Salem State College

A Comparison of Road Lengths Obtained by Odometer to Three Dimensional Calculation by GIS

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Abstract

This project calculates the lengths of the roads in Massachusetts using the Surface Length module of ArcGIS 9.1, supplying as input a layer of road centerlines and a Digital Elevation Model (DEM). The module calculates the length of each line segment as it “travels” over the 3-dimensional surface represented by the DEM. The resulting 3-dimensional road lengths are compared to the road lengths measured by odometer and recorded in the database of road centerlines maintained by Massachusetts Executive Office of Transportation. This calculation of road length by GIS may be a viable alternative to measuring the road in the field by driving it with a calibrated odometer. The total centerline lengths of roads is used as part of the calculation to apportion funding to each state and town. The change to the state's total mileage and to each town's total mileage as a result of the GIS calculation is shown. These results, if used as the basis for reporting, would change the amount of funds received by the state according to the SAFETEA-LU. Within Massachusetts, each town would have a change of funds received from the state according to Chapter 90 legislation. Anomalies in the data are: 1) roads missing geometry, 2) one road with a highly suspect odometer reading, 3) roads with no odometer readings, 4) roads that have no DEM data lying beneath them, and 5) roads with an extreme slope. These anomalies are removed to calculate the percent change in road length via GIS. The result shows that GIS calculated lengths are an overall increase of 0.5% from odometer measurements. While this is a small increase, it is statistically significant.

Acknowledgments

I would like to thank Prof. Keith Ratner of the Geography Department at Salem State College for his suggestion of this topic and his support during the work on it. Prof. Stephen Young was enthusiastic for the project and helped me present it at the AAG conference in April of 2007. Prof. Marcos Luna was a close reader of early versions of this paper and made many valuable suggestions. Mark Berger of the Massachusetts EOT, Office of Transportation Planning provided helpful comments on the data for the roads.

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Introduction

The Massachusetts Office of Transportation Planning, a department of the Executive Office of Transportation (EOT), maintains a database of all roads in the state. The data include many attributes about each road, such as: the name of the street, highway route number, jurisdiction in which the road is located, speed limit on the road, type of curb or shoulder, type of median strip, number of lanes, type and condition of the surface, etc. See Appendix 1 for descriptions of all fields. An important data attribute also stored about a road is its length. The length of a road is the length of a line along the center of the road, referred to as the road centerline. The road centerline segments in the data are characterized as starting and ending at points where attributes about the road change. Examples of endpoints of roads are: boundaries for town, state and federal jurisdiction; intersections; change in number of lanes, name of road, or type of road such as tunnel, bridge, rotary, mainline road, etc. As a result, the database contains 340,852 records for road centerlines used for reporting and apportionment purposes.

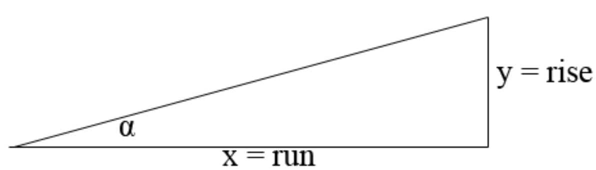
Quantity of roads, measured as total centerline length, is used in the calculation that apportions funds to state and local governments responsible for maintaining roads. At the federal level, the total linear centerline miles of roads in Massachusetts is used in several calculations to determine the amount of federal dollars received by the state from various highway programs (US FHWA 2005 Fact Sheets). Within Massachusetts, each town and city is apportioned state funds based, in part, on the total linear centerline miles of roads in the town (Mass. Municipal Assn. n.d.). Having accurate values for the lengths of the roads is necessary for these calculations. The Massachusetts roads database for 2005 has 468,803 records for roads, of which 340,852 are used to calculate centerline miles for apportioning funds to the 351 cities and towns, and are the same set of records used to report total Massachusetts centerline miles to the federal government for apportionment by FHWA. The remaining 127,951 roads are private roads, service roads, ramps at intersections, southbound or westbound sides of divided highways (only the centerline of the northbound or eastbound side of a divided highway is applied when calculating length), and roads on federal or military property, to give a few examples.

For many states, lengths of roads are determined by driving the road with a vehicle equipped with a carefully calibrated odometer (US FHWA 1998). This technology is sometimes called a Distance Measuring Instrument, or DMI for short. To produce accurate results from field work using DMI, the correct starting and stopping points for each segment of road must be correctly located and the vehicle must be correctly positioned to those points. Some states have field manuals that carefully describe operating procedures (Arizona 2006; Kentucky 2004; Oregon 2004). The vehicle must be driven along the centerline of the road, or at a constant offset from the centerline, with no lane changes or weaving about. The vehicle and DMI must be maintained in calibration, particularly regarding tire pressure, tire wear, and temperature. While DMI is an empirical method for determining the length of a road, it can be time consuming and error prone. Additional circumstances, such as crew turnover, vehicle upgrades and maintenance, and the general practice of performing the field work while the road is open to the public, can make it difficult to obtain consistent results across a large database of roads (Noronha 1999).

For 2005, the total reported centerline miles for Massachusetts was 35,855 miles. The source for the length of each segment of road is coded according to one of three methods:

- three-dimensional length as determined by DMI (98.4% of road segments)
- flat length as determined by a previous GIS (1.4% of road segments)
- a value migrated from prior versions of the data[1] (0.2% of road segments)

The flat, or horizontal, length of a geometric line as represented in GIS data differs from the three-dimensional length due to its slope as it traverses terrain of varying elevation. In a GIS database, such as an ArcGIS geodatabase, the geometric length of the road is represented as its flat length, where no effect from terrain is accounted for. DMI measures a road's length as its driven length, which does account for length due to varying slope of the road over the actual terrain.



grade = rise/run
α=arctan(grade)
length increase due to grade = 1/cos(α)

Figure 1. Road grade calculation

The slope of a road is expressed as grade, which is the ratio of vertical rise to horizontal run expressed as a percent (see Figure 1). For example, a 10% grade has 1 foot of rise for each 10 feet of

1. "Odometer prorated from CSN pair (60000-rule) during migration from coverage model" (Massachusetts, Road Inventory Year-end Report 2005)

horizontal run. The angle, α, for a 10% grade is arctan(1/10) or 5.7º. Highway construction guidelines specify design limits for road grades. These limits depend on the local terrain, speed limit and the expected usage of the road. For instance, in Massachusetts, freeways designed for 65 mph speed over rolling terrain may have a maximum grade of 4%, while a local road in mountainous terrain designed for speeds of 25 mph, may have a maximum 15% or 16% grade. (Massachusetts 2006, Design Guidebook chap. 4).

For a section of road on a straight rise, the actual length of the road, as traveled, is longer than the horizontal length of the road as represented by coordinates in GIS data. The greater the grade, the greater the increase in length of the road over its horizontal run length. For a constant 10% grade, the surface length of the road is almost 0.5% longer than the horizontal run length. Table 1 shows sample values for various grades.

Grade	Angle of inclination (degrees)	Length Increase Ratio
2%	1.15	1.0002
4%	2.29	1.0008
6%	3.43	1.0018
8%	4.57	1.0032
10%	5.71	1.0050
12%	6.84	1.0072
14%	7.97	1.0098
16%	9.09	1.0127

Table 1. Sample values for grade, angle of slope, and length increase ratio.

From data about a road's horizontal position and data about the elevation of points along the road's centerline, a GIS can compute the length of the road as it travels over hilly terrain, where the road is represented by a line and the terrain is represented by a DEM (see Figure 2). The SURFACELENGTH module of ArcGIS calculates this value by sampling the line feature at each point on the elevation model, using bi-linear interpolation to determine elevation points between pixels and at endpoints. Between each sampling point, the length of the sub-segment is computed as the euclidean distance between the two (x,y,z) coordinates of each endpoint. Since a horizontal line can only get longer as it rises or falls over the elevation points along it, the horizontal distance is the minimum length of the segment of road. Thus, a GIS calculation should produce lengths that are only greater than or equal to the the horizontal lengths, and could reasonably approximate the length of the road as measured by DMI. If such a calculation can be performed using sufficiently accurate data, the need for measuring roads with DMI could be eliminated along with the costs of maintaining and operating the equipment and staffing the crew.

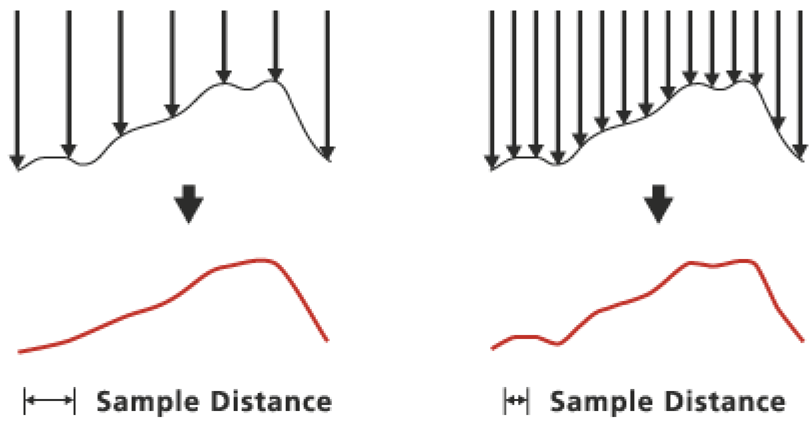


Figure 2. Example SURFACELENGTH sampling (ESRI)

This project makes the SURFACELENGTH calculation from ArcGIS and examines the change to the centerline miles for each city and town of the state, as well as for the state's total centerline miles. If the results of the calculated lengths are significantly different from the pre-existing lengths as determined by DMI, it may be necessary for government agencies to address these changes, specifically the financial ramifications to changes of apportionments that would result from unexpectedly large changes in determinations of road lengths.

