Expert Report in Support of Governor Evers's Proposed District Plans

Jeanne Clelland

December 15, 2021

1 Introduction

I am a Professor in the Department of Mathematics at the University of Colorado Boulder. Much of my research over the course of my career concerns differential geometry and applications of geometry to the study of partial differential equations. My more recent research focuses on mathematical analysis of redistricting, particularly on the use of ensemble analysis. My work includes both theoretical aspects related to the development of algorithms for sampling district plans to create ensembles and applications to identifying district plans with extreme properties. In addition to my academic work, I have conducted expert work using ensemble analysis to analyze district plans for the Colorado Independent Legislative Redistricting Commission ([1], [2]). My CV is attached to this report, and it contains a list of all my publications from the past 10 years.

I have been retained to evaluate the Governor's proposed district plans for the Wisconsin State Assembly, the Wisconsin State Senate, and the U.S. House of Representatives (a.k.a. "Congress"), regarding their statistical properties. At times, the statistical properties of the Governor's plans will be compared to the plans enacted in 2011 and/or the plans recently passed by the Wisconsin State Legislature in Legislative Bills SB 621 and SB 622, referred to throughout this report as the SB 621 and SB 622 plans.

2 Executive Summary

I analyzed the Governor's plans for population equality, core population movement (a way to measure least changes), disenfranchisement (another measure for least changes), majority-minority districts, compactness, and split geographies. In this section I will summarize my findings. More details regarding my findings are contained in Section 3, and details regarding my data sources and methodology are contained in Section 4.

2.1 Population Deviation

According to the 2020 Census, Wisconsin's total population is 5,893,718. Since Wisconsin has 99 State Assembly districts, 33 State Senate districts, and 8 Congressional districts, the ideal district populations are 59,533 for State Assembly districts, 178,598 for State Senate districts, and 736,715 for Congressional districts.

For the Governor's State Assembly plan, the mean deviation from the ideal population is 281 persons, or 0.47% of the ideal population. The largest deviation is 584 persons, or 0.98% of the ideal population. This means that all districts are within 1% of the ideal population, ranging from 0.90% below to 0.98% above the ideal population.

For the Governor's State Senate plan, the mean deviation from the ideal population is 450 persons, or 0.25% of the ideal population. The largest deviation is 1,112 persons, or 0.62% of the ideal population. This means that all districts are within 1% of the ideal population, ranging from 0.57% below to 0.62% above the ideal population.

For the Governor's Congressional plan, the mean deviation from the ideal population is 0.5 persons, or 0.00% of the ideal population. The largest deviation is 1 person, with all districts ranging from 1 person below to 1 person above the ideal population.

2.2 Core Population Movement

Core population movement measures the number of persons who are moved to a different district when redistricting takes place, i.e., persons whose district number in the 2011 enacted plan is different from their district number in the new plan.

The computation of this number is complicated by the fact that the 2011 enacted districts were based on 2010 Census geographies, while proposed plans for new districts are based on 2020 Census geographies. Specifically, all proposed new plans are constructed by assigning each 2020 Census block to a unique district in the plan. Unfortunately, 2020 Census blocks do not line up neatly with 2011 enacted districts, and in cases where a 2020 Census block intersects more than one 2011 district, a choice must be made about which 2011 district to assign that block to.

Both the U.S. Census Bureau and the Legislative Technology Services Bureau (LTSB) of the State of Wisconsin have published assignments of 2020 Census blocks to 2011 enacted districts, and there are minor discrepancies between them whose source I was not able to determine. These discrepancies in turn produce minor discrepancies in the computations of core population movement and other measures for the 2011 enacted plans, depending on which assignment is used for the 2011 enacted districts.

Depending on which block assignment is used for the 2011 enacted plan, the Governor's State Assembly plan has core population movement of 835,316 persons, representing 14.17% of the population (Census Bureau data) or 837,659 persons, representing 14.21% of the population (LTSB data). For comparison, the State Assembly plan in SB 621 has core population movement of 933,907 persons, representing 15.85% of the population (Census Bureau data) or 933,604 persons, representing 15.84% of the population (LTSB data).

The Governor's State Senate plan has core population movement of 458,750 persons, representing 7.78% of the population (Census Bureau data) or 461,228 persons, representing 7.83% of the population (LTSB data). For comparison, the State Senate plan in SB 621 has core population movement of 459,322 persons, representing 7.79% of the population (Census Bureau data) or 459,061 persons, representing 7.79% of the population (LTSB data).

The Governor's Congressional plan has core population movement of 322,362 persons, representing 5.47% of the population (Census Bureau data) or 324,415 persons, representing 5.50% of the population (LTSB data). For comparison, the Congressional plan in SB 622 has core population movement of 381,833 persons, representing 6.48% of the population (Census Bureau data) or 384,456 persons, representing 5.62% of the population (LTSB data).

Additionally, there are 13 State Assembly districts (Districts 1, 27, 28, 32, 43, 52, 58, 60, 61, 63, 74, 91, and 92) in the Governor's plan that are unchanged from the corresponding 2011 State Assembly district (in the sense that zero persons are moved either in or out of the district), based on 2020 Census data and the Census Bureau's assignment of 2020 Census blocks to 2011 enacted districts.[1]

2.3 Disenfranchised Population

Disenfranchised population measures the number of persons from odd-numbered State Senate districts who are moved to even-numbered State Senate districts. These voters would have been eligible to vote in a State Senate election in 2022 if they had not been moved, but they will now not be able to vote in a State Senate election until 2024.

The computation of this number is affected by the same ambiguity in the assignment of 2020 Census blocks to 2011 enacted districts described in the previous section.

The Governor's State Senate plan has disenfranchised population of 138,824 persons, representing 2.36% of the population (Census Bureau data) or 139,677 persons, representing 2.37% of the population (LTSB data). For comparison, the State Senate Plan in SB 621 has disenfranchised population of 138,732 persons, representing 2.35% of the population (Census Bureau data) or 138,753 persons, representing 2.35% of the population (LTSB data).

[1] The software used to draw the Governor's plans contained the Census Bureau's block assignment data, and these plans were designed to minimize core population movement accordingly. When recomputed with respect to the LTSB block assignment data, a total of 456 persons are moved either into or out of these 13 districts.

2.4 Majority-Minority Districts

In this section I will report on statistics for the districts in the Governor's plans with majority total minority (i.e., Non-White) Voting Age Population (NWVAP), as well as for districts with majority Black Voting Age Population (BVAP) and majority Hispanic Voting Age Population (HVAP). Statistics for the plans in SB 621 and SB 622 are also included for comparison.

2.4.1 Majority NWVAP Districts

The Governor's State Assembly plan contains 10 districts with at least 50% NWVAP, with the NWVAP percentages of these districts ranging from 51.02% to 81.82%. For comparison, the State Assembly plan in SB 621 contains 9 districts with at least 50% NWVAP, with the NWVAP percentages of these districts ranging from 50.34% to 85.52%.

The Governor's State Senate plan contains 3 districts with at least 50% NWVAP, with the NWVAP percentages of these districts ranging from 60.07% to 62.49%. For comparison, the State Senate plan in SB 621 also contains 3 districts with at least 50% NWVAP, with the NWVAP percentages of these districts ranging from 60.18% to 70.29%.

The Governor's Congressional plan contains 1 district with at least 50% NWVAP, and this district has 52.95% NWVAP. For comparison, the Congressional plan in SB 622 also contains 1 district1 with at least 50% NWVAP, and this district has 52.45% NWVAP.

2.4.2 Majority BVAP Districts

There are differing opinions as to how to compute Black Voting Age Population (BVAP), and in this report I consider two different values based on the following choices:

1. (more inclusive) Black alone or in combination with any number of other races, including Hispanic, referred to here as BVAP1;
2. (less inclusive) non-Hispanic Black alone or non-Hispanic (Black + White) alone, referred to here as BVAP2.

Here I will report statistics for BVAP1; statistics for BVAP2 are included in Section 3.

