau's updated county cohort population as its new base or "launch" population. The new municipal-level age/sex cohorts are then summed to their respective regions for updated 2015 launch populations in the regional model. See Figure 3 below for illustration.

Figure 3. Municipal-Level 2015 Launch Populations



The Greater Boston study-region is treated slightly differently in the launch re-set method. The U.S. Census Bureau's Vintage 2016 age/sex estimates for Suffolk County were showing a very large increase in persons in the age 25-29 cohort. This could represent real population change, or it could be an artifact of U.S. Census Bureau estimation techniques. Because the post-census estimates are not actual counts, it is hard to determine. Suffolk County is home to a large number of college and graduate students who might have been aged forward in the Census Bureau estimates when they should have been out-migrated and replaced with new students instead. The concept of treating college students as a "revolving door" population is called the "college fix", and it is a method applied by the Census Bureau in many other "college counties." Because Suffolk County is over the population-size threshold for the Bureau's college fix, this method was not applied by the Bureau in our study year.[3] For this reason, UMDI determined, in agreement with the region's MPO, to control the UMDI V2015 age/sex/MCD estimates to the *total* county population instead of controlling to the Census 2015 age/sex cohort totals. The resulting Suffolk County age/sex/municipal cohorts are the summed and added to the other municipal cohorts in the Greater Boston study region to comprise the new 2015 age/sex launch

[2] Annual Estimates of the Resident Population for Selected Age Groups by Sex for the United States, States, Counties, and Puerto Rico Commonwealth and Municipios: April 1, 2010 to July 1, 2016. (Table PEP_2016_PEPAGESEX). U.S. Census Bureau, Population Division. Release Date: June 22, 2017.

[3] The college fix WAS applied to Hampshire County in the U.S. Census Bureau's V2016 estimates series, another Massachusetts county with a large percent of population enrolled in college in the county.

populations for the regional model. In this way, the resulting population sum is the same as the Census Bureau's estimated 2015 population, but the distribution of population follows the UMDI V2015 age/sex distribution.

Deaths and Survival

The first component of change in our model is survival. Our projections require an estimate of the number of people in the current population who are expected to live an additional five years into the future. Estimating the survival rate of each cohort is fairly straightforward. For the UMDI V2015 series, the Massachusetts Department of Public Health provided us with a detailed dataset that included all known deaths in the Commonwealth that occurred between 2000 to the end of calendar year 2009. This database includes information on the sex, age, and place of residence of the deceased, which we aggregated into our study regions by age/sex cohort. In the regional model, we estimate the five-year survival rate for each cohort (*j*) in study region (*i*) as one minus the average number of deaths over the past five years (2005 to 2009) divided by the base population in 2005 and then raised to the fifth power, or:

$$Survival\ Rate_{i,j} = \left[1 - \left(\frac{Deaths_{i,j}}{Population_{i,j}}\right)\right]^5. \qquad (1)$$

Following the recommendations of Isserman (1993), we calculate an operational survival rate as the average of the five-year survival rates across successive age cohorts. The operational rate recognizes that, over the next five years, the average person will spend half their time in their current age cohort and half their time in the next cohort. We estimate the number of eventual survivors in each cohort by 2015 by multiplying the operational survival rate against the cohort population count as reported by the 2010 Census.

For the V2018 MassDOT updates, we updated births and deaths to a more current period. Because the lead time required to obtain birth and death data by age at the town level was beyond the scope of this project timeline, we reviewed publicly available state-level fertility and mortality by age over the 2003 through 2015 time series, the latest data we were able to obtain by age and sex.[4] Figures 4 and 5 below display Massachusetts male and female mortality by age from 2003 through 2015.

As rates change over time, we next had to determine whether it was more reasonable to use the most recent 5-year period rates or use a longer period of up to 15 years to project forward in our model. Figure 6 compares combined male and female deaths by age using averaged 2005-2010 rates (used in our last V2015 model) as versus longer term 2005-2015 averaged rates and most recent 2010-2015 rates. Figures 7 and 8 display this same information for the population under 50 and the population aged 50-plus, respectively. After discussion and an examination of the projected impact by region, the

[4] Source of births and deaths rates: United States Department of Health and Human Services (US DDHS) Centers for Disease Control and Prevention (CDC) National Center for Health Statistics (NCHS). See Data Sources Notes in Appendix B to this report for additional source detail. Calculations of percent change in rates by UMDI.

Projections Advisory Committee and the UMDI projections team agreed to use the most recent 5-year period of 2011-2015 as a basis for projecting forward.

To update our model, we calculate the percentage change in deaths per thousand by age and sex between the averaged 2005-2009 rates already in our model and the updated averaged 2011-2015 rates. We then apply this percent change to deaths by age in our existing regional model, shifting deaths by age to align with more current trends. The updated deaths by age are then used to calculate survival rates as described earlier in this section.

Figure 4. Massachusetts Female Mortality Rates by Age, 2003-2015

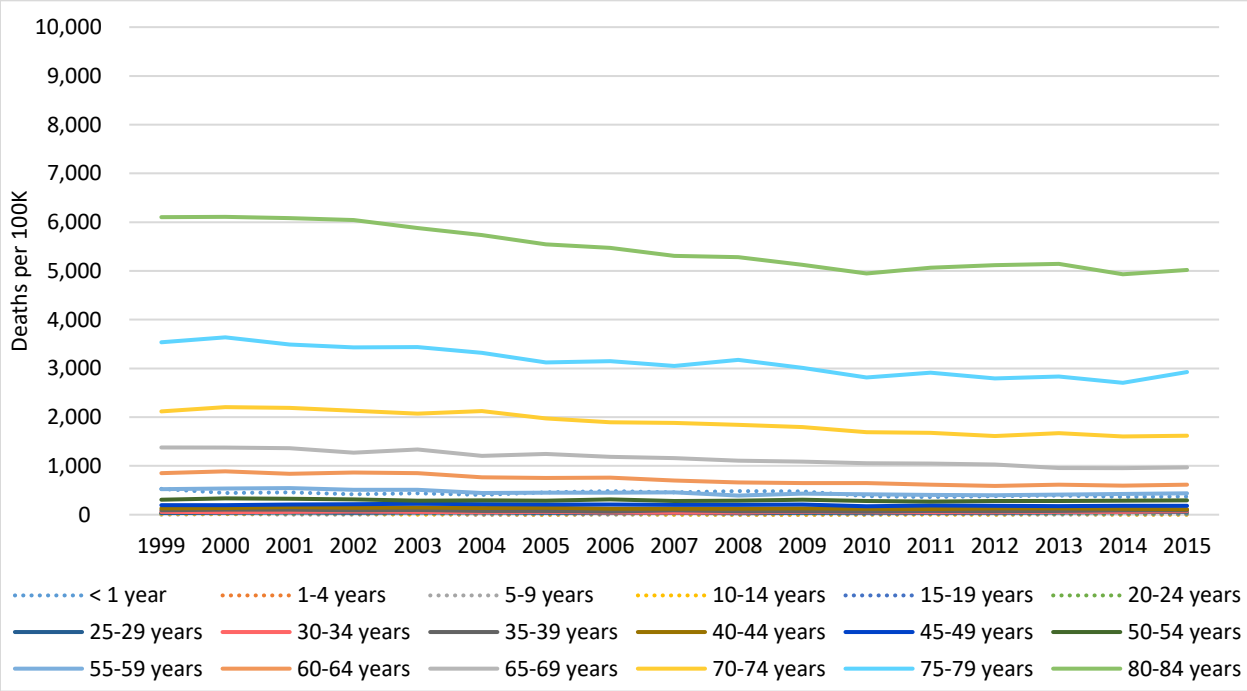


Figure 5. Massachusetts Male Mortality Rates by Age, 2003-2015

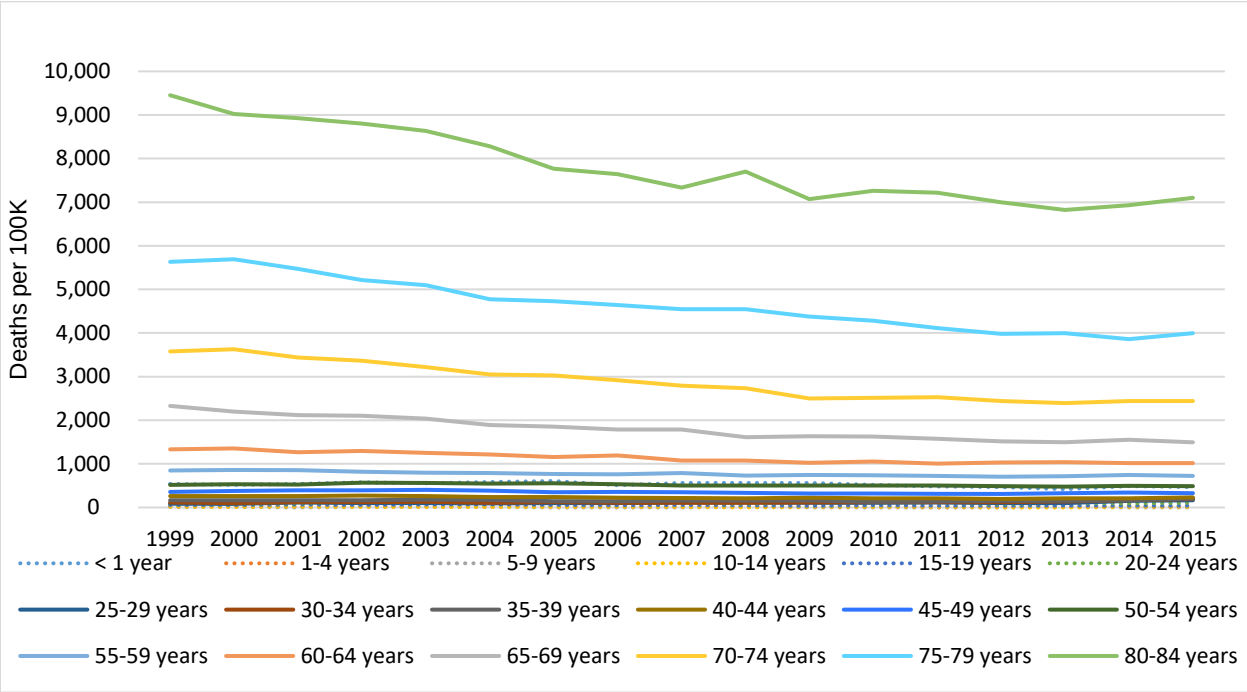


Figure 6. Massachusetts Mortality Rates by Age Comparison: 2005-2010, 2010-2015, and 2005-2015