Literature

The basis for centerline miles of roads as part of the computation for apportioning funds is established by the SAFETEA-LU act of Congress (US FHWA 2005 Fact Sheets). This legislation is large and has many spending programs for the development and maintenance of the nation's transportation infrastructure. For roads and highways, apportioning funds on a state by state basis uses various measures of quantity of roads and volume of usage to compute the funds made available. Each state is required to submit annual reports of road inventory data to the Federal Highway Administration, using the Highway Performance Monitoring System (HPMS) (US FHWA 2002).

Chapter 90, section 34 of the Massachusetts General Laws apportions funds to the cities and towns of the state based on measures of road centerline miles, population and employment rates for each town (Mass. Muni. Assoc.).

Departments of Transportation have additional reason to be driving roads besides measuring the length. Records of features along the road as well as monitoring road surface quality are also maintained. A Linear Reference System (LRS) is the most common method of recording locations of features: signs, intersections, pavement changes, etc., in the road system (Noronha 2002). An LRS describes a location as the distance driven along a pre-determined route from a pre-determined starting point. Creating an efficient system of starting points and routes has been studied by Rasdorf (2002). Measuring the lengths of the routes is an activity that can be part of gathering other data about the roads.

Using a GIS to compute the length of a road with elevation is a relatively new investigation. Less than a handful of states practice it; the majority of states continue to use DMI (Ratner 2007). There is not a large literature for using GIS to calculate road lengths over terrain. North Carolina has been the site of recent and careful studies of road length computation by GIS and comparing the results to the lengths determined by DMI (Cai 2006; Rasdorf 2004). DMI measurements were carefully made on a subset of roads for the purposes of that study. The computations used the "Surface Length" module of ArcGIS and data from the road centerline layer and elevation data from the National Elevation Dataset from USGS (Rasdorf 2003). The results of this work show that short road segments and steep road segments are more likely to have GIS-computed lengths with a greater difference from DMI-determined lengths (Rasdorf 2003). His conclusions is that GIS can produce a satisfactory and usable result if care is taken to use accurate inputs. Not surprisingly, the accuracy of the data input to such a GIS calculation are very relevant to the quality of the results - accurate horizontal positions of the road centerlines and their endpoints are critical as is elevation data that is vertically and horizontally positioned correctly.

The doctoral dissertation by Cai (2003) compared analyses done at various resolutions and sources of elevation data: LIDAR data at 20 and 50 foot interval, and NED at 15 and 30 meter interval. The model of a road centerline was constructed by hand coding in VisualBasic in ArcGIS. Generally, higher resolution elevation models produced lengths that were closer to those obtained by DMI. It was pointed out that DMI is the only method that determines a road's length in 3-dimensional space in a continuous fashion, as compared to other field methods which only collect point samples along the road. For example, surveying with a Total Station, which requires closing the road to traffic to perform the field work, is only capable of collecting sample points along the road. Likewise, using GPS produces a set of discrete points which serve only as an approximating model of the road.

Objective

The objective of this project is to calculate the SurfaceLength of the roads and show the change in total length from the current AssignedLength for the entire state and for each town. Problematic input data are identified and removed and then a proportional change in total road length mileage for the state compared to DMI measurements is determined.

Methodology

The road centerline data were obtained from Massachusetts EOT, by download over the internet as a Road Inventory Geodatabase. The DEM was obtained from MassGIS, as made available February 2005, with a cell size of 5 meters by 5 meters containing integer values representing elevation in meters above or below sea level. Both datasets were projected to Massachusetts State Plane coordinates at 1:5,000 scale.

The roads applicable to this project were extracted from the database by selecting the segments that are used for tallying centerline miles[2]. This resulted in 340,852 roads that were analyzed. Using the SURFACELENGTH module of the spatial analyst extension of ArcGIS 9.1, the length of each of these roads as draped over the DEM was computed. Since the road line geometry is in meters and the elevation is in meters, the Z factor was specified as 1. The resulting value was the SurfaceLength in meters for each road segment. The value for a road's length as assigned by EOT, in miles, is stored in the AssignedLength field of the state road inventory file, which was converted to meters by multiplying by 1,609.344 to produce a new value called AssignedLengthMeters. The SurfaceLength was subtracted from AssignedLengthMeters to produce a new value called AssignedLengthChange. Likewise, the SurfaceLength was subtracted from each road's ShapeLength to produce a new value called ShapeLengthChange. Finally, the ratio of SurfaceLength to ShapeLength was computed for each road by dividing SurfaceLength by ShapeLength. Equations 1 – 5 summarize these calculations.

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2. Select statement used: “SELECT * WHERE MileageCounted = 1 AND FacilityType IN [1,2,3,4,5,6]”, personal communication from Mark Berger, Massachusetts Office of Transportation Planning.

$$(1)\, SurfaceLength = SURFACELENGTH\,(Roads\,,\, DEM\,,\, Z=1)$$
$$(2)\, AssignedLengthMeters = AssignedLength * 1609.344$$
$$(3)\, AssignedLengthChange = SurfaceLength - AssignedLengthMeters$$
$$(4)\, ShapeLengthChange = SurfaceLength - ShapeLength$$
$$(5)\, ShapeChangeRatio = \frac{SurfaceLength}{ShapeLength}$$

The change to each town's total centerline miles was calculated by summing AssignedLengthChange for all roads assigned to each town. Roads were assigned to town not by spatial relation, but as coded in the EOT roads database. For each town and for the state as a whole, the total SurfaceLength, AssignedLengthChange and the percent change from AssignedLength to SurfaceLength was shown.

The Slope module of the spatial analyst extension of ArcGIS 9.1 is used to create a slope model of the entire state from the DEM with each resulting 5 meter by 5 meter pixel containing a value, in degrees, for the slope of the terrain in that pixel. The “Line Raster Intersection Statistics” module of Hawth's Tools (Beyer 2004) was used to assign to each line, the maximum value of a pixel in the slope model that the line overlaps. This value was stored for each road segment in the variable SlopeMax.

To compare the GIS calculated length of roads with the EOT's length of the roads as determined by DMI, the following data were removed from the roads dataset and a matched-pairs t-test was calculated between AssignedLengthMeters and SurfaceLength.

- One road in East Bridgewater whose AssignedLength is 20.24 miles, a likely data error
- 54 roads with no associated shape geometry
- 339 roads that appear to fall partially or completely outside the DEM
- 5,382 roads that have no DMI measurements
- 6,702 roads whose maximum slope pixel (SlopeMax) is greater than or equal to 20 degrees

Results

Appendix 2 shows, for each town, the number of road segments, the total new SurfaceLength for the roads, and the change from the town's total AssignedLength, in miles, given as both percent change and amount change. Values are listed in miles, as those are the units used for reporting purposes by EOT. The total change for the state, an increase of 156.38 miles, is given at the end of Appendix 2. This would increase the total mileage reported by the state from 35,855 to 36,012 miles, an increase of 0.4%. The towns are listed in Appendix 2 in order by raw amount of change, which correlates with both total length of roads and with total number of roads. This contrasts with percent change in length, which does not correlate with number of roads nor with total length of roads nor, perhaps surprisingly, with raw miles of change. Table 2 shows the six pairwise correlations of the columns in Appendix 2.

	Total Length	Miles Change	# Roads
Miles Change	r=0.996 *P=0.000*		
# Roads	r=1.000 *P=0.000*	r=0.994 *P=0.000*	
% Change	r=0.012 *P=0.819*	r=0.005 *P=0.923*	r=0.021 *P=0.688*

Table 2. Correlations, by town, for total length, miles of change, number of roads, and percent change in miles.

Figure 3 shows a choropleth of the state with each town classed by the change in number of miles of roads (the "Miles Change" column of Appendix 2). What is apparent from this map is the rarity of extreme values of change. A dotplot of the distribution is shown in Figure 4. The lowest values are for East Bridgewater (shown in the choropleth in darkest brown) with a loss of 19.37 miles, Plymouth next (shown in the choropleth in medium brown) with a loss of 5.11 miles. The top two gaining cities are Boston with 17.12 miles and Worcester with 12.5 miles, both shown in the choropleth in darkest blue. As the shape of the distribution shows, the data are otherwise tightly packed around zero, the mean change per town is a gain of 0.45 miles, with one standard deviation of 2.00 miles. This is consistent with the bulk of the choropleth appearing in the lightest colors.

Examining East Bridgewater, one road was discovered that is assigned a length of 20.24 miles. The ShapeLength for this one road is 0.236 miles. This appears to be a data entry error, as the town itself is only about 6.5 miles in the longest dimension. The effect of this error is that the town loses almost 20 miles of roads from the SurfaceLength calculation from that one road alone.

Setting aside, for the moment, the relation between SurfaceLength and AssignedLength, attention was given to the relation between ShapeLength and SurfaceLength. A histogram and boxplot of ShapeChangeRatio is shown in Figure 5. The mean increase from ShapeLength to SurfaceLength of a road is 0.12%. However, there are 54 road segments that have no geometry and are not included, thus N=340,798. Plymouth has 40 of these road segments missing geometry, however the total AssignedLength for these 40 roads is 4.33 miles which are lost as a result of the SurfaceLength calculation. This explains the bulk of Plymouth's loss of 5.11 miles. The other 14 road segments with no geometry are in 11 other towns and total 0.55 miles.