The Governor's State Assembly plan contains 7 districts with at least 50% BVAP1, with the BVAP1 percentages of these districts ranging from 50.09% to 51.39%. For comparison, the State Assembly plan in SB 621 contains 5 districts with at least 50% BVAP1, with the BVAP1 percentages of these districts ranging from 52.57% to 73.28%.

The Governor's State Senate plan contains 2 districts with at least 50% BVAP1, with the BVAP1 percentages of these districts ranging from 50.33% to 50.62%. For comparison, the State Senate plan in SB 621 also contains 2 districts with at least 50% BVAP1, with the BVAP1 percentages of these districts ranging from 56.13% to 58.76%.

Neither Congressional plan contains any districts with at least 50% BVAP1.

2.4.3 Majority HVAP Districts

The Governor's State Assembly plan contains 2 districts with at least 50% HVAP, with the HVAP percentages of these districts ranging from 52.11% to 66.56%. For comparison, the State Assembly plan in SB 621 also contains 2 districts with at least 50% HVAP, with the HVAP percentages of these districts ranging from 52.96% to 65.90%.

Neither State Senate or Congressional plan contains any districts with at least 50% HVAP.

2.5 Compactness

District **compactness** refers to the idea that a district should not be too "spread out." There is no single measure that adequately defines this concept, but the two most commonly reported measures are the **Polsby-Popper** score and the **Reock** score. It should be emphasized that both of these scores are very sensitive to differences in map projections and resolutions. See Section 4 for details of how I performed these computations.

A discrete alternative proposed by Duchin and Tenner in [3] is the **cut edges** score, which counts the number of adjacent pairs of Census blocks that lie in different districts. This number may be thought of as a discrete analog of the total perimeter of all district boundaries. Unlike the other two scores, it is not sensitive to map projections. It also has the additional feature that, since Census blocks tend to have shorter perimeter in more densely populated areas, it more closely models the number of **persons** who live near district boundaries rather than the physical lengths of the district boundaries.

For the Governor's State Assembly plan, Polsby-Popper scores range from 0.056 to 0.523, with a mean of 0.251. Reock scores range from 0.147 to 0.652, with a mean of 0.397. This plan contains 18,441 cut edges. These numbers are similar to those in the 2011 enacted plan.

For the Governor's State Senate plan, Polsby-Popper scores range from 0.053 to 0.433, with a mean of 0.217. Reock scores range from 0.135 to 0.607, with a mean of 0.392. This plan contains 11,147 cut edges. These numbers are similar to those in the 2011 enacted plan.

For the Governor's Congressional plan, Polsby-Popper scores range from 0.127 to 0.397, with a mean of 0.243. Reock scores range from 0.334 to 0.599, with a mean of 0.458. This plan contains 3,774 cut edges. These numbers are similar to those in the 2011 enacted plan.

2.6 Split Geographies

County splits measure the number of counties that are split between two or more districts, and **municipal splits** measure the number of municipalities (cites, towns, or villages) that are split between two or more districts.

The Governor's State Assembly plan splits 53 counties and 174 municipalities. For comparison, the 2011 enacted plan splits 58 counties and either 188 or 125 municipalities, depending on which 2020 Census block assignment is used.

The Governor's State Senate plan splits 45 counties and 118 municipalities. For comparison, the 2011 enacted plan splits 46 counties and either 123 or 84 municipalities, depending on which 2020 Census block assignment is used.

The Governor's Congressional plan splits 12 counties and 47 municipalities. For comparison, the 2011 enacted plan splits 12 counties and either 57 or 51 municipalities, depending on which 2020 Census block assignment is used.

3 Detailed Analysis

In this section I will present my detailed findings regarding population deviation, core population movement, disenfranchised population, majority-minority districts, compactness, and split geographies for each of the Governor's plans. Details regarding my data sources and methodology are contained in Section 4.

3.1 Population Deviation

According to the 2020 Census, Wisconsin's total population is 5,893,718. Since Wisconsin has 99 State Assembly districts, 33 State Senate districts, and 8 Congressional districts, the ideal district populations are 59,533 for State Assembly districts, 178,598 for State Senate districts, and 736,715 for Congressional districts.

Tables 1, 2, and 3 show the mean, maximum positive/negative, and overall deviations from these ideal populations for each of the Governor's plans, in both absolute and percentage terms.

State Assembly	Governor's Plan	
Deviation from Ideal Population	Persons	Percentage
Mean Deviation	281	0.47%
Largest Positive Deviation	584	0.98%
Largest Negative Deviation	−537	−0.90%
Overall Range in Deviation	± 1,121	±1.88%

Table 1: Population Deviation for Governor's State Assembly District Plan

State Senate	Governor's Plan	
Deviation from Ideal Population	Persons	Percentage
Mean Deviation	450	0.25%
Largest Positive Deviation	1,112	0.62%
Largest Negative Deviation	−1026	−0.57%
Overall Range in Deviation	± 2,138	± 1.19%

Table 2: Population Deviation for Governor's State Senate District Plan

U.S. Congress	Governor's Plan	
Deviation from Ideal Population	Persons	Percentage
Mean Deviation	0.5	0.00%
Largest Positive Deviation	1	0.00%
Largest Negative Deviation	−1	0.00%
Overall Range in Deviation	± 2	±0.00%

Table 3: Population Deviation for Governor's Congressional District Plan

3.2 Core Population Movement

Core population movement measures the number of persons who are moved to a different district when redistricting takes place, i.e., persons whose district number in the 2011 enacted plan is different from their district number in the new plan.

The computation of this number is complicated by the fact that the 2011 enacted districts were based on 2010 Census geographies, while proposed plans for new districts are based on 2020 Census geographies. Specifically, all proposed new plans are constructed by assigning each 2020 Census block to a unique district in the plan. Unfortunately, 2020 Census blocks do not line up neatly with 2011 enacted districts, and in cases where a 2020 Census block intersects more than one 2011 district, a choice must be made about which 2011 district to assign that block to. There are multiple options for how to make this choice, e.g., assigning a block to the district that contains its centroid, assigning a block to the district that it overlaps with the greatest area, assigning a block to the district that contains the largest percentage of its population, etc. Further complicating this question is that computations of centroids and areas are sensitive to map projections, so algorithms that start with different map projections may end up assigning some blocks to different districts, even if they use the same algorithm in both cases.

Both the U.S. Census Bureau and the Legislative Technology Services Bureau (LTSB) of the State of Wisconsin have published assignments of 2020 Census blocks to 2011 enacted districts, and there are minor discrepancies between them whose source I was not able to determine. These discrepancies in turn produce minor discrepancies in the computations of core population movement, depending on which assignment is used for the 2011 enacted districts. Total core population movement values for each of the Governor's plans relative to both versions of the 2011 enacted plans, in both absolute and percentage terms, are shown in Tables 4 and 5, along with data for the plans in SB 621 and SB 622 to provide context.

	Governor's Plan		SB 621/622 Plans	
Core Population Movement	Persons	Percentage	Persons	Percentage
State Assembly Plans	835,316	14.17%	933,907	15.85%
State Senate Plans	458,750	7.78%	459,322	7.79%
Congressional Plans	322,362	5.47%	381,833	6.48%

Table 4: Core Population Movement for All District Plans (Census Bureau Data)

	Governor's Plan		SB 621/622 Plans	
Core Population Movement	Persons	Percentage	Persons	Percentage
State Assembly Plans	837,659	14.21%	933,604	15.84%
State Senate Plans	461,228	7.83%	459,061	7.79%
Congressional Plans	324,415	5.50%	384,456	6.52%

Table 5: Core Population Movement for All District Plans (LTSB data)

Additionally, there are 13 State Assembly districts (Districts 1, 27, 28, 32, 43, 52, 58, 60, 61, 63, 74, 91, and 92) in the Governor's plan that are unchanged from the corresponding 2011 State Assembly district (in the sense that zero persons are moved either in or out of the district), based on 2020 Census data and the Census Bureau's assignment of 2020 Census blocks to 2011 enacted districts.[2]

[2] The software used to draw the Governor's plans contained the Census Bureau's block assignment data, and these plans were designed to minimize core population movement accordingly. When recomputed with respect to the LTSB block assignment data, a total of 456 persons are moved either into or out of these 13 districts.

