M^3 Challenge Fifth Place, Exemplary Team Prize of $5,000

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R^3: Recounting, Reapportioning, and Redistricting

Making America Fair

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Summary

Every ten years, the State governments take the new U.S. Census data and accordingly redraw the district lines for the House of Representatives. However, the 2000 Census was estimated to have undercounted about 6.4 million residents, or more than 2 percent of country's population. With a lot of government and private funding riding on the figures provided by the Census Bureau, it is essential that the population numbers provided are as accurate as possible. Through the model developed, using the 2000 Census as an example, a net total of 882,258 Hispanics, 732,822 Black or African Americans, 108,066 Asians, and 1,357,579 Whites were undercounted. By adding all of these numbers together, a net of 3,080,725 people were estimated to have been undercounted by the 2000 Census. This method accounts for the net undercount in the U.S. Census and creates more accurate figures for the population of legal residents across the country. The use of this model will result in more effective distribution of funding and other aid.

Today, many districts are unfairly apportioned. Some representatives have as few as 495,000 people (Wyoming), while others have more than 905,000 people (Montana) in their constituency. Because of this discrepancy, some voters have nearly twice as much political clout as others, since each representative gets only one vote in the House of Representatives. This problem could be solved using a new method of apportionment, in which representatives' votes would be weighted to be proportional to the number of people in their constituency. With this model, each legal citizen's voice is equal to that of any other, since the number of illegal aliens is discounted. Thus, representatives from more populous districts would have higher weighted votes, while representatives from lower population districts would have smaller weighted votes.

Every ten years, states have the opportunity to redraw their own district lines based on the new Census data. Many politicians take advantage of this opportunity to draw the lines to favor their political party, a process called gerrymandering, often resulting in extremely oddly shaped districts. Congress should recommend to states that they reduce gerrymandering by making districts more regularly shaped and similar in size.

Introduction

Background

Since the first Census was taken in 1790, the U.S. Constitution has mandated reapportionment of the House of Representatives based on the state population numbers gathered by the Census. Since 1913, the House has had 435 seats with the exception of 1959, when Hawaii and Alaska were admitted. Apportionment determines the distribution of seats between states in the House of Representatives and the number of votes in the Electoral College. Currently, the Method of Equal Proportions, developed by Joseph Hill and Edward Huntington in 1911, is used to determine the number of representatives each state is assigned.

The U.S. Census Bureau estimated after the 2000 Census that they had missed (undercounted) about 6.4 million individuals, or a little more than 2 percent of the total population. The main causes of undercounting stem from "privacy concerns, homelessness, low literacy levels, and not enough time to fill out the forms."[2] The undercounted tended to come from low income, minority households, and were often children. However, another 3.1 million individuals were counted twice (overcounted). In the current economy, federal and nonprofit funding is becoming increasingly important. Distribution of aid is often based on the population numbers provided by the U.S. Census Bureau, and it is therefore essential that these numbers be accurate.

In 2000, the population used for apportionment consisted of the resident population (all persons including legal and illegal immigrants counted in the U.S. Census) and military and civilian government personnel and their dependents who are abroad. Residents of the District of Columbia were excluded. Inclusion of noncitizens, including illegal aliens, is often a source of political debate. For example, in 2000, nine states lost a seat due to the inclusion of noncitizens in reapportionment. The 2010 Census, which will start on April 1st, will determine the apportionment for the next decade.

Restatement

Specific questions that will be addressed include the following: How should the Census figures be adjusted to account for undercounting errors? What method should Congress choose for apportioning and how is the said method superior? What recommendations can be made to the states to promote fair redistricting?

Global Assumptions

I. All data from the Census Bureau website is reliable. It is understood that Census figures may be slightly incorrect due to undercounting, but it is assumed that statistics related to the population and to undercounting (especially as they relate to race) are correct.
II. Undercounting, as worded in the Challenge problem, refers to the net undercounting (which accounts for both undercounted and overcounted people).

Undercount Adjustment

Rationale

The results of the Census are used for assessing economic well-being, distributing funding from the government and private nonprofit groups toward social welfare and education, and promoting public health.[1] Of the 6.4 million people (approximately 2% of the total population) estimated to be undercounted by the U.S. Census Bureau, many are minorities, children, or people of lower socioeconomic class. These are the people in the most need, but they do not participate in the Census for several reasons, including “privacy concerns, homelessness, low literacy levels, and not enough time to fill out the forms.”[2]To most accurately get a sense of the country’s demographics and the professed needs of people around the country, population figures should be adjusted for undercounting.