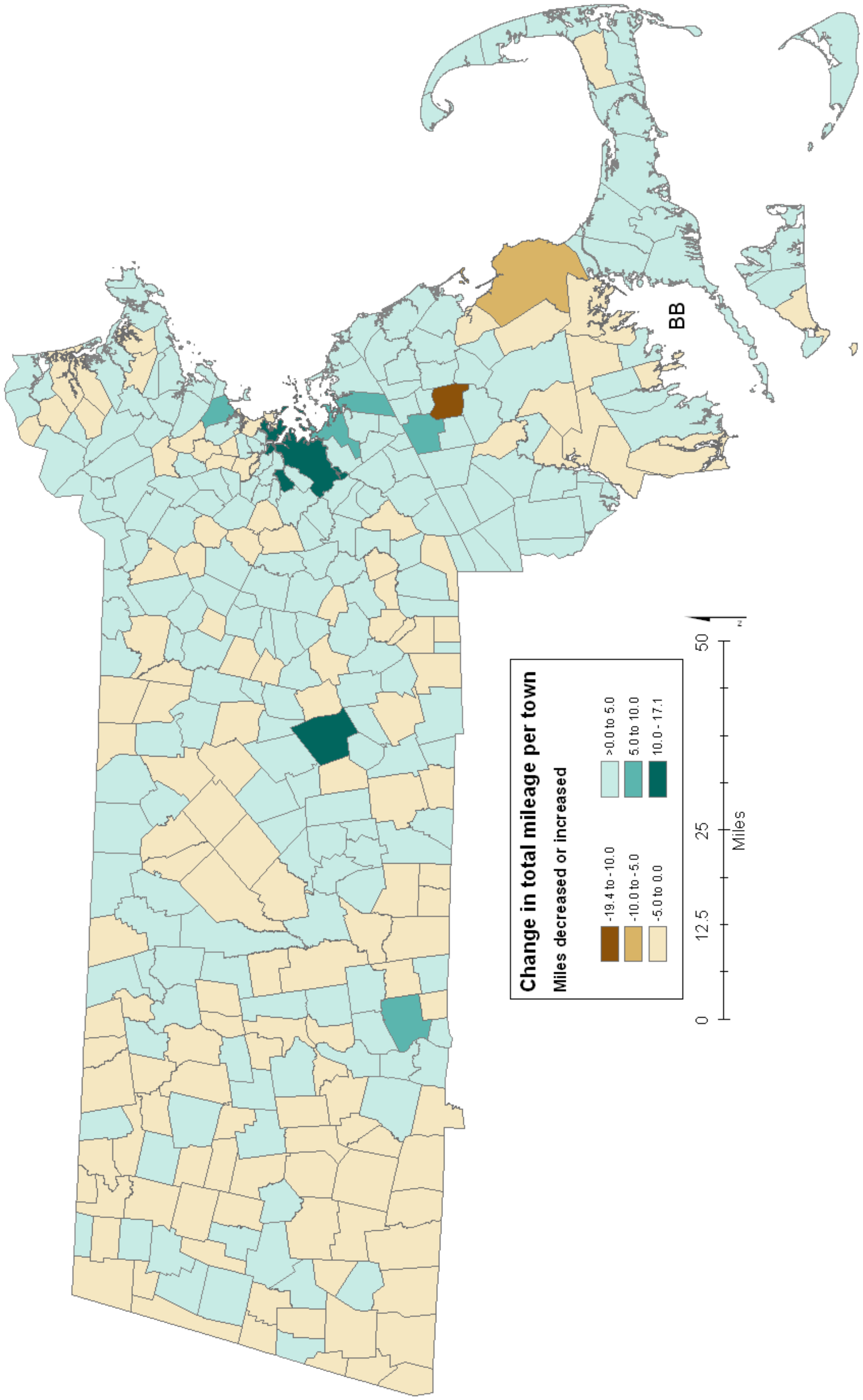

Figure 3. Choropleth showing difference from total AssignedLength to total SurfaceLength for each town in Massachusetts

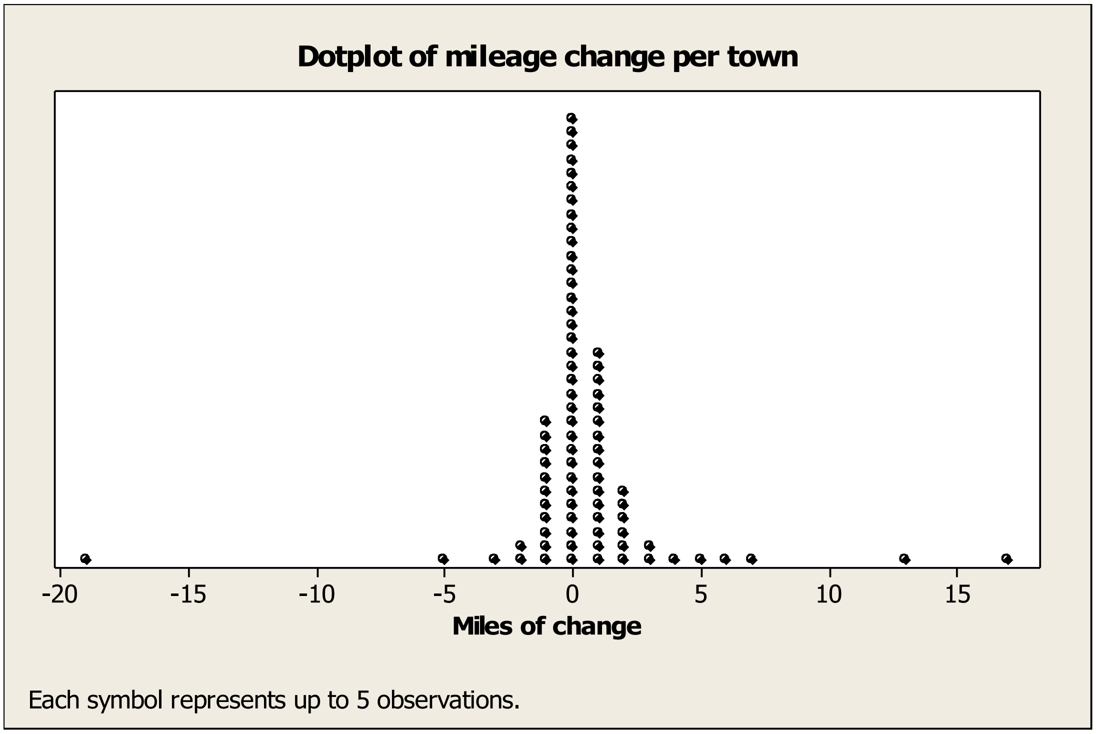

Figure 4. Dotplot of mileage change per town

Significant in Figure 5 are the roads for which the ShapeChangeRatio is less than 1.0, that is, the SurfaceLength is less than ShapeLength. Since roads should not get shorter as a result of elevation, this result is surprising and suggests problems with the input data.

Calculating the difference from ShapeLength to SurfaceLength by subtracting ShapeLength from SurfaceLength, the histogram of these values (not shown) shows 339 roads that are shortened by amounts from 0.08 meters to 1,073.5 meters. A visual examination of these 339 roads shows that they lay partly or completely outside the DEM, distributed along the entire coast of Massachusetts. Figure 6 shows an example of these roads in the northern end of the Buzzard's Bay area of southeast Massachusetts. Buzzards Bay is indicated by the “BB” on the choropleth of the state in Figure 3.