3.3 Disenfranchised Population

Disenfranchised population measures the number of persons from odd-numbered State Senate districts who are moved to even-numbered State Senate districts. These voters would have been eligible to vote in a State Senate election in 2022 if they had not been moved, but they will now not be able to vote in a State Senate election until 2024.

The computation of this number is affected by the same ambiguity in the assignment of 2020 Census blocks to 2011 enacted districts described in the previous section. The disenfranchised population for the Governor's State Senate plan relative to both versions of the 2011 enacted plan, in both absolute and percentage terms, is shown in Tables 6 and 7, along with data for the plan in SB 621 to provide context.

	Governor's Plan		SB 621 Plan	
Disenfranchised Population	Persons	Percentage	Persons	Percentage
State Senate Plans	138,824	2.36%	138,732	2.35%

Table 6: Disenfranchised Population for State Senate District Plans (Census Bureau Data)

	Governor's Plan		SB 621 Plan	
Disenfranchised Population	Persons	Percentage	Persons	Percentage
State Senate Plans	139,677	2.37%	138,753	2.35%

Table 7: Disenfranchised Population for State Senate District Plans (LTSB data)

3.4 Majority-Minority Districts

In this section I will report on statistics for the districts in the Governor's plans with majority total minority (i.e., Non-White) Voting Age Population (NWVAP), as well as for districts with majority Black Voting Age Population (BVAP) and majority Hispanic Voting Age Population (HVAP). Statistics for the plans in SB 621 and SB 622 are also included for comparison.

3.4.1 Majority NWVAP Districts

Tables 8, 9, and 10 show all districts in each of the Governor's plans with Non-White Voting Age Populations of at least 50%, ranked in order of highest to lowest NWVAP, along with analogous data for the plans in SB 621 and SB 622 to provide context.

State Assembly	Governor's Plan		SB 621 Plan	
District rank	District	NWVAP%	District	NWVAP%
1	8	81.82%	11	85.52%
2	9	68.04%	8	80.16%
3	16	65.15%	17	70.90%
4	12	63.91%	12	70.31%
5	18	63.41%	9	69.02%
6	11	61.76%	16	67.97%
7	14	61.75%	18	63.93%
8	10	60.28%	10	56.42%
9	17	58.81%	66	50.34%
10	66	51.02%		

Table 8: Districts with at least 50% NWVAP in State Assembly District Plans

State Senate	Governor's Plan		SB 621 Plan	
District rank	District	NWVAP%	District	NWVAP%
1	6	62.49%	4	70.29%
2	4	61.96%	6	67.6%
3	3	60.07%	3	60.18%

Table 9: Districts with at least 50% NWVAP in State Senate District Plans

U.S. Congress	Governor's Plan		SB 622 Plan	
District rank	District	NWVAP%	District	NWVAP%
1	4	52.95%	4	52.45%

Table 10: Districts with at least 50% NWVAP in Congressional District Plans

3.4.2 Majority BVAP Districts

There are differing opinions as to how to compute Black Voting Age Population (BVAP), and here I will consider two different values based on the following choices:

1. (more inclusive) Black alone or in combination with any number of other races, including Hispanic, referred to here as BVAP1;

2. (less inclusive) non-Hispanic Black alone or non-Hispanic (Black + White) alone, referred to here as BVAP2.

All districts that have at least 50% BVAP under the more inclusive version (BVAP1) are included here. Tables 11 and 12 show all districts in the Governor's State Assembly and State Senate plans with Black Voting Age Populations of at least 50%, ranked in order of highest to lowest BVAP1, along with analogous data for the plans in SB 621 to provide context. (There are no such districts in either Congressional plan.)

State Assembly	Governor's Plan			SB 621 Plan		
District rank	District	BVAP1%	BVAP2%	District	BVAP1%	BVAP2%
1	10	51.39%	49.99%	11	73.28%	71.47%
2	14	50.85%	49.48%	17	61.81%	60.18%
3	18	50.63%	48.88%	12	57.01%	55.49%
4	17	50.29%	48.89%	16	54.13%	52.58%
5	12	50.24%	48.74%	18	52.57%	50.80%
6	11	50.21%	48.91%			
7	16	50.09%	48.51%			

Table 11: Districts with at least 50% BVAP1 in State Assembly District Plans

State Senate	Governor's Plan			SB 621 Plan		
District rank	District	BVAP1%	BVAP2%	District	BVAP1%	BVAP2%
1	4	50.62%	49.22%	4	58.76%	57.18%
2	6	50.33%	48.76%	6	56.13%	54.49%

Table 12: Districts with at least 50% BVAP1 in State Senate District Plans

3.4.3 Majority HVAP Districts

Table 13 shows all districts in the Governor's State Assembly plan with Hispanic Voting Age Populations of at least 50%, ranked in order of highest to lowest HVAP, along with analogous data for the plan in SB 621 to provide context. (There are no such districts in either State Senate or Congressional plans.)

State Assembly	Governor's Plan		SB 621 Plan	
District rank	District	HVAP%	District	HVAP%
1	8	66.56%	8	65.90%
2	9	52.11%	9	52.96%

Table 13: Districts with at least 50% HVAP in State Assembly District Plans

3.5 Compactness

District **compactness** refers to the idea that a district should not be too "spread out." There is no single measure that adequately defines this concept, but the two most commonly reported measures are the **Polsby-Popper** score and the **Reock** score.

The Polsby-Popper score measures the ratio of a district's area to the square of its perimeter, multiplied by 4π. The possible values for this score range from 0 to 1, with a "perfect" compactness score of 1 achieved exactly when the district's boundary is a perfect circle.

The Reock score measures the ratio of a district's area to the area of the smallest circle that completely contains the district. As for Polsby-Popper, the possible values for this score range from 0 to 1, with a "perfect" compactness score of 1 achieved exactly when a district's boundary is a perfect circle.

It should be emphasized that both of these scores are very sensitive to differences in map projections and resolutions. See Section 4 for details of how I performed these computations.

A discrete alternative proposed by Duchin and Tenner in [3] is the **cut edges** score, which counts the number of adjacent pairs of Census blocks that lie in different districts. This number may be thought of as a discrete analog of the total perimeter of all district boundaries. Unlike the other two scores, it is not sensitive to map projections. It also has the additional feature that, since Census blocks tend to have shorter perimeter in more densely populated areas, it more closely models the number of **persons** who live near district boundaries rather than the physical lengths of the district boundaries.

All three of these scores for each of the Governor's plans are shown in Tables 14, 15, and 16, along with the values for both versions of the 2011 enacted plans for comparison. Note that Polsby-Popper and Reock scores are computed for each individual district, while the cut edges score is a single score for an entire district plan.

State Assembly	2011 Plan (Census)			2011 Plan (LTSB)			Governor's Plan		
Compactness Scores	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Polsby-Popper	0.260	0.562	0.050	0.260	0.562	0.048	0.251	0.523	0.056
Reock	0.396	0.664	0.147	0.390	0.664	0.147	0.397	0.652	0.147
Cut Edges	19,001			18,994			18,441		

Table 14: Compactness Scores for State Assembly District Plans

State Senate	2011 Plan (Census)			2011 Plan (LTSB)			Governor's Plan		
Compactness Scores	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Polsby-Popper	0.230	0.465	0.055	0.230	0.464	0.053	0.217	0.433	0.053
Reock	0.405	0.667	0.128	0.402	0.667	0.128	0.392	0.607	0.135
Cut Edges	10,998			10,928			11,147		

Table 15: Compactness Scores for State Senate District Plans

U.S. Congress	2011 Plan (Census)			2011 Plan (LTSB)			Governor's Plan		
Compactness Scores	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Polsby-Popper	0.214	0.432	0.118	0.209	0.432	0.118	0.243	0.397	0.127
Reock	0.440	0.537	0.302	0.440	0.537	0.302	0.458	0.599	0.334
Cut Edges	4,218			4,293			3,774		

Table 16: Compactness Scores for Congressional District Plans

3.6 Split Geographies

County splits measure the number of counties that are split between two or more districts, and **municipal splits** measure the number of municipalities (cites, towns, or villages) that are split between two or more districts. The numbers of county and municipal splits for each of the Governor's plans are shown in Tables 17 and 18, along with the values for both versions of the 2011 enacted plans for comparison.