Assumptions

The following is assumed:

I. Everyone in the United States is Hispanic, Non-Hispanic White, Non-Hispanic Black, or Non-Hispanic Asian. This is reasonable, because in the 2000 Census, these four groups consisted of 99 percent of the total population.

Design

The figures in the Census Bureau should be adjusted for the undercount because the populations in various regions directly impact the amount of government and nonprofit aid the region receives. Especially in the current economic crisis, this aid is often critical to the welfare of the residents.

The actual national population, P_a, is equal to the number of people counted in the Census, P_c, plus the number of people who are undercounted, P_u:

$$P_a = P_c + P_u$$

The overall undercounted population is equal to the product of the percentage of the residents who are undercounted, c_o, and the actual population count:

$$P_u = c_o P_a$$

Note that P_a is used here instead of P_c, since the values of c_i (the percentage of the i^{th} race which is undercounted) are based on the adjusted national population---not the national population as determined by the Census.

The percentage of the residents who are undercounted is equal to the sum of the products of the percent of the population who are of a certain race, y_i, and percentage of the i^{th} race which is undercounted, c_i:

$$c_o = \sum y_i c_i$$

Combining these equations and solving for P_a, the adjusted national population is found to be equal to the Census’s national population times a weighting factor which accounts for the original Census data as well as the estimated undercounted population. The latter is determined by the racial composition of the population and the likelihood that a percentage of a particular race will be undercounted:

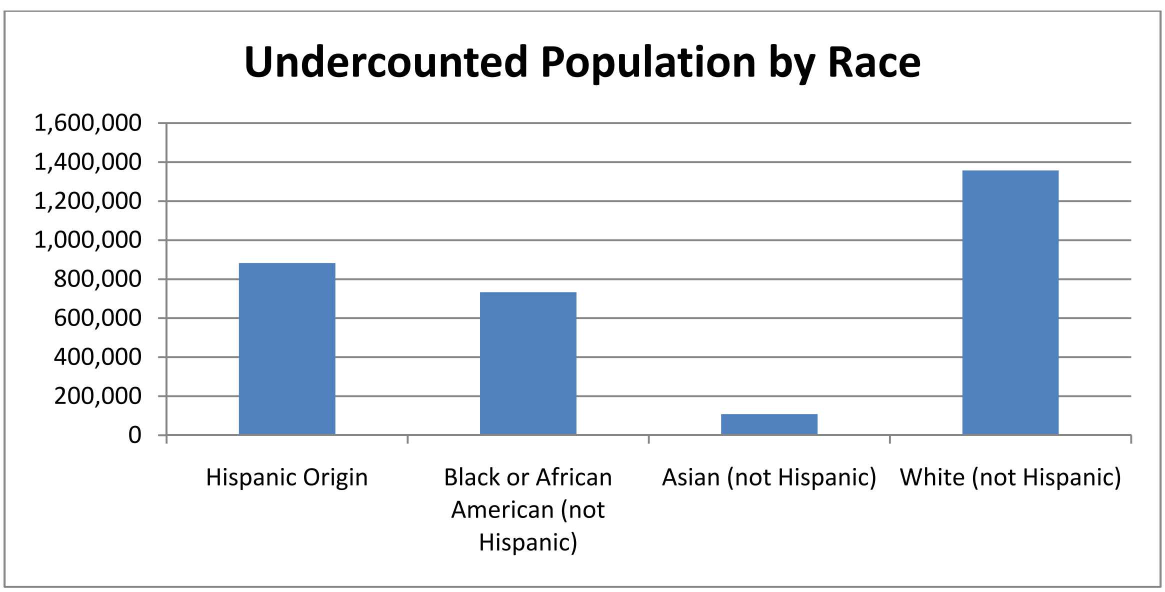
$$P_a = P_c(1 + (\sum u_i c_i)/(1 - \sum u_i c_i))$$

Race	**Percentage of Total Population**	**Percentage Undercounted**
Hispanic Origin	11	2.85
Black or African American (not Hispanic)	12	2.17
Asian (not Hispanic)	4	0.96
White (not Hispanic)	72	0.67