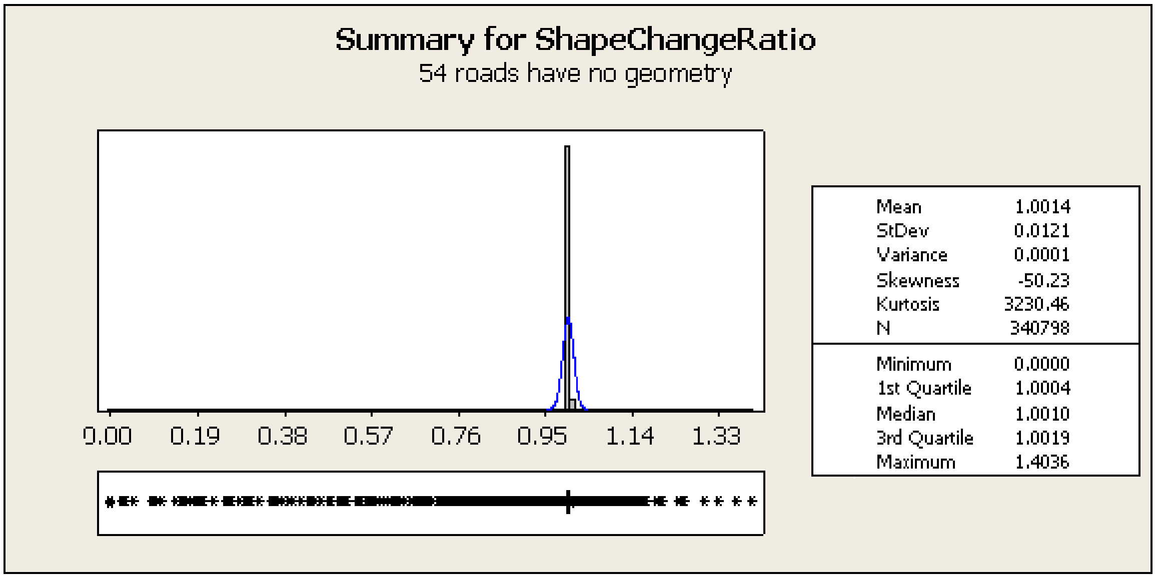

Figure 5. Distribution of ShapeChangeRatio

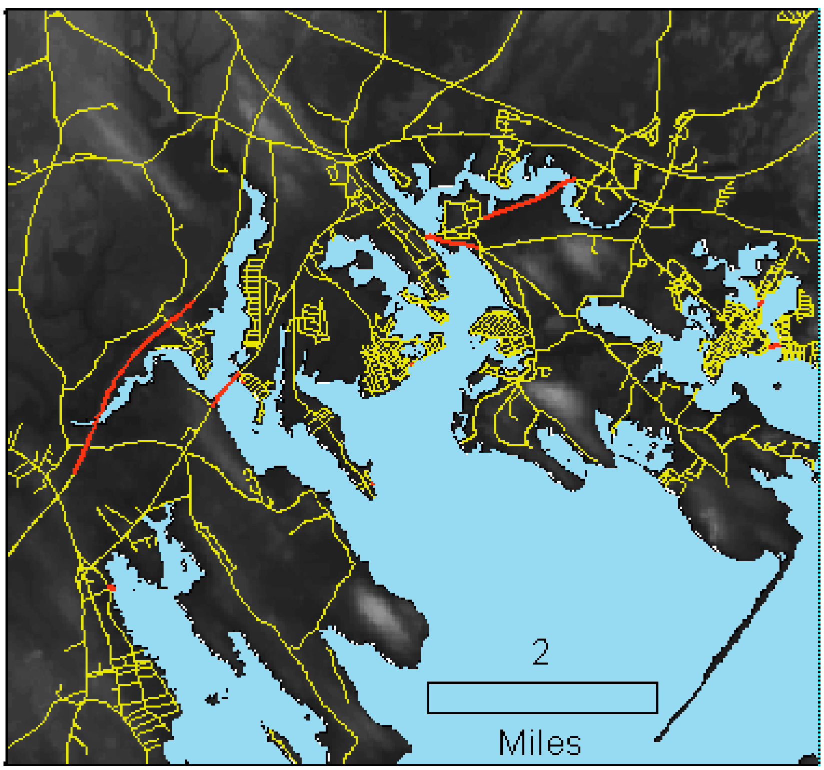

Figure 6. Roads shown in red cross outside the data area of the DEM in this closeup of an area of Buzzards Bay. The roads in yellow are entirely within the data area of the DEM. The dark background is the DEM.

Looking only at the upper tail of the distribution of ShapeChangeRatio, Figure 7 shows a scatterplot of ShapeChangeRatio vs. ShapeLength. Reference lines have been added to show where 5 and 10 meter values of ShapeLength are located along the X axis. The horizontal line indicates ShapeChangeRatio ≥ 1.01, that is, above this line are roads that increase in length by more than 1% of their ShapeLength. There are 3,479 of these segments, or about 1% of roads in the database. A 1% increase in length corresponds to about a 14% constant grade, which is quite steep. Thought was given to remove roads that exceed some threshold value of ShapeChangeRatio. However, this analysis considered a different source for this anomaly that is not dependent on the ShapeLength or SurfaceLength of a road segment. Thus, a different technique was used to detect situations that may be artificially adding length to roads.

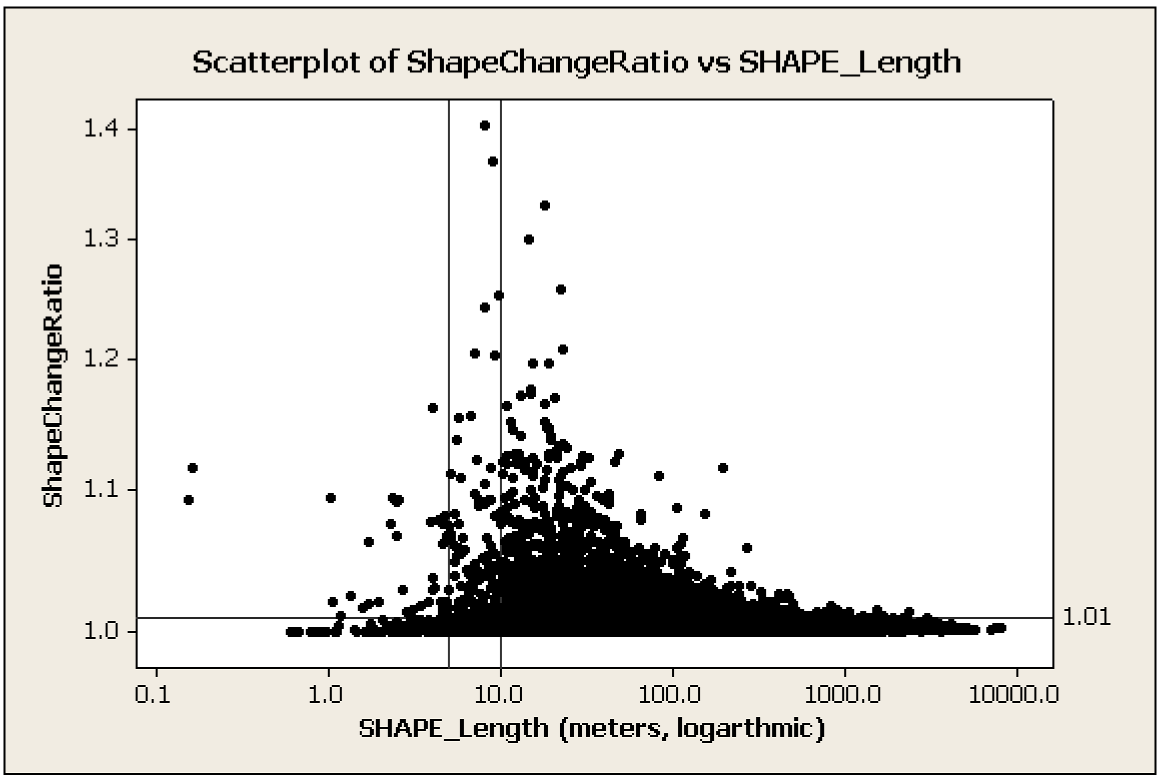

Figure 7. Scatterplot of ShapeLength vs ShapeChangeRatio with reference lines for 5 and 10 meters, and for 1.01 ShapeChangeRatio.

Using the calculation of maximum slope pixel crossed by each road's line, roads were selected for which the maximum slope pixel crossed is greater than or equal to 20 degrees. The value of 20 degrees was not chosen with any mathematical basis, but rather as a guess for a reasonable demarcation point for extreme values. The largest point slope crossed by any line is 68 degrees. There are 6,702 roads that cross a slope pixel greater than or equal to 20 degrees. A visual inspection of these roads on top of the slope model showed that bridges and overpasses are sometimes represented in the DEM and sometimes are not. See Figure 8.

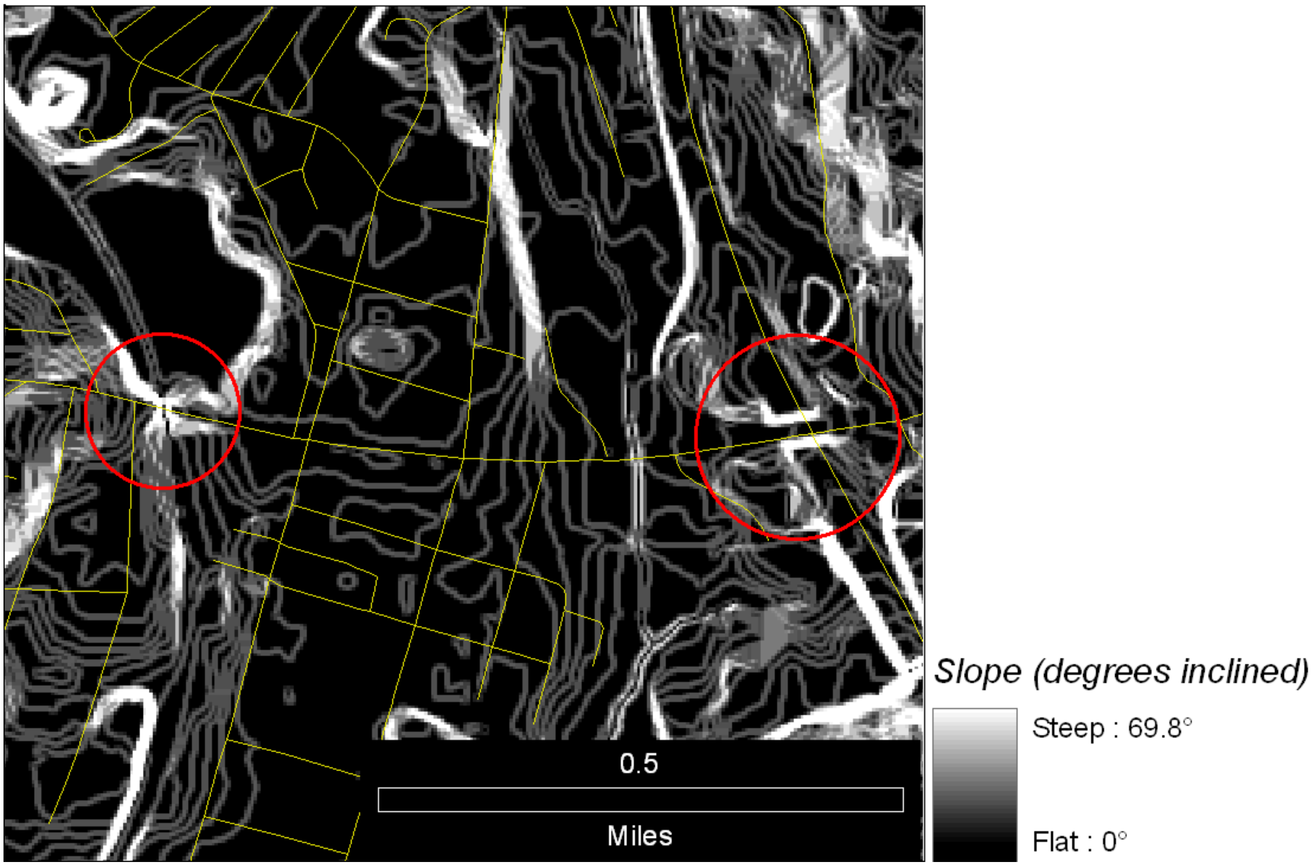

Figure 8. Roads overlaid on slope model. Bridges circled in red.