Note that both versions of the 2011 enacted plans are in agreement regarding the numbers of county splits, but they are strikingly different regarding the numbers of municipal splits. See Section 4 for details of how I performed these computations.

County Splits	2011 Plan (Census)	2011 Plan (LTSB)	Governor's Plan
State Assembly	58	58	53
State Senate	46	46	45
U.S. Congress	12	12	12

Table 17: County Splits for All District Plans

Municipal Splits	2011 Plan (Census)	2011 Plan (LTSB)	Governor's Plan
State Assembly	188	125	174
State Senate	123	84	118
U.S. Congress	57	51	47

Table 18: Municipal Splits for All District Plans

4 Data and Methodology

4.1 Data Sources

My analysis is based on the following data:

- A shapefile for 2020 Census blocks, including the U.S. Census Bureau's 2020 PL 94-171 Population data and the Census Bureau's assignments of 2020 Census blocks to 2011 enacted districts, obtained from the Redistricting Data Hub at https://redistrictingdatahub.org;
- A shapefile for 2020 Census blocks without water, including assignments of 2020 Census blocks to counties, municipalities and 2011 enacted districts, obtained from the Legislative Technology Services Bureau (LTSB) of the State of Wisconsin's Open Data Page web page at https://legis.wisconsin.gov/ltsb/gis/data/;
- 2020 Census block assignment files for Governor Evers's proposed district plans for the U.S. House of Representatives, the Wisconsin State Assembly, and the Wisconsin State Senate;
- 2020 Census block assignment files for district plans for the U.S. House of Representatives, the Wisconsin State Assembly, and the Wisconsin State Senate recently passed by the Wisconsin State Legislature in Legislative Bills SB 622 and SB 621.

By matching Census blocks according to their unique identifiers (called variously "GEOID20" or "BLOCKID"), I combined all of these files into a single shapefile containing all relevant data to use for my analysis.

In the Census Bureau shapefile, the 2011 enacted plan assignments are encoded in the fields "SLDL18" for the State Assembly plan, "SLDU18" for the State Senate plan, and "CD116" for the Congressional plan. In the LTSB shapefile, the 2011 enacted plan assignments are encoded in the fields "ASM" for the State Assembly plan, "SEN" for the State Senate plan, and "CON" for the Congressional plan. There are minor discrepancies between these two shapefiles regarding the 2020 Census block assignments to the 2011 enacted plans. These discrepancies in turn create discrepancies between the values computed for core population movement, disenfranchised population, compactness measures, and split geographies for the 2011 enacted plans, depending on which version is used. I was not able to determine the source of the discrepancies.

4.2 Methodology

4.2.1 Population Deviation

District populations for all plans were computed by summing the values for the PL 94-171 category "P0010001" (Total Population) over all the 2020 Census blocks assigned to each district. (This produces exactly the same results as summing the "PERSONS" category from the LTSB shapefile.)

4.2.2 Core Population Movement and Disenfranchised Population

Core population movement for each district plan was computed by summing the values for the PL 94-171 category "P0010001" (Total Population) over all the 2020 Census blocks for which the assigned district number for that plan differed from the assigned district number for the corresponding 2011 enacted plan.

In a similar fashion, disenfranchised population for each district plan was computed by summing the values for the PL 94-171 category "P0010001" (Total Population) over all the 2020 Census blocks for which the assigned State Senate district number in the 2011 enacted plan is odd and the assigned State Senate district number in the new plan is even.

4.2.3 Majority-Minority Districts

- Non-White Voting Age Population (NWVAP) was computed as the difference of Total Voting Age Population (PL 94-171 category P0030001, or "PERSONS18" in the LTSB shapefile) minus non-Hispanic, White-only Voting Age Population (PL 94-171 category P0040005, or "WHITE18" in the LTSB shapefile).
- Black Voting Age Population (BVAP) was computed in two ways:
    1. ("BVAP1") As the sum of all PL 94-171 categories including Black Voting Age Population plus any other combination of races, without regard to ethnicity. There are 32 PL 94-171 categories included in this sum.
    2. ("BVAP2") The sum of PL 94-171 categories P0040006 (Non-Hispanic, Black-only Voting Age Population) and P0040013 (Non-Hispanic, (Black + White) only Voting Age Population). This sum is represented as "BLACK18" in the LTSB shapefile.
- Hispanic Voting Age Population (HVAP) is PL 94-171 category P0040002, or "HISPANIC18" in the LTSB shapefile.

District-based population percentages for each of these groups were computed by calculating the ratio of the population of that group to the total Voting Age Population (PL 94-171 category P0030001, or "PERSONS18" in the LTSB shapefile) in each district.

4.2.4 Compactness

Polsby-Popper scores for each district were computed from district shapes rendered in the map projection used in the LTSB shapefile using the built-in updater for this purpose that is included in the open-source Python package "Gerrychain," available from https://github.com/mggg/GerryChain.

Reock scores for each district were computed from district shapes rendered in the map projection used in the LTSB shapefile using open-source Python code, available from
https://github.com/mggg/plan-evaluation-processing/tree/main/evaltools/geography.

Cut edges scores for each district plan were computed using the built-in updater for this purpose that is included in Gerrychain.

4.2.5 Split Geographies

The LTSB shapefile assigns each Census block to a unique county under the field "CNTY_FIPS" and to a unique municipality under the field "COUSUBFP." There are 72 unique values occurring in the "CNTY_FIPS" field, corresponding to Wisconsin's counties. There are 1,850 unique values occurring in the "COUSUBFP" field, corresponding to Wisconsin's municipalities (cities, towns, and villages).

County splits for each district plan were computed by counting the number of unique values in the "CNTY_FIPS" field that each occur in multiple blocks assigned to different districts in that plan.

Municipal splits for each district plan were computed by counting the number of unique values in the "COUSUBFP" field that each occur in multiple blocks assigned to different districts in that plan.

5 Previous Expert Testimony and Compensation

I have not served as an expert witness in any other case in the past 4 years. I am being compensated at the rate of $250 per hour for my work on this case.

References

[1] Jeanne Clelland, Daryl DeFord, Beth Malmskog, and Flavia Sancier-Barbosa, *Ensemble Analysis for 2021 State Legislative Redistricting in Colorado*, submitted to the Colorado Independent Legislative Redistricting Commission, September 26, 2021. Available online at https://coloradoincontext.wordpress.com/.

[2] ———, *Ensemble Analysis for 2021 State Legislative Redistricting in Colorado, Part 2: Comparison of Final Approved Plans to Ensembles*, submitted to the Colorado In-

dependent Legislative Redistricting Commission, October 21, 2021. Available online at https://coloradoincontext.wordpress.com/.

[3] Moon Duchin and Bridget Tenner, *Discrete geometry for electoral geography*, arXiv e-prints (2018), arXiv:1808.05860.