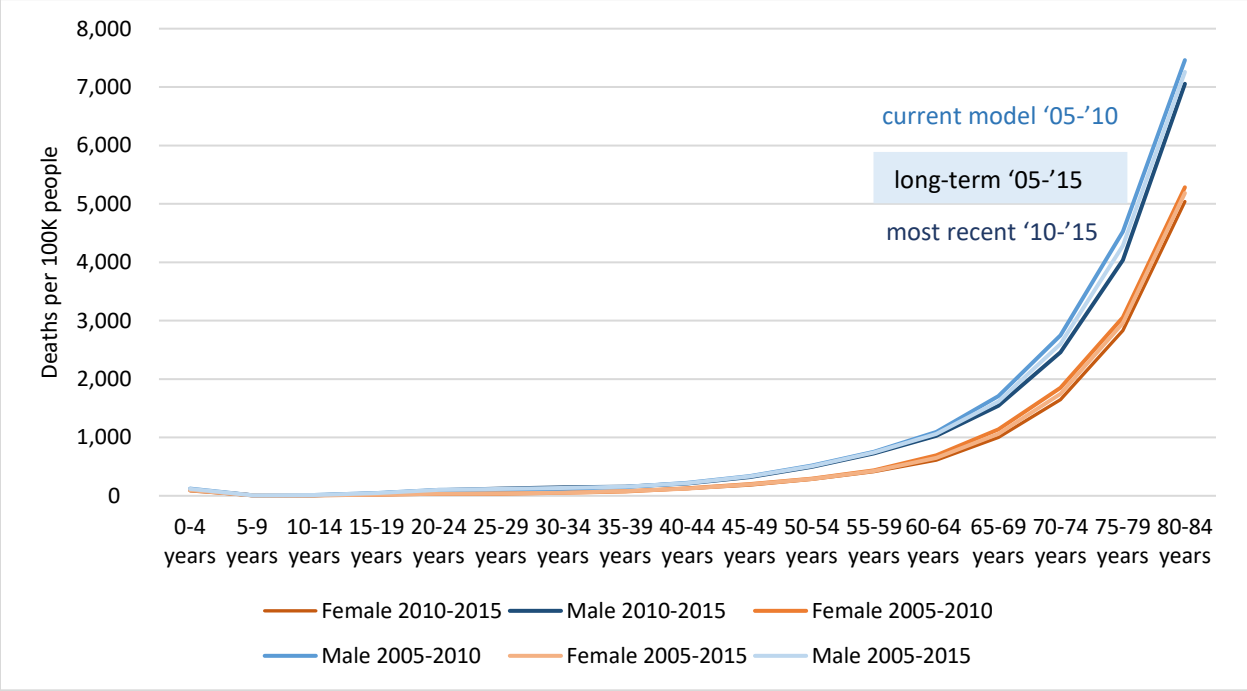


Figure 7. Massachusetts Mortality Rates by Age <50, Comparison: 2005-2010, 2010-2015, and 2005-2015

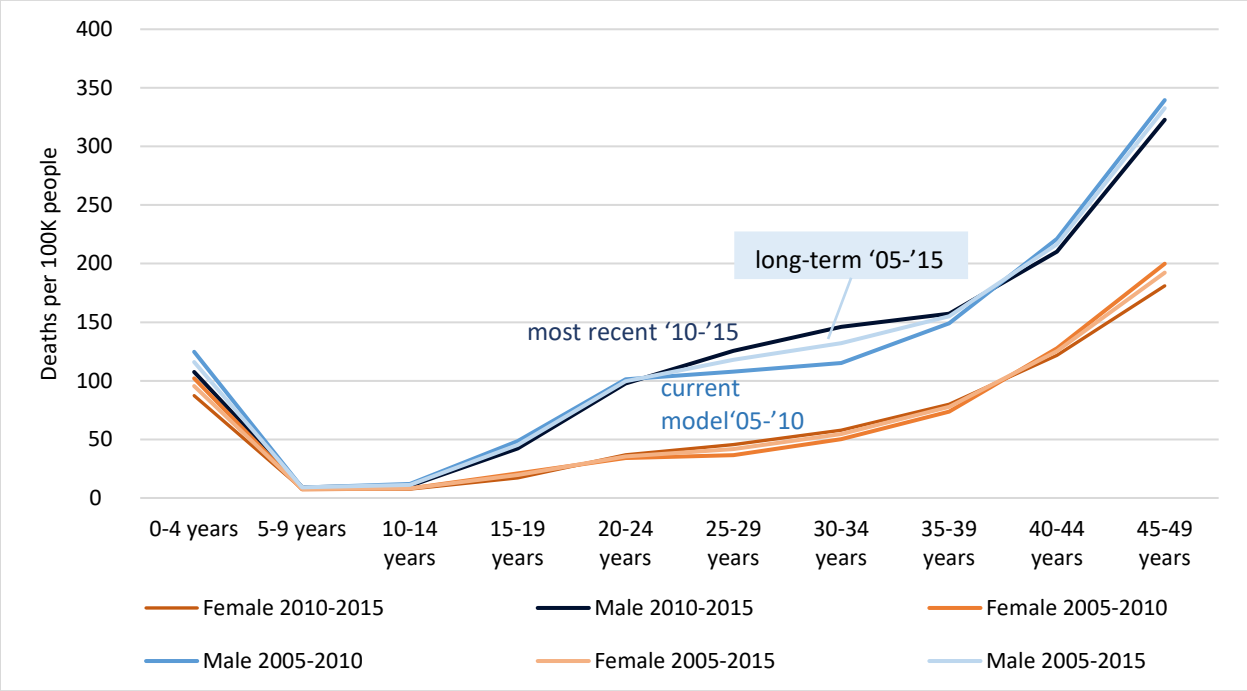
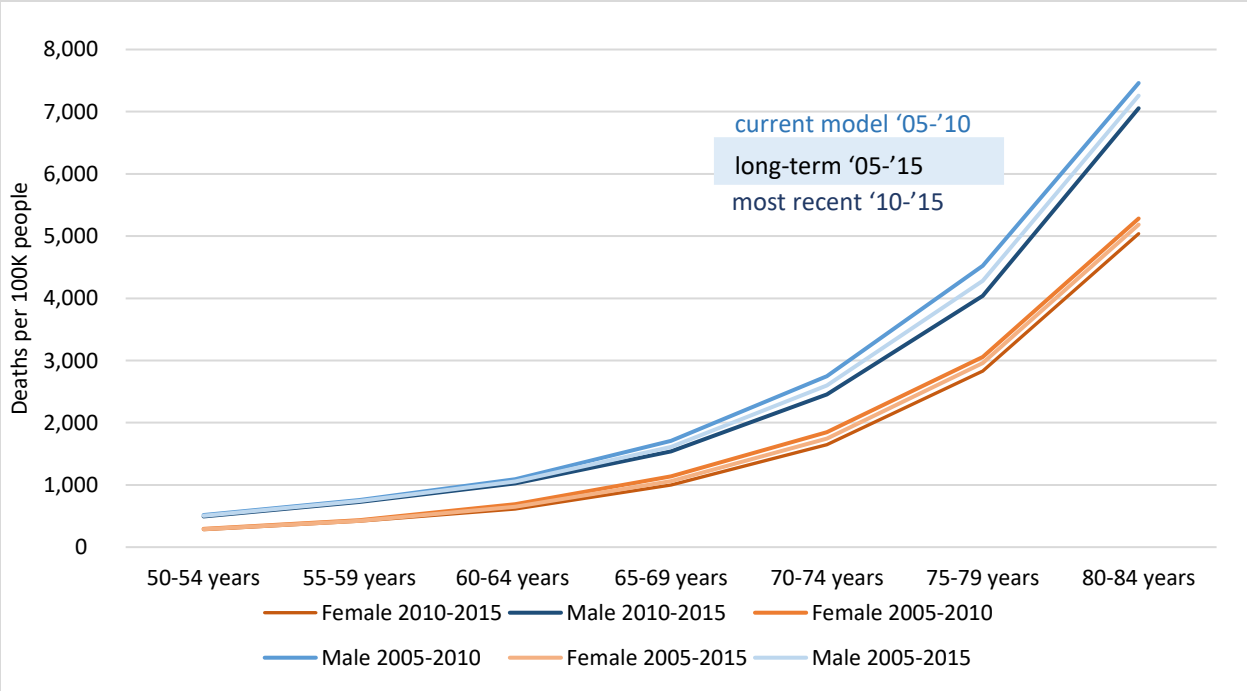


Figure 8. Massachusetts Mortality Rates by Age 50+, Comparison: 2005-2010, 2010-2015, and 2005-2015



Domestic Migration

Migration is the most dynamic component of change, the most difficult to estimate, and the most likely source of uncertainty and error in population projections. Whereas fertility and mortality follow fairly regular age-related patterns, the migration behavior of similar age groups is influenced by regional and national differences in socio-economic conditions. Furthermore, the data needed to estimate migration is often restricted or limited; especially for many small areas. Even when it is available, it is based on statistical samples and not actual population counts, and thus is prone to sampling error – which will be larger for smaller regions.

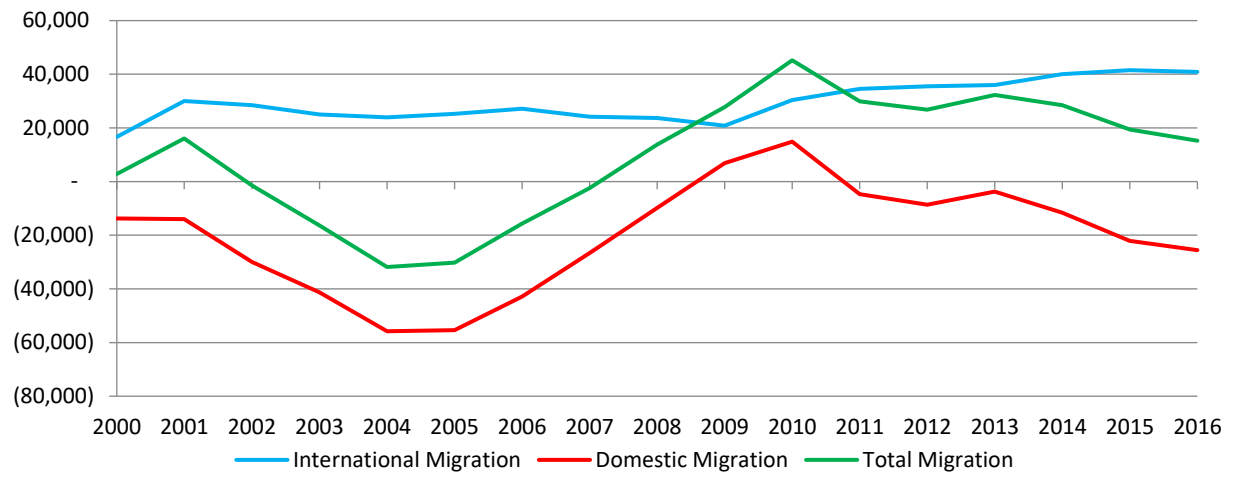
Due to data limitations and the other methodological challenges, applied demographers have developed a variety of alternate models and methods to estimate migration rates. No single method works best in all circumstances, and we evaluated numerous approaches in the development of our projections. Those presented in this report are based on a particularly novel approach known as a multi-region gross migration model as discussed by Isserman (1993); Smith, Tayman and Swanson (2001); and Renski and Strate (2013). Most analysts use a net migration approach, where a single net migration rate is calculated as the number of net new migrants per cohort (in-migrants minus out-migrants) divided by the baseline cohort population of the study region. Although common, the net migration approach suffers from several conceptual and empirical flaws. A major problem is that denominator of the net migration rate is based purely on the number of residents in the study region. However, none of the existing residents are at risk of migrating into the region – they already live there. While this may seem trivial, it has been shown to lead to erroneous and biased projections especially for fast growing and declining regions.