Source: [7]

Based on the numbers from the Census Bureau and the aforementioned model, the undercounted populations by race in the 2000 Census were as follows:

Race	**Undercounted Population**
Hispanic Origin	882,258
Black or African American (not Hispanic)	732,822
Asian (not Hispanic)	108,066
White (not Hispanic)	1,357,579
Total	3,080,725



Therefore, the estimated net undercounted population, based on the information from the U.S. Census Bureau's 2000 Census, is about 3.1 million people. The adjusted population in 2000 should then be 281.4 million plus 3.1 million, or 284.5 million people.[2]

Error

The relationship between the variables is unknown, so it is not possible to assume that they are independent and add them in quadrature. Instead, an upper bound on the error can be attained by adding the errors directly. It is reasonable to assume that the error in y_i is negligible because the undercounting in the Census will barely impact the proportional racial composition of the United States. By our global assumption, the Census population, P_c, also has no error. The uncertainty in P_u, therefore, depends only on the uncertainty of the c_i's. Using error propagation techniques, the total error in P_u was calculated to be at most

$$\delta P_u = 2P_c \sum y_i \delta c_i$$

The factor of two in the equation is derived from the fact that there is the sum of $y_i c_i$ in both the numerator and denominator of P_u.

Race	**Standard Error (percent)**
Hispanic Origin	0.38
Black or African American (not Hispanic)	0.35
Asian (not Hispanic)	0.64
White or Some Other Race	0.14

Using this formula and the standard error for each race, the total error in P_u was calculated to be at most 1.18 million people. Note that since the error in P_c is assumed to be zero, the error in the undercounted population is equal to the error in the adjusted population.

The net undercounted population in this model was 3.1 million people, but the total maximum error was only 1.18 million people. The adjusted values provide a more accurate figure for the national population than the 2000 U.S. Census and should therefore be incorporated into population data.

Method for Apportionment

Rationale

The 435 seats of the House of Representatives are split proportionately by population throughout the 50 states. Thus, the data collected by Census plays a major role in determining how many seats each state gets. The main principle behind this is the ideology of equal representation. However, because each state is guaranteed at least one representative, states with vast differences in population sometimes get the same number of votes in Congress. Clearly, this is not an effective method for implementing the "one person, one vote" principle.

To adjust for the differences in population while still maintaining at least one representative per state, votes of representatives in Congress should be weighed based on the number of people they represent. Illegal immigrants should also be removed from population data when considering apportionment of votes. This is because illegal immigrants are unlikely to be active in the political process. They are also not legal U.S. citizens and are therefore not entitled to political representation.

Assumptions

I. The movement of undercounted people does not significantly impact the percentage change in population of any given state.
II. The percentage change of population in any given state is approximately constant throughout over the course of five years.
III. The proportion of people of a particular race who are undercounted is constant throughout all states.
IV. For purposes of finding the legal residents in any state, it is assumed that the Census figures include all illegal residents. .

Design

In determining the apportionment of votes to each state, this model seeks to account for only the number of legal residents of the state, regardless of whether or not they are accounted for in the Census. The votes will be apportioned in a manner which will reflect the population growth in each state throughout the decade, so the model apportions votes based on projected growth to midway (five years) through the decade. This will ensure the fairest distribution of votes to each individual state.

The fourth assumption allows the model to determine the number of legal residents in each state by subtracting the estimated number of illegal immigrants in a state from the population of the state based on the Census. S_{legal}, the legal population of the state, is determined by subtracting the number of illegal residents, $S_{illegal}$, from the adjusted state population, S_a:

$$S_{legal} = S_a - S_{illegal}$$

The adjusted state population is determined using a methodology analogous to that used to determine the adjusted national population.