JEANNE NIELSEN CLELLAND
Department of Mathematics, 395 UCB
University of Colorado
Boulder, CO 80309-0395
(303) 492-7083
e-mail: Jeanne.Clelland@colorado.edu
December 14, 2021

EDUCATION:

- Ph.D., Mathematics, Duke University, May 1996
  Advisor: Robert Bryant
  Dissertation: *Geometry of conservation laws for a class of parabolic partial differential equations*
- M.A., Mathematics, Duke University, May 1993
- B.S. summa cum laude, Mathematics, Duke University, May 1991

ACADEMIC EMPLOYMENT:

- Professor of Mathematics, University of Colorado, Fall 2014 - present
- Associate Professor of Mathematics, University of Colorado, Fall 2007 - Spring 2014
- Assistant Professor of Mathematics, University of Colorado, Fall 1998 - Spring 2007
- National Science Foundation Postdoctoral Research Fellow, Institute for Advanced Study, Princeton, NJ, Fall 1996 - Spring 1998. Advisor: Phillip Griffiths

GRANTS, AWARDS, AND HONORS:

- University of Colorado Undergraduate Research Opportunities Program (UROP) Team Grant, August 2021 - May 2022, $3,000
- University of Colorado Undergraduate Research Opportunities Program (UROP) Team Grant, August 2019 - May 2020, $3,000
- Nominated for Haimo Teaching Award, Mathematical Association of America, March 2019
- Burton W. Jones Teaching Award, Rocky Mountain Section of the Mathematical Association of America, March 2018
- Boulder Faculty Assembly Excellence in Teaching and Pedagogy Award, March 2018
- Simons Foundation Collaboration Grant for Mathematicians, September 2017 - August 2022, $42,000
- University of Colorado Arts & Sciences Fund for Excellence travel award, April 2017, $1,500

- Nominated for Burton W. Jones teaching award, Rocky Mountain section of the Mathematical Association of America, January 2017
- National Science Foundation grant DMS-1321212 (co-PI), "Conference/Workshop: New Directions in Exterior Differential Systems," February 2013 - February 2014, $40,000
- National Science Foundation grant DMS-1206272, "Isometric Embedding and Other Problems in Geometry and Differential Equations," September 2012 - August 2015, $165,000
- National Science Foundation grant DMS-0908456, "Topics in the Geometry of Differential Equations," August 2009 - July 2012, $90,912
- American Institute of Mathematics SQuaRE (Structured Quartet Research Ensemble) workshop grant, March 2009 - March 2011
- University of Colorado Dean's Fund for Excellence grant, December 2003
- Residence Life Academic Teaching Award, Department of Housing and the Committee on Learning & Academic Support Services, University of Colorado, Spring 2003
- University of Colorado Junior Faculty Development Award, March 2001
- Awarded membership, Institute for Advanced Study, Princeton, NJ, Fall 1996 - Spring 1998
- National Science Foundation Mathematical Sciences Postdoctoral Research Fellowship, awarded February 1996
- Awarded three Association for Women in Mathematics travel grants: January 1995, July 1996, January 1998
- Graduate student teaching award – Award for demonstrated excellence in teaching from the L.P. and Barbara Smith Endowment, Duke University Department of Mathematics, August 1995 and July 1996
- National Science Foundation Graduate Fellowship, awarded Fall 1991
- Alice T. Schafer Prize, Association for Women in Mathematics, Spring 1991
- Phi Beta Kappa, Spring 1990

RESEARCH AND CREATIVE WORKS:

Peer-reviewed articles:

(1) J. Clelland, H. Colgate, D. DeFord, B. Malmskog, and F. Sancier-Barbosa, "Colorado in Context: Congressional Redistricting and Competing Fairness Criteria in Colorado," *J Comput Soc Sc* (2021), https://doi.org/10.1007/s42001-021-00119-7

(2) J. Clelland, D. DeFord, and M. Duchin, "Aftermath: The Ensemble Approach to Political Redistricting," *Math Horizons* 27 (2020), no. 3, 34-35.

(3) R.L. Bryant and J.N. Clelland, "Flat metrics with a prescribed derived coframing," *SIGMA* 16 (2020), 004, 23 pages. Published electronically at https://www.emis.de/journals/SIGMA/2020/004/.

(4) J.N. Clelland and T. Klotz, "Beltrami fields with non-constant proportionality factor via moving frames," *Arch Rational Mech Anal* (2019), https://doi.org/10.1007/s00205-019-01481-7.

(5) J.N. Clelland. Y. Hu, and M.W. Stackpole, "Dynamic Equivalence of Control Systems and Infinite Permutation Matrices," *SIGMA* 15 (2019), 063, 16 pages. Published electronically at https://www.emis.de/journals/SIGMA/2019/063/.

(6) J.N. Clelland, T.A. Ivey, N. Tehseen, and P.J. Vassiliou, "Isometric Embedding and Darboux Integrability," *Geometriae Dedicata* 203 (2019), 353-388. Published electronically at https://doi.org/10.1007/s10711-019-00441-5.

(7) J.N. Clelland and T.A. Ivey, "Geometric characterization and classification of Bäcklund transformations of sine-Gordon type," *Journal of Integrable Systems* 3 (2018), 1-44. Published electronically at https://doi.org/10.1093/integr/xyy018.

(8) J.N. Clelland, "A counterexample to Matsumoto's conjecture regarding absolute length vs. relative length in Finsler manifolds," *Reports on Mathematical Physics* 82 (2018), 21-26.

(9) G.-Q. Chen, J. Clelland, M. Slemrod, D. Wang, and D. Yang, "Isometric embedding via strongly symmetric positive systems," *The Asian Journal of Mathematics* 22 (2018), 1-40.

(10) N. Bushek and J.N. Clelland, "Geometry of centroaffine surfaces in $\mathbb{R}^5$," *SIGMA* 11 (2015), 001, 24 pages. Published electronically at
http://www.emis.de/journals/SIGMA/2015/001/.

(11) J.N. Clelland and J.M. Miller, "A characterization of hyperbolic affine flat, affine minimal surfaces in $\mathbb{A}^3$," *Differential Geometry and Its Applications* 36 (2014) 134-148.

(12) J. Clelland, E. Estrada, M. May, J. Miller, S. Peneyra, and M. Schmidt, "A Tale of Two Arc Lengths: Metric notions for curves in surfaces in equiaffine space," *Proceedings of the American Mathematical Society* 142 (2014), 2543-2558.

(13) J.N. Clelland and P.J. Vassiliou, "A Solvable String on a Lorentzian Surface," *Differential Geometry And Its Applications* 33 Suppl. (2014) 177-198.

(14) B. Carlsen and J.N. Clelland, "The geometry of lightlike surfaces in Minkowski space," *Journal of Geometry and Physics* 74 (2013) 43-55.

(15) J.N. Clelland, C.G. Moseley, and G.R. Wilkens, "Geometry of optimal control for control-affine systems," *SIGMA* 9 (2013), 034, 31 pages. Published electronically at
http://www.emis.de/journals/SIGMA/2013/034/.

(16) J.N. Clelland, "Totally quasi-umbilic timelike surfaces in $\mathbb{R}^{1,2}$," *Asian Journal of Mathematics* 16 (2012) 189-208.

(17) J.N. Clelland, C.G. Moseley, and G.R. Wilkens, "Geometry of control-affine systems," *SIGMA* 5 (2009), 095, 28 pages. Published electronically at
http://www.emis.de/journals/SIGMA/2009/095/.

(18) J.N. Clelland and T.A. Ivey, "Bäcklund transformations and Darboux integrability for nonlinear wave equations," *Asian Journal of Mathematics* 13 (2009) 15-64.

(19) J.N. Clelland, M. Kossowski, and G.R. Wilkens, "Second-order type-changing evolution equations with first-order intermediate equations," *Journal of Differential Equations* 244 (2008) 242-273.

(20) J.N. Clelland, M. Kossowski, and G.R. Wilkens, "Constructing topologically distinct energy-critical curves in the path space of the Euclidean line," *Journal of Differential Equations* 241 (2007) 305-331.

(21) J.N. Clelland, C.G. Moseley, and G.R. Wilkens, "Geometry of sub-Finsler Engel manifolds," *Asian Journal of Mathematics* 11 (2007) 699-726.

(22) J.N. Clelland and C.G. Moseley, "Sub-Finsler geometry in dimension three," *Differential Geometry And Its Applications* 24 (2006) 628-651.