A gross-migration approach calculates separate rates for in- and out-migrants. Beyond generating more accurate forecasts in most cases, it has an added benefit in that it connects regional population change to broader regional and national forces – rather than simply treating any one region as an isolated area. This type of model is made possible by utilizing the rich detail of information available through the newly released Public Use Micro-Samples (PUMS) of the American Community Survey (ACS). The ACS is a relatively new data product of the U.S. Census Bureau that replaced the detailed information collected on the long-form of the decennial census (STF 3). It asks residents questions about where they lived one year prior, which can be used to estimate the number of domestic in- and out-migrants. Unfortunately, the ACS does not report enough detail to estimate migration rates by detailed age-sex cohorts in its standard products. This information can be tabulated from the ACS PUMS – which is 5% random sample of individual records taken drawn the ACS surveys[5]. Each record in the PUMS is given a survey weight, which we use to estimate the total number of migrants by detailed age and sex cohorts. In our model, we develop migration rates using data from the 2005 to 2009 ACS PUMS as well as the 2007 to 2011 ACS

[5] To account for small or missing samples in some cohorts in some regions, we make some limited adjustments to the ACS PUMS data before calculating migration rates based on the data. In the Berkshire/Franklin region, male and female migrants under the age of 15 are assigned the male/female average number of migrants before a rate is calculated in order to smooth out male/female ratios resulting from small sample sizes. In other regions, cohorts under age 75 with a sample size of zero in the ACS data are assigned values from the opposite gender when it is available to reduce instances of rates calculated from a null value.

PUMS, the most recent five-year dataset available at the PUMA level of geography. [6] Before moving ahead with the 2005-2011 rates, we first reviewed the domestic migration component trend in Massachusetts from 2005 through 2015 to make sure that more recent net migration levels in the state were comparable to the ACS data period in our model. See figure 9 and Table 1 below for comparisons by period.

Figure 9. Massachusetts Estimated Migration, 2000-2016



Source Data: ST-2000-7; CO-EST2010-ALLDATA; and NST-EST2016-ALLDATA, U.S. Census Bureau Population Division.

Table 1. Comparison of Massachusetts Net Migration Average by Period

Average Annual	2005-2011 *In model*	2007-2016 *Last 10 years*	2012-2016 *Last 5 years*
Domestic	-1,243	-9,107	-14,329
International	23,287	32,757	38,787
Total Net	22,044	23,650	24,458

It is very important to realize that the PUMS records are based on small, although representative, samples – and that the smaller the sample the greater the margin of error[7]. Sample sizes can be

[6] Starting with the 2012 American Community Survey, migration by age/sex estimates are no longer tabulated by the U.S. Census Bureau for PUMAs, but only much larger MIGPIMA geographies. These MIGPUMAs do not allow for the geographic specificity desired in the MA DOT model.

[7] While we are aware of the potential for sampling error in using ACS PUMS data for these small regions, it is the only direct source of gross migration by age available to us at this time. IRS data on migration does include gross migration data for tax-filers at the county level; however the released data does not include age detail. The Current Population Survey, another

particularly small when distributed by age and sex cohorts for different types of migrants, especially in small regions. For this reason, the Berkshire/Franklin and Cape & Islands are two regions that can be treated with more skepticism in our projections results and which lend themselves to greater cross-examination by alternative methods[8]. These two regions were counted at fewer than 250,000 persons each in the 2010 Census and are subject to larger sampling error than the other six sub-state regions which all number more than 600,000 persons, and sometimes over 1 million. The Cape & Island Region also further breaks out into three distinct MPO regions in the MA DOT projections series. For these reasons, we use an alternative migration model in our projections for the Cape & Islands, described later in this report.

Estimating domestic out-migration is largely similar to estimating net-migration. Because current residents of the study region (*i*) are those who are 'at risk' of moving out, so the appropriate cohort (*j*) migration rate is:

$$Out\ Migration\ Rate_{i,j} = \left(\frac{OutMigrants_{i,j}}{Population_{i,j}}\right). \quad (2)$$

Because migration in the ACS is based on place of residence one-year prior, the out-migration rate reported in equation (2) is the equivalent of a single year rate. We multiply this by five to estimate the five-year equivalent rate, and, as we did with survival rates, average the five year rates across succeeding cohorts to craft an operational five year rate.[9] The operational rate for each cohort is then multiplied against the number of eventual survivors in 2015 to estimate the number of likely out-migrants from the surviving population.

In-migration is more challenging. The candidate pool of potential domestic in-migrants is not those currently living in the region, but people living elsewhere in the U.S. Modeling in-migration thus requires collecting data on the age-sex profile of not only the study region, but for other regions as well. We model two separate regions as possible sources of incoming migrants in the multi-regional framework - those originating in neighboring regions and states (New York, Connecticut, Rhode Island, New Hampshire, and other Massachusetts regions) and those coming from elsewhere in the U.S. By doing so, we recognize that most inter-regional migration is fairly local and that the migration behavior of the Northeast is likely to differ considerably from that of the rest of the nation – in part due to our older and less racially diverse demographic profile.

sample survey product from the U.S. Census Bureau, provides migration data by age, but only down to the U.S. regional level of geography. Other methods commonly used to estimate migration do so using an indirect method of calculating net migration by age as a residual of a cohort-survival method

[8] For information on alternative projections methods and results for the Berkshire/Franklin and Cape & Islands regions, researchers may contact the Population Estimates Program of the UMass Donahue Institute.

[9] This differs from calculating the five-year survival rate, where the one-year rate was taken to the fifth power. Survival is modeled as a non-recurring probability, since you can only die one. However, we assume that any individual migrant could move more than once during the study period, and multiply the single year rate by five to estimate a five-year equivalent.

Thus the in-migration rates characterizing migration behavior from neighboring regions (*NE*) to study region (*i*) and from the rest of the United States (U.S.) are calculated as:

$$In\ Migration\ Rate_{NE\ to\ i,j} = \left(\frac{InMigrants_{NE\ to\ i,j}}{Population_{NE,j} - Population_{i,j}}\right) \quad (3)$$

$$In\ Migration\ Rate_{US\ to\ i,j} = \left(\frac{InMigrants_{US\ to\ i,j} - InMigrants_{NE\ to\ i,j}}{Population_{US,j} - Population_{NE,j}}\right). \quad (4)$$

As with the out-migration, each single-year in-migration rate is converted into a five-year operational migration rate. Unlike out-migration, these in-migration rates are not multiplied against the surviving regional population for the study region but instead the cohort population for the region of origin (neighboring regions for equation 3 or the rest of the U.S. for equation 4) to reflect the true population at risk of in-migration. The data for estimating the launch year cohort size for other regions is aggregated from the 2010 Census of Population (SF 1), with the study region cohort population subtracted from the base of neighbor regions and neighbor populations subtracted from the United States cohort population.

College Migration

Tracking the migration of college students is often problematic for researchers, as neither the ACS nor conventional tax-return migration data seems to capture their movement comprehensively or accurately. For this reason, the U.S. Census Bureau applies a "college fix" in their annual county-level population estimates to areas that meet their criteria for percent of population enrolled in college and other population thresholds[10]. In the basic application of the "college fix", the college-enrolled population in a region is held back from aging and migration experienced by the non-college population over the specified time period, and is then restored to the region at the end of the period. In this way, the college-enrolled population remains more or less fixed for a region while other cohorts migrate and age over time.

In both the UMDI Vintage 2015 and the updated 2018 projections models, we apply a "college fix" method to the 15-19, 20-24, and 25-29 age cohorts in three regions: Greater Boston, Lower Pioneer Valley, and the Central Region. According to ACS 2007-2011 data, these regions all show significant percentages of college enrollment as follows:

[10] *The "College Fix": Overcoming Issues in the Age Distribution of Population in College Counties*. Ortman, Sink, King. Population Division, U.S. Census Bureau. October 2014.

Table 2. ACS 2007-2011 Population Enrolled in College or Graduate School by Region

UMDI Region	Greater Boston		Lower Pioneer Valley		Central Region	
Age cohort	# enrolled	% of cohort	# enrolled	% of cohort	# enrolled	% of cohort
15-19	55,018	39%	19,565	36%	14,207	27%
20-24	97,496	54%	30,255	57%	22,624	49%
25-29	44,479	24%	5,557	15%	5,613	14%

The UMDI college fix method, like the Census Bureau's, holds out the college enrolled portion of these three cohorts from aging and migration and then adds it back into its original cohort five years later. For each of the "College Fix" regions, we use 2007-2011 ACS data to determine the share of population enrolled in college or graduate school in each of the age cohorts. The share is based on the region's enrolled cohort as a percent of the total U.S. cohort. We apply this share by age and sex to the base year population in order to estimate the regional college population and then subtract this from the total regional population. The difference is the estimated "non-college" population. This non-college population is subject to the same migration method described in the domestic migration section above, except that the migration rates are based solely on the non-college population and migrants in the ACS data. The resulting net number of non-college domestic migrants is added to each non-college cohort, which is then aged forward by five years. Finally, the enrollment share for each cohort is applied to the latest U.S. cohort total to determine a new estimate of the college-enrolled population for the region. This updated college estimate is added to the projected population. Below is an example for the 2015 to 2020 period.