When a bridge is not present in the DEM, as in the left red circle in Figure 8, this causes the road line to follow the surface of the sides of the chasm that the bridge spans, that is, it has to travel down one side of the chasm and the back up the other side. Thus, the road segment is lengthened by approximately twice the bridge's height. When a bridge *is* present in the DEM, as in the highway overpass in the red circle on the right in Figure 8, the road traveling on the bridge is unaffected, but the road passing under the bridge is affected by having its line travel an artificial surface from its actual elevation, up to the elevation of the bridge deck, and then back down the other side to resume its actual elevation. This adds to the underpassing road's surface length an amount, as before, approximately equal to twice the height of the bridge. This cause of an increase in a road's length does not correspond to any attribute of the road other than it's position over a feature captured in the DEM. In particular, therefore, one cannot use ShapeChangeRatio to detect these situations, as longer lengths of road will hide this incorrect increase in length that is due to these abrupt changes in elevation.

An improved approximation of the change in road mileage for the state was determined by removing the above mentioned anomalous roads from the data and then recomputing the proportional change in length from the odometer readings assigned to each road. Specifically, the following roads are removed from the data:

- the 54 roads that have no geometry, and thus have zero ShapeLength
- the 339 roads that lay partially or completely outside the DEM (coastal)
- the 5,382 roads that have no odometer measurement.
- the 6,702 roads that cross a pixel with slope > 20 degrees
- the 1 road in East Bridgewater with the erroneous odometer reading.

The total odometer length of the remaining 328,374 roads is 33,291 miles. The total SurfaceLength for these roads is 33,462 miles, an increase of 0.51%. Since there are two measurements for each road segment, a matched-pairs t-test takes advantage of knowing which SurfaceLength value corresponds to which AssignedLength value, and provides a better test of significance between the two values. Using values of AssignedLengthMeters and SurfaceLength of the remaining 328,374 roads the T value is 7.99, with $P < 0.0001$, making it extremely unlikely that the difference between odometer readings and GIS calculation is random.

Discussion and Conclusions

The SurfaceLength calculation of road lengths for Massachusetts produces results that are slightly longer than odometer measurements (0.51%), and that are statistically distinct.

The overall strategy of this study can be summarized as follows:

- Compute the SurfaceLength of all 340,852 roads using GIS
- Identify and remove problematic data
- Use a matched-pairs t-test on the remaining roads to compare road length computed by GIS to road length measured by odometer

The problematic roads removed were 3.66% of roads, which totaled 0.5%, of the 33,291 miles of roads. While GIS measurement is only 0.51% larger than odometer measurement, the matched-pairs t-test indicates that this 0.51% is statistically significant. It does not, however, indicate which measurement is more correct. A study on a well-selected sample of roads with carefully gathered odometer readings may show whether or not GIS-calculated lengths are closer to ground truth.

It is worth noting that the scatterplot in Figure 7 has an apparent peak value very close to twice the cell size of the DEM. Repeating this study with a DEM with a different cell size might show an effect with the largest ratios of change occurring for roads whose ShapeLength is close to twice the DEM cell size. On the other hand, perhaps larger cells have a smoothing effect on the terrain model. Different resolutions of the elevation model, both horizontally and vertically, could also produce different results for surface length of features.

Massachusetts EOT is considering using a GIS method such as the one used in this project to calculate road lengths for reporting and apportioning purposes. By doing this, a change in the amount of funds received by the state from various FHWA programs would occur, but the exact dollar amount is beyond the scope of this work. Other variables in addition to road length are used to calculate apportionment and it is very unlikely that a 0.4% increase in centerline miles would result in a 0.4% increase in federal funds received by the state. A 0.4% increase in road centerline miles may be one consideration in the decision whether to adopt a GIS method for determining road lengths by the EOT.

Using this methodology within the state, the total state distribution of funds to the towns would be unaffected, as the formula is proportionally based. The total cost to the state would remain the same, however the distribution to towns would be adjusted such that towns with increased miles would receive increased funds, and towns with decreased miles would receive decreased funds. At the start of this work, it was expected that the most gains would be in the part of the state with the hilliest terrain, specifically the western Berkshires. Instead, the largest increases correlate very strongly to towns with the most roads. Thus, the Berkshires, being mostly rural towns, have fewer roads and therefore would have their state apportionments slightly transferred to more towns with more roads, which are mostly urban and eastern towns.

The accuracy of the horizontal positions of the road linework were not checked by other means such as visual comparison to aerial orthophotos, by field survey or GPS, or by analysis of raster images. The quality of the road attribute data was not performed, such as correct assignment of road segments to towns or correct classification of type of road segment. A casual comparison of the assigned town vs. the spatial location of each road within the town boundaries (as available from MassGIS) shows numerous discrepancies. The causes of these discrepancies were not examined. Also, there is some doubt that the values in the FacilityType field are carefully assigned, as a search for bridges by selecting FacilityType = 2, showed only eight road segments in the entire data, all in the town of Concord, MA, none of which, upon casual inspection, appear to be a bridge. The geometric accuracy of the DEM and the road linework layer was assumed sufficient to make a meaningful comparison of the calculated lengths with the assigned lengths. Clearly, the data quality of these factors could have an impact on the results. Closer analysis of the quality of these data may be addressed in future research.

DESCRIPTION OF ROAD INVENTORY FILE

Ap

ObjectID: ArcGIS internal unique identifier

Shape: ArcGIS geometry field

RoadSegment_ID: The unique identifier of the RoadInventory file

FromMeasure: The measured length along the specified RoadSegment feature where this RoadInventory segment starts

ToMeasure: The measured length along the RoadSegment feature where this RoadInventory segment ends

AssignedLength: Segment length in miles

AssignedLengthSource: Defines the source of the assigned length value
- 0 = Shape length
- 1 = Odometer
- 2 = Odometer prorated from CSN pair (60000-rule) during migration from coverage model

StreetList_ID: The identifier of the Street the segment lies on

StreetName: The name of the street the segment lies on

City
- 1= Abington & 351 = Yarmouth

County
- A = Barnstable
- B = Berkshire
- C = Bristol
- D = Dukes
- E = Essex
- F = Franklin
- G = Hampden
- H = Hampshire
- I = Middlesex
- J = Nantucket
- K = Norfolk
- L = Plymouth
- M = Suffolk
- N = Worcester

MunicipalStatus
- 1 = City
- 2 = Town

FromEndType: Defines the start of the street the segment lies on
- 1 = Cross-street
- 2 = Dead end
- 3 = Cul-de-sac
- 4 = Private property
- 5 = Town line
- 6 = State line

FromStreetName: The cross-street where the street starts (when the street starts at a cross-street)

FromCity: The city where the street starts when the street starts at a city boundary
- 1= Abington & 351 = Yarmouth

FromState: The state where the street starts when the street starts at a state boundary
- 1 = Connecticut
- 2 = New Hampshire
- 3 = New York
- 4 = Rhode Island

Appendix 1. Field descriptions of Massachusetts EOT roads database

DESCRIPTION OF ROAD INVENTORY FILE

5 = Vermont

ToEndType Defines the end of the street the segment lies on
1 = Cross-street
2 = Dead end
3 = Cul-de-sac
4 = Private property
5 = Town line
6 = State line

ToStreetName: The cross-street where the street ends (when the street ends at a cross-street)

ToCity: The city where the street ends when the street ends at a city boundary
1= Abington & 351 = Yarmouth

ToState: The state where the street ends when the street ends at a state boundary
1 = Connecticut
2 = New Hampshire
3 = New York
4 = Rhode Island
5 = Vermont

MileageCounted: Describes whether the segments length is counted towards the official statewide road centerline mileage
1 = Yes
0 = No

Note - See Facility Type

RouteKey: The primary state numbered route or designated non-numbered route on which this segment lies; when more than one route traverse a segment, the highest order (Interstate > US Highway > State Route), lowest number route is primary; non-numbered routes are used internally by Planning for pavement data collections

RouteFrom: The measured length along the specified Route where this RoadInventory segment starts

RouteTo: The measured length along the specified Route where this RoadInventory segment ends

RouteSystem
I = Interstate
US = US Highway
SR = State Route
0 = Not a numbered route

RouteNumber: The official route number designation; need not be exclusively numeric (146A, for example)

SubRoute: Optional designation to distinguish alternate sections of the same numbered route

RouteDirection
NB = North
EB = East
SB = South
WB = West

RouteType
0 = Non-numbered
1 = Numbered-Primary (NB/EB)
2 = Numbered-Opposing (SB/WB)

RouteQualifier: (Reserved for future use -- not implemented at this time)
0 = No Qualifier or Not Signed or Not Applicable
1 = Alternate
2 = Business Route
3 = Bypass
4 = Spur

Appendix 1. Field descriptions of Massachusetts EOT roads database

DESCRIPTION OF ROAD INVENTORY FILE

5 = Loop
6 = Proposed
7 = Temporary
8 = Truck Route
9 = None of the Above

RPA: Regional Planning Agency
BRPC =Berkshire Regional Planning Commission
CCC = Cape Cod Commission
CMRPC = Central Massachusetts Regional Planning Commission
FRCOG = Franklin Regional Council of Governments
MAPC = Metropolitan Area Planning Council
MRPC = Montachusett Regional Planning Commission
MVC = Marthas Vineyard Commission
MVPC = Merrimack Valley Planning Commission
NMCOG = Northern Middlesex Council of Governments
NPEDC = Nantucket Planning and Economic Development Commission
OCPC = Old Colony Planning Council
PVPC = Pioneer Valley Planning Commission
SRPEDD = Southeastern Regional Planning and Economic Development District