(23) J.N. Clelland and T.A. Ivey, "Parametric Bäcklund transformations I: Phenomenology," *Transactions of the American Mathematical Society* 357 (2005) 1061-1093.

(24) J.N. Clelland, "Homogeneous Bäcklund transformations of hyperbolic Monge-Ampère systems," *Asian Journal of Mathematics* 6 (2002) 433-480.

(25) J.N. Clelland, "A Bäcklund transformation for timelike surfaces of constant mean curvature in $\mathbb{R}^{1,2}$," *Bäcklund and Darboux Transformations. The Geometry of Solitons*, 141-150, CRM Proc. Lecture Notes 29, American Mathematical Society, Providence, RI, 2001.

(26) J.N. Clelland, "On the intermediate integral for Monge-Ampère equations," *Proceedings of the American Mathematical Society* 128 (2000) 527-531.

(27) J.N. Clelland, "Geometry of conservation laws for a class of parabolic PDEs II: Normal forms for equations with conservation laws," *Selecta Mathematica (New Series)* 3 (1997) 497-515.

(28) J.N. Clelland, "Geometry of conservation laws for a class of parabolic partial differential equations," *Selecta Mathematica (New Series)* 3 (1997) 1-77.

(29) J.A. Nielsen, "Rewritable sequencings of groups," *Ars Combinatoria* 36 (1993) 207-214.

Submitted articles:

(30) J. Clelland. N. Bossenbroek, T. Heckmaster, A. Nelson, P. Rock, and J. VanAusdall, "Compactness statistics for spanning tree recombination," submitted August 2021.

(31) C. Millar, T. Mitchell, A. Mazurek, A. Chhabra, A. Beghini, J. Clelland, A. McRobie, and W. Baker, "On designing plane-faced funicular gridshells," submitted April 2021.

(32) J.N. Clelland, T.J. Klotz, and P.J. Vassiliou, "Dynamic Feedback Linearization of Control Systems with Symmetry," submitted March 2021.

(33) J.N. Clelland and Y. Hu, "On absolute equivalence and linearization I," submitted July 2020.

Peer-reviewed Book:

(34) J.N. Clelland, *From Frenet to Cartan: The Method of Moving Frames*, Graduate Studies in Mathematics 178, American Mathematical Society (2017), 414 pp.

Preprints:

(35) J.N. Clelland and P.J. Vassiliou, "Strings attached: New light on an old problem"

Reports:

(36) J. Clelland, D. DeFord, B. Malskog, and Flavia Sancier-Barbosa, "Ensemble Analysis for 2021 State Legislative Redistricting in Colorado," submitted to the Colorado Independent Legislative Redistricting Commission, September 26, 2021. Available online at https://coloradoincontext.wordpress.com/.

(37) J. Clelland, D. DeFord, B. Malskog, and Flavia Sancier-Barbosa, "Ensemble Analysis for 2021 Congressional Redistricting in Colorado," submitted to the Colorado Independent Congressional Redistricting Commission, September 10, 2021. Available online at https://coloradoincontext.wordpress.com/.

Opinion pieces:

(38) J.N. Clelland, "Boulder Council elections disfavor minority representation," Guest Opinion in *The Daily Camera*, January 3, 2020. Available online at https://www.dailycamera.com/2020/01/03/jeanne-clelland-boulder-council-elections-disfavor-minority-representation/.

(39) J.N. Clelland, "The court seeks a standard to measure partisan gerrymandering. Mathematicians came up with one." Sunday Guest Opinion in *The Daily Camera*, July 7, 2019. Available online at https://www.dailycamera.com/2019/07/06/opinion-jeanne-clelland-the-court-seeks-a-standard-to-measure-partisan-gerrymandering-mathematicians-came-up-with-one/.

(40) J.N. Clelland, "The Mathematics of Gerrymandering and the Supreme Court," blog post on Mathematical Association of America "Math Values" blog, July 2, 2019. Available online at https://www.mathvalues.org/masterblog/the-mathematics-of-gerrymandering-and-the-supreme-court.

Published software packages:

(41) Cartan, a software package for Maple to perform computations involving differential forms in general, and to perform Cartan-Kähler analysis of linear Pfaffian exterior differential systems in particular. Available at http://math.colorado.edu/~jnc/Maple.html.

Archived lecture material:

(42) J.N. Clelland, "Lie groups and the method of moving frames," lecture notes from invited Summer 1999 Graduate Workshop at the Mathematical Sciences Research Institute, Berkeley, CA, 85 pages, available at http://math.colorado.edu/~jnc/MSRI.html. (Streaming videos of the nine workshop lectures available at http://www.msri.org/publications/video/index2.html.)

LECTURES AND PRESENTATIONS:

Invited conference talks:

(1) "District compactness in the ReCom sampling method," AMS Spring Southeastern Section Meeting, University of Virginia, March 2020 — CANCELLED due to COVID-19

(2) "Gerrymandering: What is it, how can we measure it, and what can we do about it?," plenary talk at SIAM Front Range Applied Mathematics Student Conference, CU-Denver, March 2020

(3) "Beltrami fields with non-constant proportionality factor via moving frames," AMS/MAA Joint Mathematics Meetings, Denver, CO, January 2020

(4) "Isometric embedding via strongly symmetric positive systems," invited plenary talk at Midwest Geometry Conference, Iowa State University, September 2019

(5) "Gerrymandering: What is it, how can we measure it, and what can we do about it?", keynote talk at Rocky Mountain Section meeting of the Mathematical Association of American, Fort Lewis College, Durango, CO, April 2019

(6) "The Will of the People: How we vote and why it matters," invited talk at Voting Rights Data Institute, Tufts University, June 2018

(7) "The Good, the Bad, and the Ugly: The Cartan algorithm for overdetermined PDE systems," invited semi-plenary talk for session on Symbolic Analysis at the Foundations of Computational Mathematics conference, Barcelona, Spain, July 2017

(8) "Towards a classification of quasi-linear Bäcklund transformations of wavelike PDEs, and a new example," AMS Southeastern Section meeting, Charleston, SC, March 2017

(9) "Beltrami fields with non-constant proportionality factor via moving frames," AMS Central Section Meeting, Minneapolis, MN, October 2016

(10) "Isometric embedding via strongly symmetric positive systems," Conference on PDEs and Free Boundary Problems, University of Pittsburgh, March 2015

(11) "The geometry of lightlike surfaces in Minkowski space," SIAM Conference on Applied Algebraic Geometry, Colorado State University, Ft. Collins, CO, August 2013

(12) "The geometry of lightlike surfaces in Minkowski space," New Directions in Exterior Differential Systems: a conference in honor of Robert Bryant's 60th birthday, Estes Park, CO, July 2013

(13) "Sub-Finsler geometry in dimensions three and four," Differential Geometry and Continuum Mechanics Workshop, International Centre for Mathematical Sciences, Edinburgh, Scotland, June 2013

(14) "A Tale of Two Arc Lengths," AMS Western section meeting, Tucson, AZ, October 2012

(15) "A Tale of Two Arc Lengths," Southeast Geometry Conference, College of Charleston, March 2012

(16) "Equivalence of geometric structures in control theory via moving frames," Chern Centennial Conference, Mathematical Sciences Research Institute, Berkeley, CA, November 2011

(17) "Equivalence of geometric structures in control theory via moving frames," AMS Eastern section meeting, Ithaca, NY, September 2011

(18) "Equivalence of geometric structures in control theory via moving frames," plenary talk at the Workshop on Moving Frames in Geometry, Centre de Recherches Mathématiques, Montreal, CA, June 2011

(19) "Bäcklund transformations and Darboux integrability for nonlinear wave equations," Texas Geometry and Topology Conference, Texas Tech University, February 2011

(20) "Totally quasi-umbilic timelike surfaces in $\mathbb{R}^{1,2}$," AMS central section meeting, St. Paul, MN, April 2010

(21) "Bäcklund transformations and Darboux integrability for nonlinear wave equations," Mini Workshop on Differential Systems, Utah State University, November 2009

(22) "Sub-Finsler geometry in dimensions three and four," Mini Workshop on Differential Systems, Utah State University, November 2009

(23) "Geometry of control-affine systems," AMS southeastern section meeting, Raleigh, NC, April 2009

(24) "Sub-Finsler geometry in dimensions three and four," Mathematical Sciences Research Institute Workshop on Exterior Differential Systems and the Method of Equivalence, May 2008

(25) "Bäcklund transformations and Darboux integrability for nonlinear wave equations," Lehigh University Geometry and Topology Conference, October 2007

(26) "Sub-Finsler geometry in dimensions three and four," 80ème Rencontre entre physiciens théoriciens et mathématiciens: "Géométrie de Finsler (Mathématiques et Physique)," Institut de Recherche Mathématique Avancée, Strasbourg, France, September 2007.