Figure 10. College Fix Method Example

2015		2020
non college pop 10-14	*age 5 years and add net migrants 2015-2020→*	non-college pop 15-19
college pop 15-19	*not aged; apply % enrolled to 2020 U.S. population 15-19→*	college pop 15-19
non college pop 15-19	*age 5 years and add net migrants 2015-2020→*	non-college pop 20-24
college pop 20-24	*not aged; apply % enrolled to 2020 U.S. population 20-24→*	college pop 20-24
non college pop 20-24	*age 5 years and add net migrants 2015-2020→*	non college pop 25-29
college pop 25-29	*not aged; apply % enrolled to 2020 U.S. population 25-29→*	college pop 25-29
non college pop 25-29	*age 5 years and add net migrants 2015-2020→*	non college pop 30-34

Because the college population is held out of the aging process, and because migration is only captured for the non-college population, we had to make two additional adjustments to our model. First, we allow portions of the college-enrolled population aged 20-24 and 25-29 to age forward into the non-

college population[11]. This accounts for the college-enrolled population that ages in place into the non-college population (i.e. those that come for college or graduate and stay). Additionally, we account for the region's non-college population that joins the college population upon migrating out of the region (i.e. those who leave their homes in Massachusetts to attend college elsewhere in the U.S.) by capturing them as out-migrants[12].

International Migration (immigration and emigration)

International immigration in our model is estimated according to the number of international migrants, by age and sex, indicated for each region by the ACS 2007-2011 PUMS dataset. Unlike domestic migration in our model, however, the estimates of international immigrants from the ACS are not then converted to rates. With domestic migration, we can more comfortably make the assumption that there is a relationship between the number of migrants (our numerator) and another region (our denominator) that might be expected to remain relatively constant over time - for example the number of out-migrants relative to the region's population or the number of in-migrants relative to the U.S. population. In the case of international migration, it is harder to make an assumption that, for example, as the world population by age increases, the region's immigrants will increase at the same rate. In reality, a great number of factors not related to any particular region's current population will influence future immigration levels, including federal immigration policy change, college recruitment policies, and labor needs, to name just a few. Instead of trying to guess at which way these changes will affect immigration to each region, we assume that the levels experienced in recent history, in this case the 2007 to 2011 period, will be sustained, and in our Vintage 2015 model the number of immigrants by cohort remain constant over the time period.

There is no consensus on how best to deal with emigration in a gross-migration context. One quirk of the ACS is that while it does contain information on the residence of recent international immigrants, it contains no information that might be used to estimate emigration. This is because the ACS only surveys people currently living in the U.S. This includes recent immigrants, but not people that moved out of the nation during the last year.

But, while we cannot directly estimate the number of emigrants in a five-year period using regional level ACS data, there are alternative methods that can be borrowed to at least approximate the number for each region. The U.S. Census Bureau developed emigration rates for the foreign born population -- the population most prone to emigration -- for a demographic analysis of net international migration. The rates were developed using a residual method and data from Census 2000, the American Community

[11] To determine this proportion we applied a residual survival method using estimates of the college-enrolled and total populations by age in 2005 and 2010, based on enrollment levels by age indicated in the ACS 2005-2009 PUMS data. In an adjusted to the Greater Boston regional model, we also allow some portion of the 15-19 year old college enrollees to age in place into the non-college population. This age group did not appear to be aging into non-college in the two other college regions based on our residual calculations.

[12] Out-migrants that are enrolled in college in regions outside of the study area, as captured in the ACS PUMS datasets.

Survey, and life tables from the National Center for Health Statistics[13]. They estimated emigration rates ranging from of 12.8 to 15.5 per 1,000 among the population of recently arrived foreign born (those entering the U.S. within 10 years prior to the survey) and rates of just 1.7 to 3.5 per 1,000 for the foreign born population with longer residency – (those arriving more than ten years prior to the survey).

To estimate emigration in our model, we first use ACS 2007-2011 information on the foreign born population by age and by decade of entry to create two estimates of the foreign born population for each state region: one recent-arrival group and one longer-residency group. Using a simplified survival method, we age these two populations forward every five years, decreasing them by letting the 85-and older population fall out (a rough proxy for mortality) and increasing them by the addition of new immigrants (using ACS 2007-2011 levels). After 10 years, new immigrants are moved into the longer-residency group. We apply the Census Bureau's middle-range rates for recently-arrived and longer-residency distinctly to each group in order to estimate the total number of emigrants by cohort in each time period.

It should be noted that in the Greater Boston, Central, and Lower Pioneer Valley regions, emigrating international students are already accounted for by the "revolving-door" approach of the college-fix method. In these three regions, we calculate international immigration and emigration only for the non-college population. College students in our model are withheld from the population at-risk for migration and aging. As such, they are not being counted as "immigrants" in the conventional sense, but instead are lumped in with all other college students, as a constant relative to the entire national population. In the Greater Boston region, college-enrolled immigrants ages 15-29 account for 30% of all international immigrants in the 2007-2011 ACS period, while in the Lower Pioneer Valley, they account for about 36%. These proportions can be thought of in our model as now removed from the foreign born population that would typically drive both immigration and emigration numbers, and so reduces the effect of any error in estimating emigration based on foreign born population estimates.

Finally, international immigrants who become part of the resident population are then subject to the same out-migration rates as the general population. If they move on to other parts of the U.S., they are captured as out-migrants in the next five-year period.

The final step of the migration model adds the estimated net number of domestic migrations (in-migrants minus out-migrants) and the estimated international migrants to the expected surviving population in order to estimate the expected number of "surviving stayers." This is an estimate of the number of current residents who neither die nor move out of the region in the coming five years, plus any new migrants to the region. These surviving stayers are then used as the basis for estimating anticipated births.

[13] Source: Population Division Working Paper No. 97: *Estimating Net International Migration for 2010 Demographic Analysis: An Overview of Methods and Results,* U.S. Census Bureau, February 2013.

Births and Fertility

The last component in our regional cohort-component model requires estimating fertility rates using past data on the number of live births by the age of the mother. Like survival, information on births in comes from the Massachusetts Department of Public Health and is aggregated, by region, into our five-year age cohorts according to the mother's age, and averaged over five years (2005 to2009). The number of births is then divided by the corresponding number of women in 2005 for each cohort to generate an approximate age-specific fertility rate. The births of males and females are modeled separately in our approach, however, in both cases it is only the number of women in each cohort that represents the population 'at risk' and appears in the denominator of the fertility rate. This single year fertility rate is multiplied by five to estimate a five-year equivalent, or:

$$Fertility\ Rate_{i,j} = 5\left[\left(\frac{Births_{i,j}}{Number\ of\ Women_{i,j}}\right)\right]. \tag{7}$$

Next, the estimated fertility rates are multiplied against the number of females in the child-bearing age cohorts among the number of 'surviving stayers' as estimated in the previous step. This provides an estimate of the number of babies that are anticipated within the next five years, and this number is summed across all maternal age cohorts.

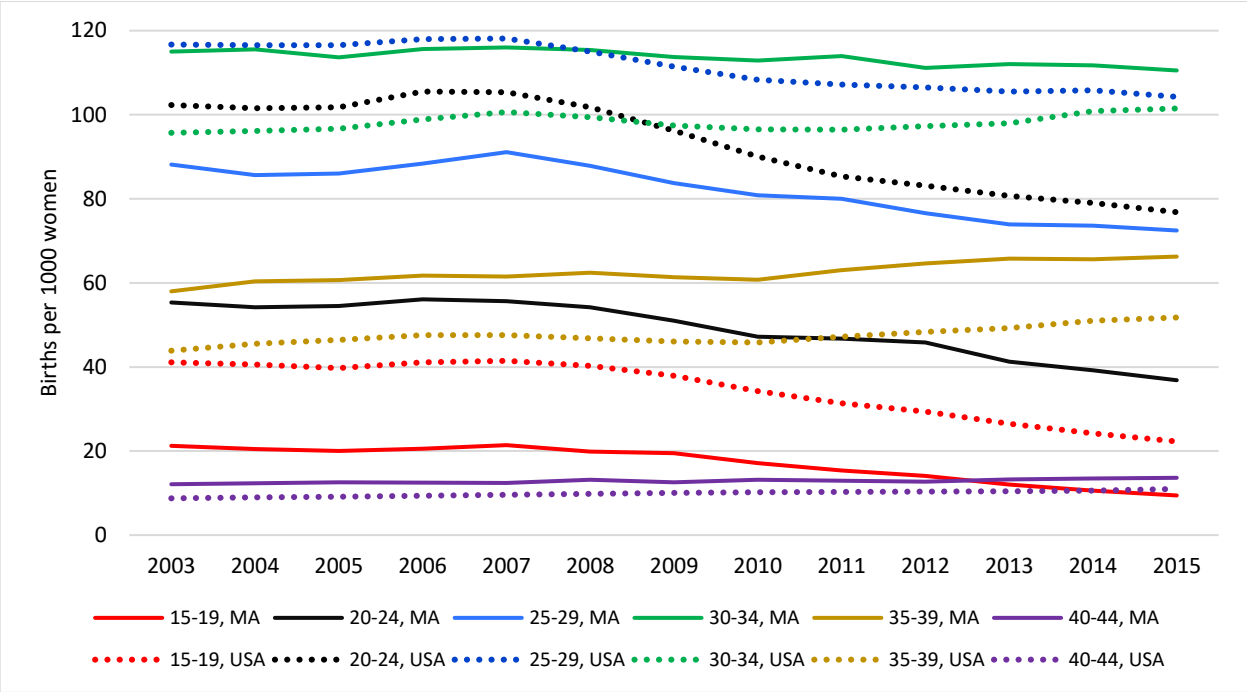
As with mortality, for the V2018 MassDOT projection series we also update births to reflect more recent fertility trends. We reviewed publicly available state-level births by age of mother over the 2003 through 2015 time series, the latest data we were able to obtain by age and sex.[14] Figure 10 below displays changes in fertility by age for both Massachusetts and the U.S. from 2003 through 2015. Notably, fertility is declining significantly in the age cohorts that contribute the greatest number of births per thousand women – ages 20-24, 25-29, and 30-34. Teen births are also declining while most other age-cohorts remain relatively level in their rates. The only cohort showing a significant increase is the 35-39 cohort, indicating that women are postponing fertility now compared to previous years.

Here again, as with mortality, we next had to determine which period rates to average and project forward in our model. After discussion and an examination of the projected impact by region, the Projections Advisory Committee and the UMDI projections team agreed to use the most recent 5-year period of 2011-2015 as a basis for projecting forward, the same period we chose for mortality.