To find the projected state population in the middle of the decade, S_{final}, it is necessary to use the second assumption. Assuming the growth rate of a state remains constant over several years, the population of a state in five years will be equal to its current population multiplied by $(1 + r)^5$, where r is the growth rate of a state:

$$S_{final} = S_{legal}(1 + r)^5$$

To find the total adjusted national population of legal residents P_{legal}, sum all of the S_{legal} for each state:

$$P_{legal} = \sum S_{legal}$$

The average number of constituents per representative, *n*, is equal to the total population divided by the number of representatives in the House of Representatives, which is 435:

$$n = P_{total}/435$$

The number of votes per state, V_{state}, is calculated by dividing the number of legal residents in a state by the average number of constituents per representative:

$$V_{state} = S_{legal}/n$$

The number of representatives per state, R_{state}, is calculated by rounding the number of votes in each state to the nearest whole number. Each state is guaranteed to have at least one vote:

$$R_{state} = MAX(\lfloor V_{state} + 0.5 \rfloor, 1)$$

The weight of each district's vote in the House, $W_{district}$, can be calculated by finding the product of the number of votes per state and the ratio of the number of legal residents in the district, $S_{district}$, and the total number of legal residents. $S_{district}$ should be calculated in the same way that S_{legal} was calculated, by taking the adjusted population of a district and subtracting the estimated number of illegal immigrants in that district:

$$W_{district} = V_{state}(S_{district}/S_{legal})$$

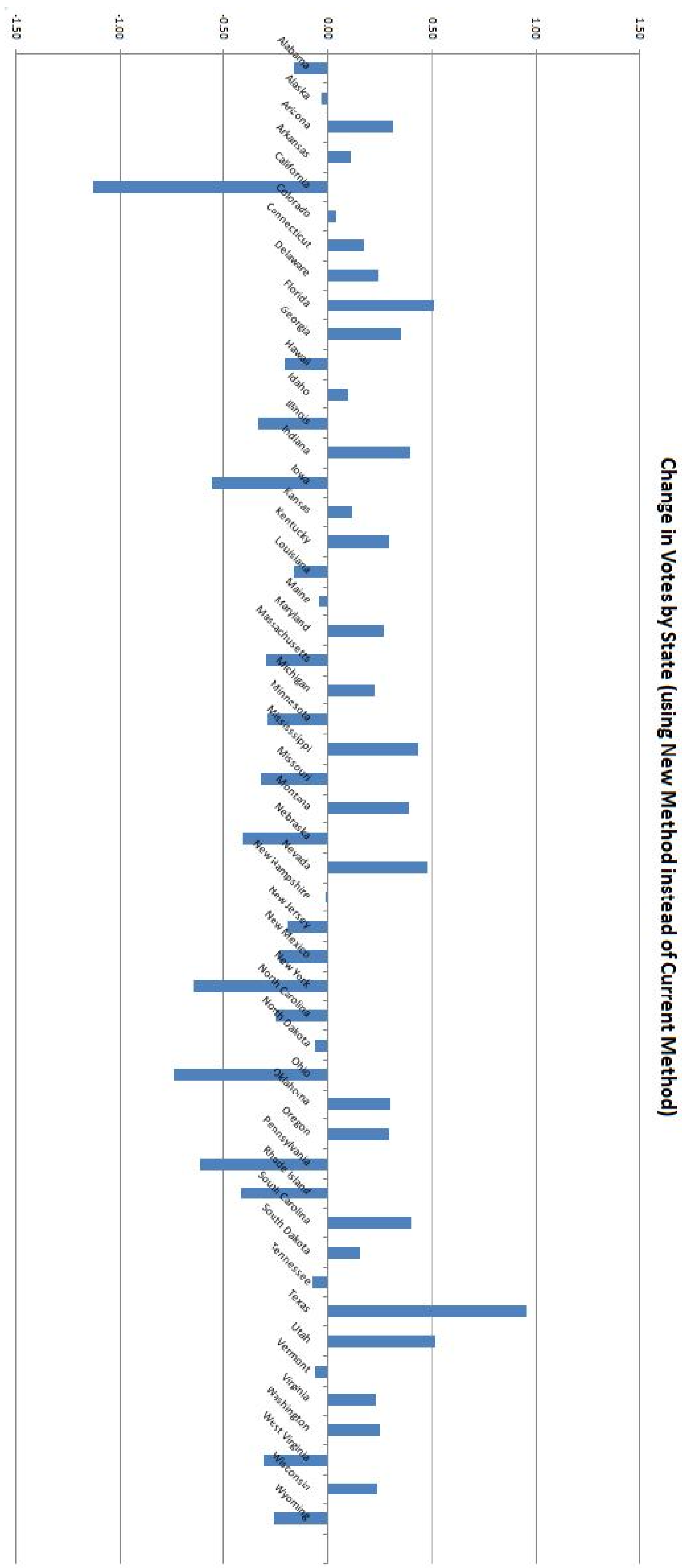
If this model is used, and the supposed number of representatives is either greater than or less than 435 representatives, then the following expression should be calculated for each state to see how adding or subtracting a representative will change the average weight of a state's representatives:

$$|1 - V_{state}/(R_{state} \pm 1)| - |1 - V_{state}/R_{state}|$$

If the total calculated number of representatives is less than 435, the denominator in the first part of the equation should equal R_{state}+1. If the total calculated number of representatives is greater than 435, then the denominator of the equation should be R_{state}-1. The state with the largest value of the above equation will gain a representative if the total number of representatives is less than 435 or lose a representative if the number of representatives is more than 435. This process should be repeated until the total number of representatives in the House is equal to 435.

With the application of this model, several states with large illegal alien populations stand to lose votes in the House (see graph below). No states are slated to lose more than one vote except for California, and only 5 states are slated to lose more than 0.5 votes: California, Iowa, North Carolina, Ohio, and Pennsylvania. On the other hand, only three states are supposed to gain more than 0.5 votes (Florida, Texas, and Utah), and no states gain more than 1.0 vote. With the new vote, applied to information from the 2000 U.S. Census, each vote in the House of Representatives effectively represents exactly 669,192 legal residents. This means that each resident has equal voice in the House, whereas, in the current method, each representative has from less than 500,000 constituents to more than 900,000 constituents.

The specific data for these graphs can be found in the Appendix. The estimated population five years after the 2000 Census is based on the methodology from “Undercount Adjustment.”


Change in Votes by State (using New Method instead of Current Method)
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
Alabama
Alaska
Arizona
Arkansas
California
Colorado
Connecticut
Delaware
Florida
Georgia
Hawaii
Idaho
Illinois
Indiana
Iowa
Kansas
Kentucky
Louisiana
Maine
Maryland
Massachusetts
Michigan
Minnesota
Mississippi
Missouri
Montana
Nebraska
Nevada
New Hampshire
New Jersey
New Mexico
New York
North Carolina
North Dakota
Ohio
Oklahoma
Oregon
Pennsylvania
Rhode Island
South Carolina
South Dakota
Tennessee
Texas
Utah
Vermont
Virginia
Washington
West Virginia
Wisconsin
Wyoming

Recommendations for Redistricting

Analysis

Members of the House of Representatives are elected through single member districts by plurality voting (a winner-take-all system). As a result, politicians often abuse redistricting powers in order to favor one political party over another. They accomplish this through gerrymandering (drawing districts in strange shapes) or exploiting the contiguous rule by allowing districts to cross over bodies of water. In order to prevent this type of corruption, it makes sense to redistrict in a politically unbiased manner. One way to achieve this is to redistrict areas so that people in a district are tightly clustered; that is, districts are drawn so that the average distance from a district member to the center of the district is minimized. This would be a politically impartial method that prevents gerrymandering. It is also effective because it keeps district members in close proximity.

States should also account for undercounted residents in their redistricting and each representative's vote weight should be determined by the number of legal people in his or her district.

Assumptions

I. Census figures have been adjusted and congressional votes have been reapportioned in accordance with the methods proposed in the previous sections.

Design

In order to create evenly proportioned districts, each state must meet two constraints during redistricting while also ensuring that all residents are in a district and no districts overlap. Districts should also be designed to avoid splitting communities or cities, favoring either major political party, or compromising opportunities for certain groups of the population. The first constraint minimizes the average distance between the center of the district and any given resident of the district. The second constraint minimizes the difference in the populations between districts by ensuring that the number of people per district is as close as possible to the ideal number determined by dividing the state population by the number of representatives.

Constraint 1:

Given that a district resident's location is represented by (x, y), the center of the district is located at (x_0, y_0), and the number of the residents in the district is n, the average distance of each distance from the center of the district is

$$(1/n)\left(\sum_{residents}\sqrt{(x-x_0)^2+(y-y_0)^2}\right)$$

When redistricting, states should aim to minimize this expression in order to ensure that members of a district are as geographically close as possible.