(27) "Sub-Finsler geometry in dimensions three and four," Southeast Geometry Conference, College of Charleston, March 2006

(28) "Geometry of sub-Finsler Engel manifolds," AMS central section meeting, Lincoln, NE, October 2005

(29) "Sub-Finsler geometry in dimension three," Lehigh University Geometry and Topology Conference, June 2004

(30) "Sub-Finsler geometry in dimension three," Southeast Geometry Conference, College of Charleston, March 2003

(31) "Sub-Finsler geometry in dimension three," AMS central section meeting, Madison, WI, October 2002

(32) "Homogeneous Bäcklund transformations of hyperbolic Monge-Ampère systems," Southeast Geometry Conference, University of Georgia, April 2002

(33) "Bäcklund transformations of hyperbolic Monge-Ampère equations," Soliton Equations: Applications and Theory conference, University of Colorado at Colorado Springs, August 2001

(34) "Bäcklund transformations of hyperbolic Monge-Ampère equations," Lehigh University Geometry and Topology Conference, June 2001

(35) "Bäcklund transformations of hyperbolic Monge-Ampère equations," Southeast Geometry Conference, College of Charleston, March 2000

(36) "Bäcklund transformations of hyperbolic Monge-Ampère equations," Robby Fest, a conference in honor of Robert Gardner, University of North Carolina, October 1999

(37) "Homogeneous Bäcklund transformations of hyperbolic Monge-Ampère equations," AARMS-CRM Workshop on Bäcklund and Darboux Transformations, June 1999

(38) "Homogeneous Bäcklund transformations of hyperbolic Monge-Ampère equations," First Workshop on Formal Geometry and Mathematical Physics, Utah State University, May 1999

(39) "Some classical results on Bäcklund transformations," First Workshop on Formal Geometry and Mathematical Physics, Utah State University, May 1999

(40) "Bäcklund transformations of hyperbolic Monge-Ampère systems," AWM workshop, Baltimore, MD, January 1998

(41) "Geometry of conservation laws for parabolic PDEs," AMS Summer Research Institute on Differential Geometry and Control, University of Colorado, Boulder, July 1997

(42) "Geometry of conservation laws for parabolic PDEs," Geometry Festival, Duke University, March 1997

(43) "Geometry of conservation laws for parabolic PDEs," Southeast Geometry Conference, University of South Carolina, May 1996

Invited seminar talks:

(44) "Colorado in Context: Using Mathematics to Detect and Prevent Gerrymandering in Colorado and Beyond" (joint talk with Beth Malmskog), New York University Math and Democracy Seminar, November 2021

(45) "Gerrymandering: What is it, how can we measure it, and what can we do about it?," Applied Math Seminar, Northeastern Illinois University, February 2020

(46) "Gerrymandering: What is it, how can we measure it, and what can we do about it?," Institute for Policy Research, Northwestern University, February 2020

(47) "Isometric embedding via strongly symmetric positive systems," University of Minnesota, March 2018

(48) "Isometric embedding via strongly symmetric positive systems," Wichita State University, March 2018

(49) "Isometric embedding via strongly symmetric positive systems," Duke University, June 2015

(50) "Isometric embedding via strongly symmetric positive systems," Australian National University, April 2015

(51) "Isometric embedding via strongly symmetric positive systems," University of Sydney (Australia) Geometry Seminar, March 2015

(52) "Isometric embedding via strongly symmetric positive systems," Texas A&M University, February 2015

(53) "Equivalence of geometric structures in control theory via moving frames," Australian National University, November 2012

(54) "Equivalence of geometric structures in control theory via moving frames," Universidade de Brasilia, June 2012

(55) "Bäcklund transformations and Darboux integrability for nonlinear wave equations," Texas A&M University, November 2009

(56) "Constructing topologically distinct energy-critical curves in the path space of the Euclidean line," University of Wisconsin, February 2009

(57) "Sub-Finsler geometry in dimensions three and four," Duke University, October 2006

(58) "Conservation laws for second-order evolution equations," Kansas State University, April 2006

(59) "Sub-Finsler geometry," Colorado State University, January 2005

(60) "Sub-Finsler geometry in dimension three," University of Colorado, Colorado Springs, April 2003

(61) "Bäcklund transformations of hyperbolic Monge-Ampère equations," Department of Applied Mathematics Dynamics seminar, University of Colorado, February 2002

(62) "Bäcklund transformations of hyperbolic Monge-Ampère equations," University of Chicago, October 2001

Invited colloquium talks:

(63) "A Tale of Two Arc Lengths," Australian National University, November 2012

(64) "A Tale of Two Arc Lengths," Instituto de Matematica, Universidade Federal do Rio de Janeiro, June 2012

(65) "Classical results on Bäcklund transformations," Texas A&M University, November 2009

(66) "PDEs for geometers and vice-versa: Intro to exterior differential systems," Wake Forest University, April 2009

(67) "PDEs for geometers and vice-versa: An introduction to exterior differential systems," Wesleyan University, March 2008

(68) "PDEs for geometers and vice-versa: An introduction to exterior differential systems," Kansas State University, April 2006

(69) "PDEs for geometers: Introduction to exterior differential systems," Lehigh University, December 1996

(70) "PDEs for geometers: Introduction to exterior differential systems," University of Georgia, November 1996

Invited talks for students:

(71) "The Will of the People: How we vote and why it matters," CU-Boulder math club, April 2019

(72) "The Will of the People: How we vote and why it matters," Fairview High School math club, January 2019

(73) "The Poincaré conjecture in dimension 2, or why topologists can't tell their donuts from their cups of coffee," Wake Forest University, March 2017

(74) "The Poincaré conjecture in dimension 2, or why topologists can't tell their donuts from their cups of coffee," Calvin College Math Club, October 2010

(75) "The Poincaré conjecture in dimension 2, or why topologists can't tell their donuts from their cups of coffee," Wesleyan University Math Club, March 2008

(76) "The Poincaré conjecture in dimension 2, or why topologists can't tell their donuts from their cups of coffee," Duke Math Alumni Lecture Series, Duke University, October 2006

Public lectures:

(77) "Redistricting and Gerrymandering: When is a district map "fair"?" Ethics and Ecological Economics (EEE) Forum on "The Right to Vote: The National Context and Colorado's Story," November 2021.

(78) "What Can Mathematics Tell Us About Fairness for Redistricting?" Gerrymandering and Congressional Redistricting meeting, sponsored by the Library of Congress Phillip Lee Phillips Map Society and the Rocky Mountain Map Society, January 2021.

(79) "What Can Mathematics Tell Us About Fairness for Redistricting in Colorado?" Connecting Colorado for Fair Redistricting: A Public Symposium and Call to Action (online), September 2020. Video of talk available online at https://www.youtube.com/watch?v=xn0ziuym2PI&feature=youtu.be&t=7275

(80) "Math vs. Gerrymandering: Using math to work for fair maps in Colorado and everywhere," joint talk with Beth Malmskog, Free and Equal Elections Foundation Annual Electoral Reform Symposium, Denver, CO, Dec. 7, 2019. Video of the entire symposium available at https://www.youtube.com/embed/FDZYPhGkK-4; talk starts at 33-minute mark.