MPO: Metropolitan Planning Organization
Berkshire
Boston Region
Cape Cod
Central Massachusetts
Franklin
Martha's Vineyard
Merrimack Valley
Montachusett
Nantucket
Northern Middlesex
Old Colony
Pioneer Valley
Southeastern Massachusetts

MassHighwayDistrict
MinValue: 1
MaxValue: 5

UrbanType
1 = Urbanized area – Densely settled territory that contains 50,000 people or more
2 = Urban cluster – Densely settled territory that contains at least 5,000 people but fewer than 50,000 people
5 = Rural

UrbanizedArea
0 = RURAL
7 = Boston (MA-NH-RI)
26 = Providence (RI-MA)
43 = Springfield (MA-CT)
76 = Worcester (MA-CT)
127 = New Bedford
189 = Leominster-Fitchburg
199 = Pittsfield
246 = Nashua (NH-MA)
394 = Barnstable Town
A = Amherst
B = Athol
C = Great Barrington
D = Greenfield
E = Lee
F = Nantucket
G = North Adams (MA-VT)

Appendix 1. Field descriptions of Massachusetts EOT roads database

DESCRIPTION OF ROAD INVENTORY FILE

I = Pepperell
K = Stafford (CT-MA)
L = Vineyard Haven
M = Ware
O = Winchendon (MA-NH)

FunctionalClassification: Note: use urban/rural designation to interpret functional classification
0 = Local
1 = Interstate
2 = Principal arterial
3 = Rural minor arterial or urban principal arterial
5 = Urban minor arterial or rural major collector
6 = Urban collector or rural minor collector

Jurisdiction
1 = Massachusetts Highway Department
2 = City or Town accepted road
3 = Department of Conservation and Recreation
4 = Massachusetts Turnpike Authority
5 = Massachusetts Port Authority
6 = State Park or Forest
7 = State Institutional
8 = Federal Park or Forest
9 = County Institutional
0 = Unaccepted by city or town
B = State college or university
C = US Department of Defense
D = US Army Corps of Engineers
E = Federal Institutional
F = Other Federal
G = Federal Bureau of Indian Affairs
H = Private

Truck Route
0 = Not a parkway - not on a designated truck route
1 = Designated truck route under Federal Authority in 23 CFR 658
Available to STAA vehicles (Twin 28' Semi-trailer-trailer and 48' Semi-trailer combinations)
2 = Designated truck route ONLY under State Authority.
Fully available to both types of STAA vehicles described above
3 = Department of Conservation and Recreation Parkway – No trucks allowed

NHSStatus: National Highway System Status
0 = Not on NHS
1 = NHS - Interstate
2 = NHS - Strategic Defense Highway System (STRAHNET)
3 = NHS - STRAHNET Connector
4 = NHS - Other - One-way pair
5 = NHS - Other - Truck route exclusion
6 = NHS - Major Airport
7 = NHS - Major Port Facility
8 = NHS - Major Amtrak Station
9 = NHS - Major Rail/Truck terminal
10 = NHS - Major Intercity Bus Terminal
11 = NHS - Major Public Transit or Multi-Modal Passenger Terminal
12 = NHS - Major Pipeline Terminal
13 = NHS - Major Ferry Terminal
14 = NHS - Other (not in above categories)

FederalAidRouteNumber: Maintained for historical purposes

FacilityType
1 = Mainline roadway*
2 = Bridge*
3 = Tunnel*

Appendix 1. Field descriptions of Massachusetts EOT roads database

DESCRIPTION OF ROAD INVENTORY FILE

4 = Doubledeck*
5 = Rotary*
6 = Causeway*
7 = Simple ramp
8 = Ramp - NB/EB
9 = Ramp - SB/WB
10 = Collector - Distributor
11 = Simple Ramp - Tunnel
12 = Bicycle

*Road types included in official statewide road centerline mileage

StreetOperation
1 = One-way traffic
2 = Two-way traffic

AccessControl
0 = No control
1 = Full control
2 = Partial control

TollRoad
0 = Not a toll road
1 = A toll road

NumberOfPeakHourLanes: Number of lanes open for vehicles during Peak travel times including breakdown and high-occupancy vehicle lanes

RightSidewalkWidth:
Width of the sidewalk in feet on the right side of the road traveling in the primary (NB/EB) direction of travel

RightShoulderType: Type of shoulder on the right side of the road traveling in the primary (NB/EB) direction of travel
0 = No Shoulder
1 = Stable - Unruttable compacted subgrade
2 = Unstable shoulder
3 = Hardened bituminous mix or penetration
4 = Combination shoulder

RightShoulderWidth: Width of shoulder in feet on the right side of the road traveling in the primary (NB/EB) direction of travel

MedianType: Type of median on divided roadways
0 = None
1 = Curbed
2 = Positive barrier
3 = Unprotected

MedianWidth: Width of median in feet on divided roadways
MinValue: 1
MaxValue: 999

LeftSidewalkWidth: Width of the sidewalk in feet on the left side of the road traveling in the primary (NB/EB) direction of travel; on divided roadways, this will fall on the opposing direction (see illustration)

LeftShoulderType: Type of shoulder on the left side of the road traveling in the primary (NB/EB) direction of travel; for divided roadways median shoulders are assumed to be of the same type
0 = No Shoulder
1 = Stable - Unruttable compacted subgrade
2 = Unstable shoulder
3 = Hardened bituminous mix or penetration
4 = Combination shoulder

LeftShoulderWidth: Width of shoulder in feet on the left side of the road traveling in the primary (NB/EB)

Appendix 1. Field descriptions of Massachusetts EOT roads database

direction of travel; for divided roadways median shoulders are assumed to be of the same type

SurfaceType
1 = Unimproved, graded earth, or soil surface road
2 = Gravel or stone road
3 = Brick road
4 = Block road
5 = Surface-treated road
6 = Bituminous concrete road
7 = Portland cement concrete road
8 = Composite road; flexible over rigid
9 = Composite road; rigid over flexible or rigid over rigid ("white topping")

SurfaceWidth: Surface width in feet; measurement of traveled way, excluding shoulders/auxiliary lanes

RightOfWayWidth: Right-of-way width in feet

NumberOfTravelLanes: Number of travel lanes (for undivided roadways, number of lanes in both directions of travel, for divided roadways, number of lanes on the given segment only)
MinValue: 1
MaxValue: 6

OppositeNumberOfTravelLanes: Number of travel lanes in the opposite direction of a divided roadway
MinValue: 1
MaxValue: 6

Curbs
0 = None
1 = Left side only
2 = Right side only
3 = Both sides
4 = Along median only
5 = All curbs (divided highway)

Terrain
1 = Level
2 = Rolling
3 = Mountainous

SpeedLimit
MinValue: 5
MaxValue: 65

StructuralCondition
1 = Good
2 = Fair
3 = Deficient
4 = Intolerable

ADT: Average Annual Daily Traffic

ADTStationNumber: ADT count station location number; used to reference Traffic Data Collections counting station number

ADTDerivation
0 = Not applicable
1 = Derived from counts collected on or adjacent to the section during the current year
2 = Derived from factoring counts from the previous year count-base AADT that is less than three years old
3 = Derived from count data that is three or more years old
4 = Derived from an estimate
5 = Working code for principal arterial counting program

ADTYear: Year of ADT collection

Appendix 1. Field descriptions of Massachusetts EOT roads database

2005 Road Inventory Year-End Report

DESCRIPTION OF ROAD INVENTORY FILE

IRI: Pavement Roughness; value reflects calibrated value in inches of roughness per mile

IRIYear: Year of IRI collection

IRIStatus
- 1 = IRI data collected
- 2 = No IRI data collected due to speed
- 3 = No IRI data collected due to construction
- 4 = No data collected due to bridge deck

PSR: Pavement Serviceability Rating

PSRYear: Year of PSR collection

HPMSCode
- 0 = Not an HPMS section nor on a road that has an HPMS section
- 1 = Not an HPMS section but is on a road that has an HPMS section
- 2 = An HPMS section

HPMSSample_ID: The HPMS Sample identifier for sections lying on a designated HPMS sample

AddedRoadType: Description of roads added to the GIS that are 250 feet or more and serve a specific land use
- 0 = Default/Not applicable
- 1 = Public road (but not highway ramp)
- 3 = Highway ramp
- 4 = Road appears in 1:5000-scale centerline file, but not in DLG or orthophotos
- 5 = Research park, industrial park, office park, shopping mall or center, condominium complex or subdivision
- 6 = Airport passenger or cargo area, port access road, intermodal terminal access road, or major truck terminal
- 7 = Treatment plant, electrical plant, petroleum depot, town or state facility, or other water, sewer, power, or communication facility
- 8 = State park or other recreational area
- 9 = Cul-de-sac
- 10 = Other private road
- 11 = Rest area

DateActive: The date the road became active, or, if not known, the date it was entered into the system; all roads active when this field was implemented were assigned a date 1/1/2004