Constraint 2:

Next, to minimize the difference in populations between districts, the ideal population of a district must be found by dividing the state's total legal population by the number of districts in the state:

$$P_{ideal} = S_{legal} / R_{state}$$

Then, the sum of the deviations of the districts' populations from their ideals should be minimized:

$$\sum_{districts} (|S_{district} - P_{ideal}|)$$

In attempting to meet these constraints, states should endeavor to meet the first constraint more closely than the second, since representatives' votes will be weighed to guarantee that each legal resident has equal representation.

Testing

If these constraints are followed, then in future elections fewer incumbents should be reelected following Census years (compared to past historical results) since they will not have the advantage of being able to redistrict to their advantage. Preventing gerrymandering may also cause significant changes in the political tendencies of states.

Conclusion

Census figures should be adjusted for the undercount, which accounts for a total of 3.1 million people as calculated by the formula which takes into account racial breakdowns and the percentage of the population undercounted by race. In order to create equal representation as mandated by the Constitution, Congress should weight representatives' votes in accordance with the number of constituents a House member represents. The current method used to apportion the House of Representatives does not make a significant effort to ensure this fairness. When drawing Congressional districts, states should attempt to reduce gerrymandering by making districts more regularly shaped. This is done by minimizing the average distance of each resident from the center of the district.

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Appendix

State	2000 Census Population[5]	Estimated Illegal Population[5]	Growth Rate[13]	Calculated 2000 Undercounted Population	Adjusted 2000 Population	Adjusted 2000 Legal Population	Projected 2005 Legal Population
AL	4,461,130	22,632	0.4	48,882	4,510,012	4,487,380	4,577,849
AK	628,933	4,715	0.7	4,374	633,307	628,592	650,903
AZ	5,140,683	266,869	2.4	67,417	5,208,100	4,941,231	5,563,332
AR	2,679,733	25,461	0.5	26,143	2,705,876	2,680,415	2,748,099
CA	33,930,798	2,083,087	1.4	533,419	34,464,217	32,381,130	34,712,171
CO	4,311,882	135,792	2.2	49,401	4,361,283	4,225,491	4,711,201
CT	3,409,535	36,777	0.3	35,293	3,444,828	3,408,051	3,459,480
DE	785,068	9,430	1.3	8,427	793,495	784,065	836,372
FL	16,028,890	317,791	1.4	213,912	16,242,802	15,925,011	17,071,415
GA	8,206,975	215,004	2	100,960	8,307,935	8,092,931	8,935,249
HI	1,216,642	1,886	-0.4	9,811	1,226,453	1,224,567	1,200,271
ID	1,297,274	17,917	1.7	11,055	1,308,329	1,290,412	1,403,890
IL	12,439,042	407,376	0.5	149,680	12,588,722	12,181,346	12,488,940
IN	6,090,782	42,435	0.6	53,470	6,144,252	6,101,817	6,287,081
IA	2,931,923	22,632	0.3	22,487	2,954,410	2,931,778	2,976,020
KS	2,693,824	44,321	0.6	24,686	2,718,510	2,674,189	2,755,383
KY	4,049,431	14,145	0.7	32,863	4,082,294	4,068,149	4,212,542
LA	4,480,271	4,715	0.2	54,359	4,534,630	4,529,915	4,575,396
ME	1,277,731	825	0.4	8,775	1,286,506	1,285,681	1,311,601
MD	5,307,886	52,808	0.8	63,439	5,371,325	5,318,517	5,534,689
MA	6,355,568	82,041	0.5	58,065	6,413,633	6,331,592	6,491,473
MI	9,955,829	66,010	0.4	95,258	10,051,087	9,985,077	10,186,383
MN	4,925,670	56,580	1	38,687	4,964,357	4,907,777	5,158,123
MS	2,852,927	7,544	0.6	35,539	2,888,466	2,880,922	2,968,393
MO	5,606,260	20,746	0.6	49,463	5,655,723	5,634,977	5,806,067