To apply these updates to our model, we calculate the percentage change in births per thousand by age between the averaged 2005-2009 rates already in our model and the updated averaged 2011-2015 rates. We then apply this percent change to births by age by region in our existing regional model. The updated births by age are then summed for all maternal cohorts in the region and added to the next period as aged 0-4 population, as described earlier in this section.

[14] ibid

Figure 10. Massachusetts and US Fertility Rates by Age-of-Mother, 2003-2015



Aging the population and generating projections for later years

Having already re-set the 2015 base as described earlier, the next step in generating our first set of five year forecasts (for year 2020) is to age the surviving stayers in all cohorts by five years. The first (0- 4) and final (85+) cohorts are treated differently. The number of anticipated babies estimated in the previous step becomes the number of 0- 4 year olds in 2020. The number of persons in the 85+ cohort in 2020 is the number of surviving stayers in the 80- 84 age cohort (in 2015) added to the number of surviving stayers in the 85 and older cohort. As we made separate estimates for males and females, the two populations are added and summed across all cohorts to determine the projected number of residents in 2020.

This process is essentially repeated for all future year projections, except that the rates developed from historic data remain the same throughout the forecast horizon. Our 2020 projection becomes our launch year population for estimating the 2025 population, which in turn is used to launch the 2030 population and so-forth. The only notable difference in the process used to generate the later year forecasts is the need to have outside projections of future population levels for the nation as a whole and for neighboring states. This is necessary for estimating population 'at-risk' of domestic in-migration. We use the U.S. Census Bureau's December 2014 national population forecasts which are based on

information from the 2010 Decennial Census.[15] Unfortunately, the Census Bureau no longer generates detailed state-level long-term projections; their last state-level projections were developed in 2005. So for estimating future in-migrants from neighboring Northeast states, we use the state-level age/sex projections developed by the University of Virginia's Weldon Cooper Center for Public Service[16] (release 2013).

Municipal-Level Methods and Assumptions

MCD-Level Model Overview

Municipal, or "MCD-level" population projections served as stand-alone output products in the UMDI V2015 Long-Term Population Projections for Massachusetts Municipalities series (V2015). For the UMDI Vintage 2018 updated series for MA DOT (V2018), they serve multiple purposes. Primarily, the V2018 municipal age/sex projections are aggregated to form the regional age/sex projections for each MPO, each of which conforms to municipal boundaries. Also, while some MPOs created their own sub-regional population distributions based on local knowledge of new or anticipated development at the town-level, other MPOs were able to use the V2018 projections as they were. Finally, municipal age/sex projections were used as a basis for employment and household projections for some areas as part of the larger transportation planning process.

As described in the regional-level methods section of this report, separate projections are produced for the 351 MCDs and for the eight state sub-regions made up of aggregate PUMAs. The MCD results are then controlled to the corresponding projected regional cohorts to help smooth any inconsistences in the MCD-level results and to reflect migration trends that may be more accurately reflected by the regional projection methodology.[17] While both of the regional and MCD-level projections are prepared using a cohort-component method, the MCD estimates rely on residual net migration rates computed from vital statistics, while the sub-region projections use gross domestic migration rates based on the American Community Survey Public Use Microdata (ACS PUMS).

The population aged five and over is projected by the mortality and migration methods, while the population age 0-4 is projected by the fertility method. The initial launch year is 2010, with projections made in five-year intervals from 2015 to 2035 using the previous projection as the new launch population. Projections for eighteen five-year age groups (0-4, 5-9 …80-84, and 85–and older) are reported for males and females. (Throughout this document, the term "age" refers to a five-year age cohort). The cohort-component method is used to account for the effects of mortality, migration, and

[15] Source: http://www.census.gov/population/projections/

[16] Source: *Population Projections by Age for the U.S. and States*. Updated August 9, 2013. Weldon Cooper Center for Public Service, University of Virginia. http://www.coopercenter.org/demographics/national-population-projections

[17] The regional projection methodology, discussed at length in Section 3.A. of this report, projects domestic migration using migration data from the American Community Survey, therefore explicitly accounting for recent domestic migration trends. As explained in this section, the MCD methodology uses a "residual" method based on vital statistics to project migration.

fertility on population change. For the V2018 series, the 2015 launch population by age, sex, and MCD is is first controlled to the U.S. Census Bureau's Vintage 2016 population estimates by age, sex, and county for 2015 before launching to the 2020 projection.[18]

Population projections for each age and sex cohort for each five-year period are created by applying a survival rate to the base population, adding net migration for each age/ sex/ MCD cohort, and finally adding births by sex and mother's age, as shown in the table below.

Table 3. Projection Method by Component

Component	Projection
Mortality	Survived population by age/sex
Migration	Net migration by age/sex
Fertility	Births by sex and mother's age
Launch	2010 Census count by age/sex for 2015 projection, controlled to Census age/sex/county estimates for 2015; five year projection thereafter

Data Sources

The launch populations by sex, age cohort, and MCD were obtained from U.S. Census 2010 data[19]. UMDI estimated population by age and sex for 2005 from the 2000 and 2010 U.S. Censuses using a

[18] See Section 3.A. of this report, subsection "*Determining the launch year and cohort classes" for a more detailed description of this process.*

[19] An exception is made in our model for the town of Lincoln, Massachusetts. For the Lincoln base we have instead created 2010 age/sex estimates using cohort-change ratios observed in the 1990-2000 period applied to the Census 2000 age/sex base. We do this because Lincoln was counted in Census 2010 with a significantly reduced population. This happened because, at the time of the Census count, a large number of the housing units at a military base had been demolished, with their replacement happening only later in 2011. This gave the town a Census 2010 base count that was out of trend with its population in the years right before and again shortly after, with population reduced by as much as 21%. While the 2010 Census may be considered as a relatively accurate point-in-time count, using it as a point of reference in a residual net migration model will create drastically altered migration rates for the town, and using it as the population base for future years will also produce unreasonably low projections.

simple linear interpolation by age and sex. The 2015 age/sex/MCD distributions were then controlled to the U.S. Census Bureau's Vintage 2016 estimates of population by age, sex, and county. [20]

UMDI requested and received confidential vital statistics data for births and deaths from January 1, 2000 through December 31, 2009 from the Massachusetts Department of Public Health. From these, UMDI estimated survival, birth and residual net migration rates.

MCD Projections Launch Population

Initial Launch Population

The initial launch population for the 2015 projection is the 2010 Census population by age/sex for each MCD[21]. Corrected census counts from the Count Question Resolution (CQR) program are incorporated where applicable. Each projection thereafter uses the previous projection as the launch population (i.e. the 2020 projection uses the 2015 projection as the launch population). As mentioned above, in the V2018 series, the projected 2015 launch population by age, sex, and MCD is controlled to the U.S. Census Bureau's most recent county-level population estimates by age and sex for 2015 to create an updated launch population.[22]

MCD Projections: Mortality

Forward Cohort Survival Method

The forward cohort survival method is used to account for the mortality component of population change. This procedure applies five-year survival rates by age/sex to the launch population by age/sex for MCDs in order to survive their populations out five years, resulting in the expected population age five and over before accounting for migration.

Five-Year Survival Rates by Age/Sex

UMDI calculated five-year survival rates by age and sex using deaths by age, sex and MCD from 2000 to 2009 (January 1, 2000 through December 31, 2009). Survival rates by age, sex and MCD were assumed to be constant for the duration of the projections at the MCD level, but note that in the V2018 series

[20] Annual Estimates of the Resident Population for Selected Age Groups by Sex for the United States, States, Counties, and Puerto Rico Commonwealth and Municipios: April 1, 2010 to July 1, 2016. (Table PEP_2016_PEPAGESEX). U.S. Census Bureau, Population Division. Release Date: June 22, 2017.

[21] See footnote (above) on exception in the town of Lincoln.

[22] Annual Estimates of the Resident Population for Selected Age Groups by Sex for the United States, States, Counties, and Puerto Rico Commonwealth and Municipios: April 1, 2010 to July 1, 2016. (Table PEP_2016_PEPAGESEX). U.S. Census Bureau, Population Division. Release Date: June 22, 2017.

these rates are later adjusted at the regional level after MCDs are summed to their respective regions.[23] Survival rates for each age cohort up to 80-84 were averaged with the next-older cohort to account for the fact that roughly half of each cohort would age into the next cohort over the course of each five-year period. The 85-and older cohort's survival rate was used as-is, since there was no older cohort to average.

MCDs with smaller populations demonstrated a degree of variability in survival rates that we considered too broad for optimal results. Therefore, for MCDs with populations lower than 10,000 as of the 2000 Census, we used regional survival rates by age and sex instead of MCD-specific rates to smooth the results.

Survived Population for MCDs

The base population by age/sex for MCDs is survived to the next five-year projection by applying the corresponding averaged five-year survival rates by age/sex.

Key Assumptions

The methodology assumes that survival rates vary most significantly by age and sex. To some extent, the use of MCD-specific rates will also indirectly account for varying socioeconomic factors, including race and ethnicity, which vary by MCD and may affect survival rates. The methodology assumes that survival rates by age, sex and MCD will stay constant over the next 25 years.

MCD Projections: Migration

Residual Net Migration from Vital Statistics

The residual net migration method is used to account for the migration component of population change. "Residual" refers to the fact that migration is assumed to be responsible for past population change after accounting for births and deaths. This residual net migration is then used to estimate past migration rates. The procedure applies the resulting net migration rates by age/sex estimated for each MCD to the MCD's survived population by age/sex in order to project net migration by age/sex for the population ages five and older. For the population ages 0-4, it is assumed that residence of infants will be determined by the migration of their birth mothers. For MCDs with 2000 Census population below 10,000, a linear migration assumption (described below) is used to smooth migration.

Determination of Net Migration Rates

Vital statistics are used to infer net migration totals for 2000 to 2009. In order to calculate five-year net migration by age, sex and MCD, natural increase (births minus deaths) by age/ sex for 2000 to 2005 is added to the 2000 population by age/ sex for each MCD. The results are then subtracted from the

[23] See the regional methodology section of this report for additional detail.

interpolated 2005 population by age/ sex for each MCD to estimate net migration by age/ sex and MCD for 2000 to 2005. A similar process calculates migration between 2005 and 2010.

For MCDs with 2000 population equal to or greater 10,000, the two five-year net migration estimates are averaged and rates are then calculated for each age, sex and MCD. The resulting rates are applied to the base population to project five-year net migration. The resulting average five-year net migration rates by age/sex are held constant throughout the projection period.