LifeCycleStatus
- 1 = Proposed
- 2 = In Construction
- 3 = Active

RoadInventory_ID: A sequential identifier assigned to each RoadInventory segment

Appendix 2. Total change in miles per town – ordered by Miles Change

Town	# Roads	Surface Length	% Change	Miles Change
East Bridgewater	645	76.94	-20.1%	-19.37
Plymouth	4,090	475.61	-1.1%	-5.11
Townsend	486	92.58	-3.1%	-2.94
Wakefield	1,329	103.56	-2.7%	-2.83
Sutton	647	108.33	-1.9%	-2.11
Stoneham	1,069	78.98	-2.5%	-2.02
Weston	881	111.06	-1.7%	-1.96
Wilbraham	874	113.7	-1.7%	-1.93
Revere	1,560	107.6	-1.6%	-1.77
Lunenburg	597	93.71	-1.6%	-1.56
Sheffield	404	101.05	-1.4%	-1.47
Hadley	423	82.19	-1.7%	-1.43
Hardwick	322	86.72	-1.6%	-1.39
North Adams	832	84.44	-1.6%	-1.36
Georgetown	498	62.58	-2.1%	-1.36
Carver	584	104.18	-1.2%	-1.30
Belchertown	803	155.87	-0.7%	-1.16
Blandford	204	88.27	-1.3%	-1.12
Granville	196	72.69	-1.5%	-1.11
Chester	186	64.59	-1.6%	-1.05
Kingston	839	98.72	-1.0%	-1.04
Chelmsford	1,883	199.21	-0.5%	-1.02
Becket	275	84.65	-1.1%	-0.97
Leicester	627	89.92	-1.0%	-0.95
Fall River	3,644	276.32	-0.3%	-0.93
Hubbardston	338	83.74	-1.1%	-0.91
Charlton	788	153.44	-0.6%	-0.88
Waltham	2,329	159.43	-0.5%	-0.86
Southwick	479	82.68	-1.0%	-0.85
Otis	225	63.84	-1.3%	-0.82
Richmond	188	47.1	-1.7%	-0.79
Tolland	77	41.55	-1.8%	-0.77
Essex	212	30.19	-2.5%	-0.77
Lenox	463	64.09	-1.2%	-0.77
Goshen	193	43.5	-1.7%	-0.76
Barre	481	115.8	-0.6%	-0.76
Stockbridge	332	54.89	-1.3%	-0.70
Shelburne	267	58.48	-1.2%	-0.70
Dalton	446	46.4	-1.4%	-0.68
Tyringham	82	26.65	-2.4%	-0.67
Walpole	1,285	126.07	-0.5%	-0.67
Westminster	572	108.69	-0.6%	-0.66
Ashby	287	64.08	-1.0%	-0.64
Sterling	581	106.2	-0.6%	-0.62
Berlin	242	43.77	-1.4%	-0.62

Town	# Roads	Surface Length	% Change	Miles Change
Great Barrington	681	95.4	-0.6%	-0.61
Brewster	1,532	167.6	-0.4%	-0.61
Milford	1,320	119.49	-0.5%	-0.61
Rowe	108	35.64	-1.7%	-0.60
Rowley	351	48.82	-1.2%	-0.60
Huntington	182	53.73	-1.1%	-0.58
Sunderland	229	45.75	-1.2%	-0.57
Sandisfield	217	92.55	-0.6%	-0.57
Russell	170	35.67	-1.6%	-0.56
Princeton	302	82.52	-0.7%	-0.56
Southampton	351	75.04	-0.7%	-0.56
Lincoln	408	60.31	-0.9%	-0.55
Petersham	214	78.51	-0.7%	-0.54
Wareham	2,152	178.85	-0.3%	-0.52
Cummington	261	61.3	-0.8%	-0.50
Monson	456	112.65	-0.4%	-0.50
Worthington	185	63.85	-0.8%	-0.50
Plainfield	153	48.3	-1.0%	-0.48
Uxbridge	753	114.07	-0.4%	-0.47
Bolton	381	62.75	-0.7%	-0.46
Phillipston	197	51.57	-0.8%	-0.42
Templeton	630	101.16	-0.4%	-0.42
Shrewsbury	1,809	174.37	-0.2%	-0.41
Leyden	120	37.8	-1.0%	-0.38
Monroe	54	18.01	-2.1%	-0.38
Shirley	318	48.45	-0.8%	-0.38
Fairhaven	1,254	103.99	-0.4%	-0.37
Raynham	533	81.62	-0.4%	-0.36
Colrain	319	86.25	-0.4%	-0.34
Lynnfield	762	73.88	-0.4%	-0.33
Winthrop	673	39.64	-0.8%	-0.32
Egremont	191	43.25	-0.7%	-0.32
East Longmeadow	878	93.89	-0.3%	-0.31
Wales	119	28.54	-1.1%	-0.31
Conway	261	70.66	-0.4%	-0.30
Windsor	181	76.01	-0.4%	-0.30
Brimfield	276	79.22	-0.4%	-0.29
Warwick	211	64.26	-0.4%	-0.29
Dudley	629	87.71	-0.3%	-0.28
Lakeville	771	109.21	-0.2%	-0.27
Blackstone	425	46.24	-0.6%	-0.26
Bernardston	244	57.8	-0.5%	-0.26
Mendon	320	59.66	-0.4%	-0.26
Millis	367	50.94	-0.5%	-0.25
Buckland	237	49.61	-0.5%	-0.25

Appendix 2. Total change in miles per town – ordered by Miles Change

Town	# Roads	Surface Length	% Change	Miles Change
North Reading	752	83.72	-0.3%	-0.24
Newbury	524	64.23	-0.4%	-0.23
Westhampton	150	47.55	-0.5%	-0.23
Gill	239	43.36	-0.5%	-0.22
Boxborough	229	37.41	-0.6%	-0.21
Melrose	1,184	81.55	-0.2%	-0.20
Williamstown	516	76.11	-0.3%	-0.20
Westport	1,035	151.51	-0.1%	-0.20
Merrimac	388	46.81	-0.4%	-0.19
Medway	682	72.67	-0.3%	-0.19
Hatfield	262	59.24	-0.3%	-0.19
Mount Washington	43	17.44	-1.0%	-0.18
Savoy	139	54.5	-0.3%	-0.17
Pelham	129	45.81	-0.4%	-0.17
Wrentham	610	94.43	-0.2%	-0.16
Rochester	350	67.73	-0.2%	-0.15
Peru	136	38.63	-0.4%	-0.14
Westborough	974	110.86	-0.1%	-0.13
Leverett	209	42.9	-0.3%	-0.13
Montgomery	104	30.69	-0.4%	-0.12
Groton	802	110.88	-0.1%	-0.11
Easthampton	856	89.02	-0.1%	-0.11
Marion	339	40.36	-0.3%	-0.11
Alford	83	17.36	-0.6%	-0.10
Freetown	690	103.8	-0.1%	-0.10
Hancock	121	28.06	-0.3%	-0.09
New Marlborough	292	85.82	-0.1%	-0.07
New Ashford	72	17.88	-0.4%	-0.07
Berkley	309	59.96	-0.1%	-0.07
Carlisle	365	55.81	-0.1%	-0.05
Florida	137	46.82	-0.1%	-0.05
Hamilton	461	51.55	-0.1%	-0.05
Holland	182	37.15	-0.1%	-0.04
Hopedale	296	29.33	-0.1%	-0.04
West Newbury	296	51.93	-0.1%	-0.03
Ashland	677	72.95	0.0%	-0.03
Deerfield	547	100.4	0.0%	-0.03
Bedford	737	80.35	0.0%	-0.02
South Hadley	1,015	104.03	0.0%	-0.02
Charlemont	227	57.54	0.0%	-0.01
Medford	2,104	137.23	0.0%	-0.01
Palmer	815	114.83	0.0%	-0.01
Chilmark	155	22.05	0.0%	0.00
Dunstable	199	41.12	0.0%	0.00
Eastham	1,178	103.47	0.0%	0.01

Town	# Roads	Surface Length	% Change	Miles Change
Leominster	1,892	177.01	0.0%	0.01
Gosnold	21	2.03	0.5%	0.01
Topsfield	371	60.67	0.0%	0.01
Harvard	436	77.37	0.0%	0.02
Provincetown	454	28.97	0.1%	0.02
Rockport	574	40.62	0.0%	0.02
Cheshire	293	56.61	0.1%	0.03
Middlefield	80	38.39	0.1%	0.04
Foxborough	777	98.65	0.0%	0.04
Millbury	767	80.75	0.1%	0.04
New Braintree	179	50.94	0.1%	0.04
Manchester	365	39.04	0.1%	0.05
Granby	307	67.8	0.1%	0.05
Whately	172	48.35	0.1%	0.05
Montague	901	115.58	0.0%	0.05
Middleton	444	56.11	0.1%	0.05
Aquinnah	98	12.96	0.5%	0.06
Erving	219	39.23	0.2%	0.06
Pittsfield	2,413	223.75	0.0%	0.07
Plympton	158	35.63	0.2%	0.07
Williamsburg	207	50.66	0.1%	0.07
Wellfleet	606	70.95	0.1%	0.07
Norton	775	108.18	0.1%	0.07
Lancaster	510	69.81	0.1%	0.07
Woburn	1,946	151.49	0.1%	0.08
Northfield	420	83.72	0.1%	0.08
Paxton	290	45.03	0.2%	0.09
Holbrook	533	47.28	0.2%	0.09
Dover	424	61.45	0.2%	0.10
Yarmouth	3,450	250.44	0.0%	0.11
Medfield	645	77.09	0.2%	0.12
West Tisbury	166	22.81	0.5%	0.12
Westford	1,368	164.86	0.1%	0.12
West Bridgewater	352	55.46	0.2%	0.12
Northampton	1,645	181.2	0.1%	0.13
Shutesbury	170	42.1	0.3%	0.14
Clarksburg	140	20.16	0.7%	0.14
Pepperell	524	78.46	0.2%	0.14
Wendell	210	66.62	0.2%	0.14
New Salem	289	103.94	0.2%	0.17
Greenfield	1,299	131.18	0.1%	0.17
Rehoboth	622	133.63	0.1%	0.17
Boxford	599	99.67	0.2%	0.17
Stow	411	60.49	0.3%	0.17
Orange	707	102.13	0.2%	0.18