MT	905,316	825	0.4	6,114	911,430	910,605	928,963
NE	1,715,369	22,632	0.3	14,690	1,730,059	1,707,427	1,733,192
NV	2,002,032	95,243	3.8	25,147	2,027,179	1,931,936	2,327,981
NH	1,238,415	825	1.3	8,908	1,247,323	1,246,498	1,329,655
NJ	8,424,354	208,403	0.6	102,382	8,526,736	8,318,333	8,570,896
NM	1,823,821	36,777	0.4	30,990	1,854,811	1,818,034	1,854,687
NY	19,004,973	461,127	0.2	243,855	19,248,828	18,787,701	18,976,331
NC	8,067,673	194,258	1.4	88,678	8,156,351	7,962,093	8,535,265
ND	643,756	825	-0.6	4,326	648,082	647,257	628,071
OH	11,374,540	37,720	0.2	100,633	11,475,173	11,437,453	11,552,286
OK	3,458,819	43,378	0.6	28,954	3,487,773	3,444,395	3,548,974
OR	3,428,543	84,870	1	29,888	3,458,431	3,373,561	3,545,646
PA	12,300,670	46,207	-0.1	110,418	12,411,088	12,364,881	12,303,180
RI	1,049,662	15,088	0.3	9,837	1,059,499	1,044,411	1,060,172
SC	4,025,061	33,948	1.2	46,990	4,072,051	4,038,103	4,286,274
SD	756,874	825	0.3	4,942	761,816	760,991	772,475
TN	5,700,037	43,378	0.9	55,035	5,755,072	5,711,694	5,973,389
TX	20,903,994	981,663	1.7	347,669	21,251,663	20,270,000	22,052,535
UT	2,236,714	61,295	1.4	19,858	2,256,572	2,195,277	2,353,310
VT	609,890	825	0.5	4,231	614,121	613,296	628,782
VA	7,100,702	97,129	1.2	76,631	7,177,333	7,080,204	7,515,335
WA	5,908,684	128,248	1.2	52,236	5,960,920	5,832,672	6,191,132
WV	1,813,077	825	-0.3	13,248	1,826,325	1,825,500	1,798,281
WI	5,371,210	38,663	0.5	45,024	5,416,234	5,377,571	5,513,361
WY	495,304	825	-0.1	4,074	499,378	498,553	496,066
Total	**281,424,177**	**6,595,341**		**3,270,624**	**284,694,801**	**278,099,460**	**291,098,560**

State	Number of Votes per State by Current Method	Number of Constituents per Vote by Current Method	Number of Votes per State by New Method	Number of Constituents per Vote by New Method
AL	7	637,304	6.84	669,192
AK	1	628,933	0.97	669,192
AZ	8	642,585	8.31	669,192
AR	4	669,933	4.11	669,192
CA	53	640,204	51.87	669,192
CO	7	615,983	7.04	669,192
CT	5	681,907	5.17	669,192
DE	1	785,068	1.25	669,192
FL	25	641,156	25.51	669,192
GA	13	631,306	13.35	669,192
HI	2	608,321	1.79	669,192
ID	2	648,637	2.10	669,192
IL	19	654,686	18.66	669,192
IN	9	676,754	9.40	669,192
IA	5	586,385	4.45	669,192
KS	4	673,456	4.12	669,192
KY	6	674,905	6.29	669,192
LA	7	640,039	6.84	669,192
ME	2	638,866	1.96	669,192
MD	8	663,486	8.27	669,192
MA	10	635,557	9.70	669,192
MI	15	663,722	15.22	669,192
MN	8	615,709	7.71	669,192
MS	4	713,232	4.44	669,192

MO	9	622,918	8.68	669,192
MT	1	905,316	1.39	669,192
NE	3	571,790	2.59	669,192
NV	3	667,344	3.48	669,192
NH	2	619,208	1.99	669,192
NJ	13	648,027	12.81	669,192
NM	3	607,940	2.77	669,192
NY	29	655,344	28.36	669,192
NC	13	620,590	12.75	669,192
ND	1	643,756	0.94	669,192
OH	18	631,919	17.26	669,192
OK	5	691,764	5.30	669,192
OR	5	685,709	5.30	669,192
PA	19	647,404	18.39	669,192
RI	2	524,831	1.58	669,192
SC	6	670,844	6.41	669,192
SD	1	756,874	1.15	669,192
TN	9	633,337	8.93	669,192
TX	32	653,250	32.95	669,192
UT	3	745,571	3.52	669,192
VT	1	609,890	0.94	669,192
VA	11	645,518	11.23	669,192
WA	9	656,520	9.25	669,192
WV	3	604,359	2.69	669,192
WI	8	671,401	8.24	669,192
WY	1	495,304	0.74	669,192
Total	**435**		**435.00**	