For MCDs with 2000 population under 10,000, five-year net migration by age, sex and MCD is held constant, and population cohorts are never allowed to go below zero. This avoids applying unrealistically high migration rates to small populations. For instance, if an MCD starts with four males aged 70-74 and net migration shows four more move in over five years, the result is a migration rate of 2. This results in highly variable and unrealistic results in some cases. In this example, holding migration linear means that in each five-year projection period, four males aged 70-74 will move into the MCD. UMDI conducted sensitivity testing for this method and found that the model with constant migration for small places in most cases resulted in more realistic, gradual population growth or decline, as well as more realistic sex and age profiles for these MCDs.

Key Assumptions

The use of a net migration rate relies on a base for migration that includes only current residents – in other words, only those at risk of out-migration. Nonresidents who are at risk of in-migration are not explicitly accounted for in the MCD method, and this results in some inaccuracy which is minimized by the process of controlling to regional total projections that are based on a gross migration model.

We assume that age, sex and MCD are the key factors by which migration rates vary. Other factors, including non-demographic factors such as macroeconomic factors or local policy changes, are not explicitly included in this model. Future projection models may incorporate these or other factors.

MCD Projections: Fertility

Vital Statistics Method

We apply age-specific fertility rates to the migrated female population by age to project births by age of mother, followed by survival rates for the population aged 0-4. Total survived births are then derived by summing across all maternal age groups, and the results represent the projected population age 0-4. For each MCD, the number of males and females is assumed to be the same as the proportion of male or female births statewide.

Fertility by Age of Mother

Average births by age of mother for each MCD are calculated for two five-year periods (2000 to 2005 and 2005 to 2010) using nine maternal age groups, from 10-14…50-54. As with mortality, in the V2018

series fertility rates are adjusted at the regional level after MCDs are summed to their respective regions.[24]

Fertility Rates

Age-specific fertility rates are computed for each time period by dividing the average number of births by age of mother by the corresponding number of females of that age group. The average age-specific fertility rates are held constant throughout the projection period. The base population for launching a new five-year projection is the survived, post-migration projected female population by age.

MCDs with smaller populations demonstrated a degree of variability in fertility rates that we considered too broad for optimal results. Therefore, for MCDs with populations lower than 10,000 as of the 2000 Census, we used regional fertility rates by age and sex instead of MCD-specific rates to smooth the results[25].

Key Assumptions

We assume age, sex and MCD to be adequate indicators of fertility rates for MCD for the first vintage projections. We assume that the proportion of male to female births does not vary significantly by geography or maternal age. We assume that fertility rates by maternal age and MCD will not change significantly over time. Future iterations of the projections may amend these assumptions based on available data.

Controlling to the Regional-level Projections

The resulting MCD-level projected cohorts are finally controlled to the regional-level projected cohorts. To do this, we assume that each MCD's share of the region's population, for each age and sex cohort, is given by the MCD population projections. Those shares are then applied to the regional projections to arrive at adjusted age/ sex cohorts for each MCD.

[24] See the regional methodology section of this report for additional detail.

[25] While MCDs with populations less than 10,000 are given the regional rate in this model, we make exception for "college bedroom" towns. Because fertility rates are generally lower among females enrolled in college compared to the general population of the same age group, applying regional fertility rates to small towns with high percentages of college-enrolled population resulted in inflated births. We developed criteria for identifying "college bedroom" towns and applied town-specific fertility rates to these instead of the regional rates. Criteria is: population under 10,000 in 2010; >20% of 18 and over female population is enrolled in college or graduate school according to 2008-2012 ACS; and use of regional fertility rate resulted in a ≥25% Increase in the 0-4 age group from 2010 to 2015. The three MCDs subject to the "college bedroom" exception include Wenham, Sunderland, and Williamstown.

Alternative Model for Cape & Island Regions

In the regional methodology section of this report, we discuss the limitations of using ACS data to calculate migration rates in small regions, specifically due to the small sample size available in the Census Public-Use Microdata Sample (PUMS) data, the only direct source of migration by age and sex available at the sub-state, regional level. Because the Cape and Island Region is one of the smallest study regions in the model, there are concerns about the margins of error associated with ACS rates by age/sex specifically for this region. In addition, this very small model region breaks out even further into three distinct MPO regions in the statewide travel model. Furthermore, in component data available through U.S. Census annual estimates, these three sub-regional MPOs display differing and sometimes opposite trends in fertility and migration.[26] All of these reasons make this a challenging region to work with in our existing regional model, and caused concern over applying the UMDI V2018 statewide method to this unique region.

On a positive note, because these three Cape & Island MPO regions align with county boundaries - unlike other MPO regions around the state – we are able to access specific county-level data resources that are not available in other state regions not conforming to county boundaries. These county-level resources include both migration-by-age estimates from the University of Wisconsin and county-level fertility rates by age from vital statistics. Given both the challenges and data opportunities available in this region, the Projections Advisory Committee and UMDI decided to use an alternative method to model Cape & Island projections, completing distinct county-level estimates for each using the same basic framework.

For each Cape & Island County, including Barnstable, Dukes, and Nantucket, UMDI used a cohort-component model. This is the same model concept used statewide; we start with a base population to which we apply migration, fertility, and mortality rates by age and sex to estimate the next launch population, and then apply rates again. This process is repeated until we reach the end of the projection term.

Migration

The differences in the custom Cape models and the statewide V2018 method include the source and type of migration and source of fertility data. While in the statewide model we use a gross migration rates, estimating in, out, and net international migrants separately, for the Cape & Islands regions we instead use *net* migration rates, which combine in, out, and international migrants into one combined rate by age and sex. We obtain these rates from the University of Wisconsin, which uses decennial Census counts by age, sex, and county together with birth and death counts by age, sex, and county over

[26] Population, population change and estimated components of population change: April 1, 2010 to July 1, 2016 (CO-EST2016-alldata). U.S. Census Bureau, Population Division. Release Date: March 2017.

the intercensal years to calculate residual net migrants by age, sex, and county.[27] This removes concerns about error margins associated with ACS data for small areas, as rates instead are based on full count and complete vital statistics data instead of survey sample data. These 10-year migration rates by age and sex are first converted to 5-year rates in our application so that populations can be projected in 5-year intervals as in our statewide method. As with our statewide method, the first launch period is 2015. For the Cape & Island counties we use the Census Bureau's latest annual estimates of population by age, sex, and county for 2015 without first needing to reallocate to regions as we do in the main model.[28]

Fertility and Survival

For fertility rates in the Cape & Island counties, we use the most specific fertility data we can obtain for each county.[29] For Barnstable County, the largest of the Cape & Island counties, we are able to use county-specific fertility rates by age for 2011-2015.[30] For Nantucket and Dukes counties, fertility rates by age are modeled using 5-year fertility rates by age from 2000-2009 specific to each county – which we calculated from town-level births by age for our V2015 series - that are then controlled to 5-year birth *totals* from 2011-2015 for each county. Note that current rates by age for Dukes and Nantucket are not available in the CDC Wonder datasets due to small cohort sizes.

Survival rates are used from UMDI V2015 Cape & Islands Region updated by percent changes in statewide rates, as with the statewide V2018 method. We need to revert to the regional rates in this instance because the specific county-level rates included too many "unreliable" rates by age in the 2011-2015 CDC Wonder datasets.

Customizations to the Cape & Island data sources resulted in projections that were slightly higher than the statewide method in the short term, and also showed a smoother age-cohort progression over time.

[27] Age-Specific Net Migration Estimates for US Counties, 1950-2010. Applied Population Laboratory, University of Wisconsin-Madison, 2013. Web. [Downloaded 12/1/2017.] < http://www.netmigration.wisc.edu/>.

[28] Annual Estimates of the Resident Population for Selected Age Groups by Sex for the United States, States, Counties, and Puerto Rico Commonwealth and Municipios: April 1, 2010 to July 1, 2016. (Table PEP_2016_PEPAGESEX). U.S. Census Bureau, Population Division. Release Date: June 22, 2017.

[29] Source of births and deaths rates: United States Department of Health and Human Services (US DDHS) Centers for Disease Control and Prevention (CDC) National Center for Health Statistics (NCHS). See Data Sources Notes in Appendix B to this report for additional source detail.

[30] except for maternal cohort aged 45-49, which we take UMDI V2015 Cape & Islands Region updated by % changes in statewide rates. Current Massachusetts and Barnstable rates are not available for this age group.

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Appendix A: Crosswalk of Municipalities by MPO Region, County, and UMDI Migration Region

MPO Region	MCD Name	County	UMDI Migration Region
BRPC	Adams	Berkshire	Berkshire and Franklin
BRPC	Alford	Berkshire	Berkshire and Franklin
BRPC	Becket	Berkshire	Berkshire and Franklin
BRPC	Cheshire	Berkshire	Berkshire and Franklin
BRPC	Clarksburg	Berkshire	Berkshire and Franklin
BRPC	Dalton	Berkshire	Berkshire and Franklin
BRPC	Egremont	Berkshire	Berkshire and Franklin
BRPC	Florida	Berkshire	Berkshire and Franklin
BRPC	Great Barrington	Berkshire	Berkshire and Franklin
BRPC	Hancock	Berkshire	Berkshire and Franklin
BRPC	Hinsdale	Berkshire	Berkshire and Franklin
BRPC	Lanesborough	Berkshire	Berkshire and Franklin
BRPC	Lee	Berkshire	Berkshire and Franklin
BRPC	Lenox	Berkshire	Berkshire and Franklin
BRPC	Monterey	Berkshire	Berkshire and Franklin
BRPC	Mount Washington	Berkshire	Berkshire and Franklin
BRPC	New Ashford	Berkshire	Berkshire and Franklin
BRPC	New Marlborough	Berkshire	Berkshire and Franklin
BRPC	North Adams	Berkshire	Berkshire and Franklin
BRPC	Otis	Berkshire	Berkshire and Franklin
BRPC	Peru	Berkshire	Berkshire and Franklin
BRPC	Pittsfield	Berkshire	Berkshire and Franklin
BRPC	Richmond	Berkshire	Berkshire and Franklin
BRPC	Sandisfield	Berkshire	Berkshire and Franklin
BRPC	Savoy	Berkshire	Berkshire and Franklin
BRPC	Sheffield	Berkshire	Berkshire and Franklin
BRPC	Stockbridge	Berkshire	Berkshire and Franklin
BRPC	Tyringham	Berkshire	Berkshire and Franklin
BRPC	Washington	Berkshire	Berkshire and Franklin
BRPC	West Stockbridge	Berkshire	Berkshire and Franklin
BRPC	Williamstown	Berkshire	Berkshire and Franklin
BRPC	Windsor	Berkshire	Berkshire and Franklin
CCC	Barnstable	Barnstable	Cape and Islands