Appendix 2. Total change in miles per town – ordered by Miles Change

Town	# Roads	Surface Length	% Change	Miles Change
Edgartown	545	52.18	0.4%	0.18
Royalston	220	72.3	0.2%	0.18
Webster	949	83.48	0.2%	0.18
Nahant	291	18.62	1.1%	0.20
Hawley	105	48.74	0.4%	0.21
Ware	739	117.62	0.2%	0.22
Lanesborough	398	62.78	0.4%	0.23
Whitman	556	54.38	0.4%	0.23
Ashfield	275	83.44	0.3%	0.24
Sudbury	1,071	137.7	0.2%	0.24
Amesbury	819	73.75	0.3%	0.24
Orleans	1,059	95.75	0.3%	0.25
Norfolk	460	68.41	0.4%	0.25
Groveland	433	43.88	0.6%	0.25
Chesterfield	153	58.56	0.4%	0.26
Dighton	365	62.73	0.4%	0.27
Winchester	1,190	92.61	0.3%	0.28
Winchendon	654	115.39	0.2%	0.28
Oxford	828	111.08	0.3%	0.28
Ipswich	823	96.26	0.3%	0.29
Plainville	399	51.6	0.6%	0.30
Heath	176	59.84	0.5%	0.30
Upton	413	81.13	0.4%	0.31
Hampden	263	55.16	0.6%	0.32
East Brookfield	180	27.89	1.2%	0.33
Southborough	562	74.24	0.5%	0.35
North Attleborough	1,224	130.32	0.3%	0.35
Douglas	444	82.05	0.5%	0.37
Hopkinton	845	124.42	0.3%	0.37
Wenham	234	31.42	1.2%	0.38
Oakham	188	51.06	0.8%	0.38
Northbridge	684	79.68	0.5%	0.41
Bridgewater	946	126.3	0.3%	0.42
Boylston	337	50.63	0.8%	0.42
Hinsdale	229	42.46	1.0%	0.43
Sherborn	259	56.13	0.8%	0.43
Seekonk	970	106.75	0.4%	0.43
West Stockbridge	248	44.4	1.0%	0.43
Swansea	1,092	120.12	0.4%	0.44
West Boylston	506	61.92	0.7%	0.45
Brookfield	279	39.97	1.2%	0.47
Hanson	501	62.76	0.8%	0.48
Ashburnham	484	98.32	0.5%	0.48
Monterey	228	57.83	0.9%	0.49
Ayer	549	49.56	1.0%	0.50

Town	# Roads	Surface Length	% Change	Miles Change
Warren	416	75.48	0.7%	0.50
Tisbury	342	24.93	2.0%	0.50
Rutland	546	100	0.5%	0.51
Gardner	1,145	115.46	0.5%	0.54
Hudson	897	91.72	0.6%	0.54
Acushnet	635	67.88	0.8%	0.57
North Brookfield	455	73.3	0.8%	0.57
Halifax	461	58.69	1.0%	0.59
Acton	1,095	120.41	0.5%	0.60
Adams	607	65.07	1.0%	0.63
Duxbury	1,031	128.78	0.5%	0.64
Truro	500	60.26	1.1%	0.64
Amherst	1,391	137.74	0.5%	0.65
Abington	596	67.38	1.0%	0.65
Lee	505	71.94	1.0%	0.68
Washington	104	49.41	1.4%	0.69
Beverly	1,866	149.87	0.5%	0.69
Salisbury	455	55.19	1.3%	0.69
Franklin	1,495	170.45	0.4%	0.70
Rockland	612	57.07	1.2%	0.70
Northborough	818	93.37	0.8%	0.72
Clinton	677	52.37	1.4%	0.74
Middleborough	1,185	199.12	0.4%	0.74
Holden	943	121.71	0.6%	0.75
West Brookfield	378	67.4	1.1%	0.75
Oak Bluffs	578	37.8	2.0%	0.76
Scituate	1,296	119	0.6%	0.76
Fitchburg	2,312	200.7	0.4%	0.79
Mattapoisett	540	58.91	1.4%	0.80
Norwell	573	86.77	1.0%	0.83
Millville	171	22.56	3.8%	0.84
Danvers	1,345	127.72	0.7%	0.86
Pembroke	952	109.89	0.8%	0.89
Grafton	889	100.08	0.9%	0.89
Hull	833	54.14	1.7%	0.91
Malden	1,970	109.78	0.8%	0.92
Wilmington	1,292	124.52	0.7%	0.93
Chelsea	758	49.85	1.9%	0.93
Gloucester	2,065	167.79	0.6%	0.94
Sturbridge	690	119.97	0.8%	0.94
Randolph	1,434	116.68	0.8%	0.97
Agawam	1,419	152.99	0.6%	0.98
Reading	1,192	100.88	1.0%	1.00
Somerset	1,318	98.2	1.0%	1.00
New Bedford	4,193	282.98	0.4%	1.01

Appendix 2. Total change in miles per town – ordered by Miles Change

Town	# Roads	Surface Length	% Change	Miles Change
Billerica	2,395	223.46	0.5%	1.03
Wayland	792	96.52	1.1%	1.03
Canton	1,081	109.47	1.0%	1.05
Ludlow	1,146	133.56	0.8%	1.06
Hanover	715	85.6	1.3%	1.06
Littleton	721	83.6	1.4%	1.18
Needham	1,646	140.5	0.8%	1.18
Cambridge	2,562	142.58	0.8%	1.18
Nantucket	1,425	132.67	0.9%	1.18
Marblehead	1,255	78.58	1.5%	1.18
Marlborough	1,617	166.41	0.7%	1.18
Norwood	1,363	110.33	1.1%	1.23
Framingham	2,792	243.59	0.5%	1.25
Athol	944	112.56	1.1%	1.26
Tyngsborough	622	76.78	1.7%	1.27
Spencer	758	113.4	1.2%	1.29
Harwich	1,736	152.97	0.9%	1.30
Burlington	1,218	115.56	1.2%	1.33
Longmeadow	1,064	100.84	1.3%	1.34
Braintree	1,888	145.63	1.0%	1.37
Attleboro	2,104	183.23	0.8%	1.39
Holliston	717	91.19	1.6%	1.40
Salem	1,613	97.54	1.5%	1.40
Newburyport	1,038	76.63	1.9%	1.41
Swampscott	797	47.76	3.0%	1.41
Concord	1,176	128.02	1.1%	1.44
Avon	362	35.15	4.4%	1.48
Maynard	595	42.71	3.6%	1.48
Bellingham	892	96.54	1.6%	1.48
Chatham	1,439	115.03	1.3%	1.49
Watertown	1,276	79.03	1.9%	1.50
Mansfield	1,161	124.71	1.2%	1.51
Cohasset	550	50.01	3.1%	1.52
Hingham	1,260	127.34	1.2%	1.52
Arlington	1,903	122.79	1.3%	1.55
North Andover	1,192	140.59	1.1%	1.58
Barnstable	5,087	451.63	0.4%	1.59
Southbridge	860	85.88	1.9%	1.59
Westwood	891	90.11	1.8%	1.62
Dennis	2,748	214.28	0.8%	1.67
Auburn	1,060	113.12	1.5%	1.68
Milton	1,500	127.78	1.3%	1.70
West Springfield	1,488	145.7	1.2%	1.72
Mashpee	1,363	132.64	1.3%	1.73
Dedham	1,359	104.43	1.7%	1.74
Dartmouth	2,097	215.91	0.8%	1.77
Methuen	2,416	215.22	0.9%	1.87
Andover	2,063	224.76	0.9%	1.96
Holyoke	1,909	175.43	1.2%	2.00
Tewksbury	1,425	144.67	1.4%	2.01
Dracut	1,542	154.47	1.3%	2.03
Sandwich	2,098	218.39	1.0%	2.07
Saugus	1,502	108.79	2.0%	2.16
Easton	1,117	130.94	1.7%	2.25
Everett	1,170	66.12	3.7%	2.33
Wellesley	1,576	132.87	1.8%	2.37
Taunton	2,468	263.84	0.9%	2.40
Westfield	2,072	251.51	1.0%	2.40
Natick	1,890	156.71	1.6%	2.41
Marshfield	1,824	169.14	1.5%	2.43
Lexington	1,750	156.48	1.6%	2.47
Sharon	1,020	126.21	2.0%	2.52
Somerville	1,970	108.38	2.5%	2.67
Brookline	1,604	113.82	2.5%	2.74
Belmont	1,258	85.05	3.5%	2.89
Bourne	2,098	192.34	1.6%	2.95
Falmouth	3,915	351.38	0.9%	3.06
Lowell	3,826	242.58	1.4%	3.37
Peabody	2,050	178.96	2.0%	3.50
Lawrence	2,178	141.22	2.9%	3.97
Stoughton	1,373	127.91	3.4%	4.16
Haverhill	3,071	262.82	1.6%	4.20
Chicopee	3,438	266.41	1.7%	4.40
Newton	4,555	314.21	1.6%	4.82
Brockton	3,788	289.48	1.8%	5.25
Lynn	2,748	174.37	3.3%	5.57
Quincy	3,407	228.98	2.6%	5.76
Weymouth	2,392	182.13	3.3%	5.87
Springfield	6,552	504.74	1.4%	7.06
Worcester	7,305	526.72	2.4%	12.50
Boston	15,277	931.66	1.9%	17.12
Total	340,852	36,011.59	0.4%	156.38

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