CCC	Bourne	Barnstable	Cape and Islands
CCC	Brewster	Barnstable	Cape and Islands
CCC	Chatham	Barnstable	Cape and Islands
CCC	Dennis	Barnstable	Cape and Islands
CCC	Eastham	Barnstable	Cape and Islands
CCC	Falmouth	Barnstable	Cape and Islands
CCC	Harwich	Barnstable	Cape and Islands
CCC	Mashpee	Barnstable	Cape and Islands
CCC	Orleans	Barnstable	Cape and Islands
CCC	Provincetown	Barnstable	Cape and Islands
CCC	Sandwich	Barnstable	Cape and Islands
CCC	Truro	Barnstable	Cape and Islands
CCC	Wellfleet	Barnstable	Cape and Islands
CCC	Yarmouth	Barnstable	Cape and Islands
CMRPC	Auburn	Worcester	Central
CMRPC	Barre	Worcester	Central
CMRPC	Berlin	Worcester	MetroWest
CMRPC	Blackstone	Worcester	MetroWest
CMRPC	Boylston	Worcester	Central
CMRPC	Brookfield	Worcester	Central
CMRPC	Charlton	Worcester	Central
CMRPC	Douglas	Worcester	Central
CMRPC	Dudley	Worcester	Central
CMRPC	East Brookfield	Worcester	Central
CMRPC	Grafton	Worcester	Central
CMRPC	Hardwick	Worcester	Berkshire and Franklin
CMRPC	Holden	Worcester	Central
CMRPC	Hopedale	Worcester	MetroWest
CMRPC	Leicester	Worcester	Central
CMRPC	Mendon	Worcester	MetroWest
CMRPC	Millbury	Worcester	Central
CMRPC	Millville	Worcester	MetroWest
CMRPC	New Braintree	Worcester	Berkshire and Franklin
CMRPC	North Brookfield	Worcester	Central
CMRPC	Northborough	Worcester	Central
CMRPC	Northbridge	Worcester	Central
CMRPC	Oakham	Worcester	Central
CMRPC	Oxford	Worcester	Central
CMRPC	Paxton	Worcester	Central

CMRPC	Princeton	Worcester	Central
CMRPC	Rutland	Worcester	Central
CMRPC	Shrewsbury	Worcester	Central
CMRPC	Southbridge	Worcester	Central
CMRPC	Spencer	Worcester	Central
CMRPC	Sturbridge	Worcester	Central
CMRPC	Sutton	Worcester	Central
CMRPC	Upton	Worcester	MetroWest
CMRPC	Uxbridge	Worcester	Central
CMRPC	Warren	Worcester	Central
CMRPC	Webster	Worcester	Central
CMRPC	West Boylston	Worcester	Central
CMRPC	West Brookfield	Worcester	Central
CMRPC	Westborough	Worcester	Central
CMRPC	Worcester	Worcester	Central
FRCOG	Ashfield	Franklin	Berkshire and Franklin
FRCOG	Bernardston	Franklin	Berkshire and Franklin
FRCOG	Buckland	Franklin	Berkshire and Franklin
FRCOG	Charlemont	Franklin	Berkshire and Franklin
FRCOG	Colrain	Franklin	Berkshire and Franklin
FRCOG	Conway	Franklin	Berkshire and Franklin
FRCOG	Deerfield	Franklin	Berkshire and Franklin
FRCOG	Erving	Franklin	Berkshire and Franklin
FRCOG	Gill	Franklin	Berkshire and Franklin
FRCOG	Greenfield	Franklin	Berkshire and Franklin
FRCOG	Hawley	Franklin	Berkshire and Franklin
FRCOG	Heath	Franklin	Berkshire and Franklin
FRCOG	Leverett	Franklin	Berkshire and Franklin
FRCOG	Leyden	Franklin	Berkshire and Franklin
FRCOG	Monroe	Franklin	Berkshire and Franklin
FRCOG	Montague	Franklin	Berkshire and Franklin
FRCOG	New Salem	Franklin	Berkshire and Franklin
FRCOG	Northfield	Franklin	Berkshire and Franklin
FRCOG	Orange	Franklin	Berkshire and Franklin
FRCOG	Rowe	Franklin	Berkshire and Franklin
FRCOG	Shelburne	Franklin	Berkshire and Franklin
FRCOG	Shutesbury	Franklin	Berkshire and Franklin
FRCOG	Sunderland	Franklin	Lower Pioneer Valley
FRCOG	Warwick	Franklin	Berkshire and Franklin

FRCOG	Wendell	Franklin	Berkshire and Franklin
FRCOG	Whately	Franklin	Berkshire and Franklin
MAPC	Acton	Middlesex	MetroWest
MAPC	Arlington	Middlesex	Greater Boston
MAPC	Ashland	Middlesex	MetroWest
MAPC	Bedford	Middlesex	MetroWest
MAPC	Bellingham	Norfolk	MetroWest
MAPC	Belmont	Middlesex	Greater Boston
MAPC	Beverly	Essex	Northeast
MAPC	Bolton	Worcester	MetroWest
MAPC	Boston	Suffolk	Greater Boston
MAPC	Boxborough	Middlesex	MetroWest
MAPC	Braintree	Norfolk	Greater Boston
MAPC	Brookline	Norfolk	Greater Boston
MAPC	Burlington	Middlesex	Northeast
MAPC	Cambridge	Middlesex	Greater Boston
MAPC	Canton	Norfolk	Greater Boston
MAPC	Carlisle	Middlesex	MetroWest
MAPC	Chelsea	Suffolk	Greater Boston
MAPC	Cohasset	Norfolk	Southeast
MAPC	Concord	Middlesex	MetroWest
MAPC	Danvers	Essex	Northeast
MAPC	Dedham	Norfolk	Greater Boston
MAPC	Dover	Norfolk	Greater Boston
MAPC	Essex	Essex	Northeast
MAPC	Everett	Middlesex	Greater Boston
MAPC	Foxborough	Norfolk	MetroWest
MAPC	Framingham	Middlesex	MetroWest
MAPC	Franklin	Norfolk	MetroWest
MAPC	Gloucester	Essex	Northeast
MAPC	Hamilton	Essex	Northeast
MAPC	Hanover	Plymouth	Southeast
MAPC	Hingham	Plymouth	Southeast
MAPC	Holbrook	Norfolk	Greater Boston
MAPC	Holliston	Middlesex	MetroWest
MAPC	Hopkinton	Middlesex	MetroWest
MAPC	Hudson	Middlesex	MetroWest
MAPC	Hull	Plymouth	Southeast
MAPC	Ipswich	Essex	Northeast

MAPC	Lexington	Middlesex	Greater Boston
MAPC	Lincoln	Middlesex	Greater Boston
MAPC	Littleton	Middlesex	MetroWest
MAPC	Lynn	Essex	Greater Boston
MAPC	Lynnfield	Essex	Northeast
MAPC	Malden	Middlesex	Greater Boston
MAPC	Manchester-by-the-Sea	Essex	Northeast
MAPC	Marblehead	Essex	Northeast
MAPC	Marlborough	Middlesex	MetroWest
MAPC	Marshfield	Plymouth	Southeast
MAPC	Maynard	Middlesex	MetroWest
MAPC	Medfield	Norfolk	MetroWest
MAPC	Medford	Middlesex	Greater Boston
MAPC	Medway	Norfolk	MetroWest
MAPC	Melrose	Middlesex	Greater Boston
MAPC	Middleton	Essex	Northeast
MAPC	Milford	Worcester	MetroWest
MAPC	Millis	Norfolk	MetroWest
MAPC	Milton	Norfolk	Greater Boston
MAPC	Nahant	Essex	Greater Boston
MAPC	Natick	Middlesex	MetroWest
MAPC	Needham	Norfolk	Greater Boston
MAPC	Newton	Middlesex	Greater Boston
MAPC	Norfolk	Norfolk	MetroWest
MAPC	North Reading	Middlesex	Northeast
MAPC	Norwell	Plymouth	Southeast
MAPC	Norwood	Norfolk	MetroWest
MAPC	Peabody	Essex	Northeast
MAPC	Quincy	Norfolk	Greater Boston
MAPC	Randolph	Norfolk	Greater Boston
MAPC	Reading	Middlesex	Northeast
MAPC	Revere	Suffolk	Greater Boston
MAPC	Rockland	Plymouth	Southeast
MAPC	Rockport	Essex	Northeast
MAPC	Salem	Essex	Northeast
MAPC	Saugus	Essex	Greater Boston
MAPC	Scituate	Plymouth	Southeast
MAPC	Sharon	Norfolk	MetroWest
MAPC	Sherborn	Middlesex	MetroWest

MAPC	Somerville	Middlesex	Greater Boston
MAPC	Southborough	Worcester	MetroWest
MAPC	Stoneham	Middlesex	Greater Boston
MAPC	Stow	Middlesex	MetroWest
MAPC	Sudbury	Middlesex	MetroWest
MAPC	Swampscott	Essex	Northeast
MAPC	Topsfield	Essex	Northeast
MAPC	Wakefield	Middlesex	Northeast
MAPC	Walpole	Norfolk	MetroWest
MAPC	Waltham	Middlesex	Greater Boston
MAPC	Watertown	Middlesex	Greater Boston
MAPC	Wayland	Middlesex	MetroWest
MAPC	Wellesley	Norfolk	Greater Boston
MAPC	Wenham	Essex	Northeast
MAPC	Weston	Middlesex	Greater Boston
MAPC	Westwood	Norfolk	MetroWest
MAPC	Weymouth	Norfolk	Southeast
MAPC	Wilmington	Middlesex	Northeast
MAPC	Winchester	Middlesex	Greater Boston
MAPC	Winthrop	Suffolk	Greater Boston
MAPC	Woburn	Middlesex	Greater Boston
MAPC	Wrentham	Norfolk	MetroWest
MRPC	Ashburnham	Worcester	Central
MRPC	Ashby	Middlesex	Central
MRPC	Athol	Worcester	Berkshire and Franklin
MRPC	Ayer	Middlesex	MetroWest
MRPC	Clinton	Worcester	Central
MRPC	Fitchburg	Worcester	Central
MRPC	Gardner	Worcester	Central
MRPC	Groton	Middlesex	Northeast
MRPC	Harvard	Worcester	MetroWest
MRPC	Hubbardston	Worcester	Berkshire and Franklin
MRPC	Lancaster	Worcester	MetroWest
MRPC	Leominster	Worcester	Central
MRPC	Lunenburg	Worcester	Central
MRPC	Petersham	Worcester	Berkshire and Franklin
MRPC	Phillipston	Worcester	Berkshire and Franklin
MRPC	Royalston	Worcester	Berkshire and Franklin
MRPC	Shirley	Middlesex	MetroWest

MRPC	Sterling	Worcester	Central
MRPC	Templeton	Worcester	Central
MRPC	Townsend	Middlesex	MetroWest
MRPC	Westminster	Worcester	Central
MRPC	Winchendon	Worcester	Central
MVC	Aquinnah	Dukes	Cape and Islands
MVC	Chilmark	Dukes	Cape and Islands
MVC	Edgartown	Dukes	Cape and Islands
MVC	Gosnold	Dukes	Cape and Islands
MVC	Oak Bluffs	Dukes	Cape and Islands
MVC	Tisbury	Dukes	Cape and Islands
MVC	West Tisbury	Dukes	Cape and Islands
MVPC	Amesbury	Essex	Northeast
MVPC	Andover	Essex	Northeast
MVPC	Boxford	Essex	Northeast
MVPC	Georgetown	Essex	Northeast
MVPC	Groveland	Essex	Northeast
MVPC	Haverhill	Essex	Northeast
MVPC	Lawrence	Essex	Northeast
MVPC	Merrimac	Essex	Northeast
MVPC	Methuen	Essex	Northeast
MVPC	Newbury	Essex	Northeast
MVPC	Newburyport	Essex	Northeast
MVPC	North Andover	Essex	Northeast
MVPC	Rowley	Essex	Northeast
MVPC	Salisbury	Essex	Northeast
MVPC	West Newbury	Essex	Northeast
NMCOG	Billerica	Middlesex	Northeast
NMCOG	Chelmsford	Middlesex	Northeast
NMCOG	Dracut	Middlesex	Northeast
NMCOG	Dunstable	Middlesex	Northeast
NMCOG	Lowell	Middlesex	Northeast
NMCOG	Pepperell	Middlesex	Northeast
NMCOG	Tewksbury	Middlesex	Northeast
NMCOG	Tyngsborough	Middlesex	Northeast
NMCOG	Westford	Middlesex	Northeast
NPEDC	Nantucket	Nantucket	Cape and Islands
OCPC	Abington	Plymouth	Southeast
OCPC	Avon	Norfolk	Southeast

OCPC	Bridgewater	Plymouth	Southeast
OCPC	Brockton	Plymouth	Southeast
OCPC	Duxbury	Plymouth	Southeast
OCPC	East Bridgewater	Plymouth	Southeast
OCPC	Easton	Bristol	Southeast
OCPC	Halifax	Plymouth	Southeast
OCPC	Hanson	Plymouth	Southeast
OCPC	Kingston	Plymouth	Southeast
OCPC	Pembroke	Plymouth	Southeast
OCPC	Plymouth	Plymouth	Southeast
OCPC	Plympton	Plymouth	Southeast
OCPC	Stoughton	Norfolk	Greater Boston
OCPC	West Bridgewater	Plymouth	Southeast
OCPC	Whitman	Plymouth	Southeast
PVPC	Agawam	Hampden	Lower Pioneer Valley
PVPC	Amherst	Hampshire	Lower Pioneer Valley
PVPC	Belchertown	Hampshire	Lower Pioneer Valley
PVPC	Blandford	Hampden	Berkshire and Franklin
PVPC	Brimfield	Hampden	Central
PVPC	Chester	Hampden	Berkshire and Franklin
PVPC	Chesterfield	Hampshire	Berkshire and Franklin
PVPC	Chicopee	Hampden	Lower Pioneer Valley
PVPC	Cummington	Hampshire	Berkshire and Franklin
PVPC	East Longmeadow	Hampden	Lower Pioneer Valley
PVPC	Easthampton	Hampshire	Lower Pioneer Valley
PVPC	Goshen	Hampshire	Berkshire and Franklin
PVPC	Granby	Hampshire	Lower Pioneer Valley
PVPC	Granville	Hampden	Berkshire and Franklin
PVPC	Hadley	Hampshire	Lower Pioneer Valley
PVPC	Hampden	Hampden	Lower Pioneer Valley
PVPC	Hatfield	Hampshire	Lower Pioneer Valley
PVPC	Holland	Hampden	Central
PVPC	Holyoke	Hampden	Lower Pioneer Valley
PVPC	Huntington	Hampshire	Lower Pioneer Valley
PVPC	Longmeadow	Hampden	Lower Pioneer Valley
PVPC	Ludlow	Hampden	Lower Pioneer Valley
PVPC	Middlefield	Hampshire	Berkshire and Franklin
PVPC	Monson	Hampden	Lower Pioneer Valley
PVPC	Montgomery	Hampden	Lower Pioneer Valley

PVPC	Northampton	Hampshire	Lower Pioneer Valley
PVPC	Palmer	Hampden	Lower Pioneer Valley
PVPC	Pelham	Hampshire	Berkshire and Franklin
PVPC	Plainfield	Hampshire	Berkshire and Franklin
PVPC	Russell	Hampden	Lower Pioneer Valley
PVPC	South Hadley	Hampshire	Lower Pioneer Valley
PVPC	Southampton	Hampshire	Lower Pioneer Valley
PVPC	Southwick	Hampden	Lower Pioneer Valley
PVPC	Springfield	Hampden	Lower Pioneer Valley
PVPC	Tolland	Hampden	Berkshire and Franklin
PVPC	Wales	Hampden	Central
PVPC	Ware	Hampshire	Lower Pioneer Valley
PVPC	West Springfield	Hampden	Lower Pioneer Valley
PVPC	Westfield	Hampden	Lower Pioneer Valley
PVPC	Westhampton	Hampshire	Berkshire and Franklin
PVPC	Wilbraham	Hampden	Lower Pioneer Valley
PVPC	Williamsburg	Hampshire	Lower Pioneer Valley
PVPC	Worthington	Hampshire	Berkshire and Franklin
SRPEDD	Acushnet	Bristol	Southeast
SRPEDD	Attleboro	Bristol	Southeast
SRPEDD	Berkley	Bristol	Southeast
SRPEDD	Carver	Plymouth	Southeast
SRPEDD	Dartmouth	Bristol	Southeast
SRPEDD	Dighton	Bristol	Southeast
SRPEDD	Fairhaven	Bristol	Southeast
SRPEDD	Fall River	Bristol	Southeast
SRPEDD	Freetown	Bristol	Southeast
SRPEDD	Lakeville	Plymouth	Southeast
SRPEDD	Mansfield	Bristol	Southeast
SRPEDD	Marion	Plymouth	Southeast
SRPEDD	Mattapoisett	Plymouth	Southeast
SRPEDD	Middleborough	Plymouth	Southeast
SRPEDD	New Bedford	Bristol	Southeast
SRPEDD	North Attleborough	Bristol	Southeast
SRPEDD	Norton	Bristol	Southeast
SRPEDD	Plainville	Norfolk	MetroWest
SRPEDD	Raynham	Bristol	Southeast
SRPEDD	Rehoboth	Bristol	Southeast
SRPEDD	Rochester	Plymouth	Southeast

SRPEDD	Seekonk	Bristol	Southeast
SRPEDD	Somerset	Bristol	Southeast
SRPEDD	Swansea	Bristol	Southeast
SRPEDD	Taunton	Bristol	Southeast
SRPEDD	Wareham	Plymouth	Southeast
SRPEDD	Westport	Bristol	Southeast

Appendix B: Data Source Notes on Fertility and Mortality

Fertility

Statewide yearly fertility rates for cohorts 15-19 years, 20-24 years, 25-29 years, 30-34 years, 35-39 years, and 40-44 years in Massachusetts are sourced from WONDER data (SEE CITATION) and averaged to create 5-year fertility rates for 2005-2009 and 2011-2015 for each cohort. USA data is used for cohorts 10-14 and 45-49 years, due to lack of available statewide data. The ratio of the 2011-2015 rate over the 2005-2009 rate for each cohort was used as a multiplier to adjust births from 2009 levels within the model. No fertility data were available for the 50-59-year cohort, so fertility rates were not altered from the 2005-2009 model.

2005-2006 Massachusetts data from United States Department of Health and Human Services (US DDHS) Centers for Disease Control and Prevention (CDC) National Center for Health Statistics (NCHS) "Natality Public-use data 2003-2006" on CDC WONDER Online Database, March 2009. Accessed at http://wonder.cdc.gov/natality-v2006.html.

2007-2015 Massachusetts data from US DDHS CDC NCHS "Natality Public-use data 2007-2015" on CDC WONDER Online Database, February 2017. Accessed at http://wonder.cdc.gov/natality-current.html.

USA data from US DDHS CDC NCHS "The Public Use Natality File—2015 Update" Accessed at ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Dataset_Documentation/DVS/natality/UserGuide2015.pdf

Mortality

Because of how data is organized by age in the data available to us, two CDC datasets were used for informing the model. These datasets come from the same source of raw data, but have differently amalgamated cohorts, as well as other health and demographic details, for use in various health related analyses. These are the Compressed Mortality file and Multiple Cause of Death Files.

For cohorts 0-4, 5-9, 10-14, 15-19, 20-24, and 85+ Compressed Mortality data are used. Within this dataset, death rates are flagged as "unreliable" when the rate is calculated from fewer than 20 deaths. This occurred in several years for cohorts 14 years and younger for both sexes. However, because we calculated 5-year average mortality rates for 2005-2009 and 2011-2015, and the fact that there were so few deaths overall for these cohorts, we used the information gleaned from these rates in the model. For all other cohorts, the Multiple Cause of Death 1999-2015 dataset is used. For all mortality rates, except cohort 0-4, a 5-year average of annual mortality rates provided by the appropriate data set over the 2005-2009 and 2011-2015 time periods were calculated for each sex. Mortality rates if cohort 0-4 was calculated by UMDI from the total deaths of the 0-4 population divided by the sum of the 0-4 population for the 2005-2009 and 2011-2015 time periods. The ratio of 2011-2015 over 2005-2009 for each sex and age cohort was calculated and used as a multiplier to adjust deaths from 2009 levels within the model.

Compressed: Centers for Disease Control and Prevention, National Center for Health Statistics. Compressed Mortality File. 1999-2015 on CDC WONDER Online Database, released December 2016. Data are from the Compressed Mortality File 1999-2015 Series 20 No. 2U, 2016, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Accessed at http://wonder.cdc.gov/cmf-icd10.html on Sep 18, 2017.

Multiple: Centers for Disease Control and Prevention, National Center for Health Statistics. Multiple Cause of Death 1999-2015 on CDC WONDER Online Database, released December, 2016. Data are from the Multiple Cause of Death Files, 1999-2015, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Accessed at http://wonder.cdc.gov/mcd-icd10.html on Jul 5, 2017.