(81) "The Will of the People: How we vote and why it matters," League of Women Voters of Boulder County Community Conversation, November 10, 2019. Video of the talk available at https://www.youtube.com/watch?v=nK34leqGbLs&feature=youtu.be.

(82) "POINCARÉ WAS RIGHT: If it looks like a sphere and quacks like a sphere, then it IS a sphere! (So why is this worth a Fields Medal?)," Math Awareness Month Lecture, University of Colorado, April 2007

Podcasts:

(83) Featured guest on "My Favorite Theorem" podcast, Episode 11, January 2018. Podcast and accompanying Scientific American blog post available at https://blogs.scientificamerican.com/roots-of-unity/jeanne-clellands-favorite-theorem/

Posters:

(84) "Conservation laws for parabolic PDEs," Julia Robinson Celebration of Women in Mathematics, Mathematicial Sciences Research Institute, July 1996

(85) "Exterior differential systems and conservation laws for partial differential equations," AWM workshop, San Francisco, CA, January 1995

CONSULTING WORK:

- Ensemble analysis consultant to the Colorado Independent Legislative Redistricting Commission, August 2021 - October 2021

TEACHING EXPERIENCE AND ACCOMPLISHMENTS:

Invited lecture series:

- "Lie groups and Cartan's method of moving frames," mini-course of six lectures, Universidade de Brasilia, June 2012
- "Lie groups and the method of moving frames," invited series of nine lectures, Summer Graduate Workshop at the Mathematical Sciences Research Institute, Berkeley, CA, July 1999

Postdoctoral fellows supervised:

- Yuhao Hu, Fall 2018 - Spring 2020
- Sunita Vatuk, Fall 2009 - Spring 2010

New courses developed:

- FYSM 1000: First-Year Seminar: "How Not To Be Wrong"
- MATH 4230/5230: Differential Geometry of Curves and Surfaces
- MATH 4810/5810: Special Topics in Mathematics: Mathematics of Redistricting

,

Courses taught:

- Professor of Mathematics, University of Colorado:
  - FYSM 1000-040: First-Year Seminar: "How Not To Be Wrong" – Fall 2017
  - MATH 2001: Introduction to Discrete Math – Spring 2019, Fall 2019
  - MATH 3430: Ordinary Differential Equations – Spring 2018, Fall 2019
  - MATH 4230/5230: Differential Geometry of Curves and Surfaces – Fall 2014, Fall 2016, Fall 2018, Fall 2020
  - MATH 4470/5470: Introduction to Partial Differential Equations – Spring 2016, Spring 2020, Spring 2021
  - MATH 4810/5810: Special Topics in Mathematics: Mathematics of Redistricting – Fall 2020
  - MATH 6230: Introduction to Differential Geometry I – Spring 2016, Spring 2018, Spring 2019
  - MATH 6240: Introduction to Differential Geometry II – Fall 2015
- Associate Professor of Mathematics, University of Colorado:
  - MATH 2001: Introduction to Discrete Math – Spring 2010, Fall 2011
  - MATH 2400: Calculus III – Fall 2012
  - MATH 3130: Introduction to Linear Algebra – Spring 2009, Spring 2011
  - MATH 4200: Introduction to Topology – Spring 2011, Spring 2014
  - MATH 4230: Geometry of Curves and Surfaces – Fall 2008, Fall 2009, Fall 2010, Fall 2012
  - MATH 4430: Ordinary Differential Equations – Spring 2010
  - MATH 4470: Introduction to Partial Differential Equations – Fall 2008, Spring 2012
  - MATH 5470: Introduction to Partial Differential Equations – Spring 2012
  - MATH 6230: Introduction to Differential Geometry I – Spring 2014
- Assistant Professor of Mathematics, University of Colorado:
  - MATH 1300: Calculus I – Spring 1999, Fall 2005
  - MATH 2300: Calculus II – Spring 2000
  - MATH 2420: Honors Calculus III – Fall 2001
  - MATH 3200: Introduction to Topology – Spring 2003
  - MATH 4230: Geometry of Curves and Surfaces – Spring 2001, Spring 2003, Spring 2005, Spring 2007
  - MATH 4430: Ordinary Differential Equations – Fall 1998, Fall 1999, Spring 2002 (2 sections), Fall 2002, Spring 2006 (2 sections), Spring 2007
  - MATH 6230: Introduction to Differential Geometry I – Fall 2006
  - MATH 6240: Introduction to Differential Geometry II – Spring 1999, Spring 2001, Spring 2005
  - MATH 6350: Complex Variables I – Fall 1999, Fall 2002
  - MATH 6360: Complex Variables II (Introduction to Algebraic Curves) – Spring 2000
- Instructor, Duke University:
  - Introductory Calculus II – Fall 1994, Fall 1995
  - Introductory Calculus III – Spring 1995

- Teaching Assistant, Duke University Talent Identification Program:
  - Taught Algebra I to gifted 7th grade students – Summer 1988

SERVICE AND OUTREACH ACTIVITIES:

Service to the Department of Mathematics, University of Colorado:

- Chair, Primary Unit Evaluation Committee for Assistant Professor Magdalena Czubak's Tenure and Promotion to Associate Professor, Fall 2019
- Chair, Primary Unit Evaluation Committee for Assistant Professor Magdalena Czubak's Comprehensive Review, Fall 2017
- Chair, Primary Unit Evaluation Committee for Instructor Faan Tone Liu's Reappointment and Promotion to Senior Instructor, Fall 2017
- Associate Chair for Undergraduate Studies, Fall 2012 - Spring 2017 (on sabbatical Spring 2015)
- Faculty mentor to Magdalena Czubak, Fall 2016 - present
- Faculty mentor to Anca Radalescu, Fall 2010 - Spring 2014
- Department representative to Mathematical Sciences Research Institute Sponsors Day, March 2013
- Faculty Course Supervisor (a.k.a. "Calc Czar") for MATH 1300 (Calculus I), Fall 2005
- Kempner Colloquium chair, Fall 1999 - Spring 2000
- Hiring committees:
  - Chair, Stochastic and deterministic differential equations faculty hiring committee, Fall 2019
  - Chair, Differential geometry faculty hiring committee, Fall 2015 - Spring 2016
  - Chair, Calc czar hiring committee, Spring 2013
  - Member, IT staff position hiring committee, Spring 2013
  - Member, Analysis faculty hiring committee, Fall 2012 - Spring 2013
  - Member, Geometry faculty hiring committee, Fall 2011 - Spring 2012
  - Member, IT staff position hiring committee, Fall 2011 - Spring 2012
  - Member, Differential equations faculty hiring committee, Spring 2006
  - Member, Algebra faculty hiring committee, Spring 2003
  - Member, Analysis faculty hiring committee, Spring 2002
  - Member, Algebraic topology faculty hiring committee, Spring 2000
- Graduate exam committees:
  - Member, Geometry/topology preliminary exam committee, January 2020
  - Member, Geometry/topology preliminary exam committee, August 2018
  - Member, Geometry/topology preliminary exam committee, January 2018
  - Member, Geometry/topology preliminary exam committee, August 2016
  - Member, Geometry/topology preliminary exam committee, August 2014
  - Member, Geometry/topology preliminary exam committee, January 2013
  - Member, Geometry/topology preliminary exam committee, January 2012
  - Member, Analysis preliminary exam committee, August 2001

- Member, Algebra preliminary exam committee, January 1999
- Member, Masters degree exam committee for Rebecca Wilczak, April 2012
- Member, Masters degree exam committee for Ivyl Boyce, July 2006
- Member, Masters degree exam committee for Daniel Champion, May 2005
- Member, Masters degree exam committee for Catherine Moody, April 2004
- Member, Masters degree exam committee for Lynn Schooley, April 2000
- Member, Masters degree exam committee for Kimberly Wey, April 2000
- Member, Masters degree exam committee for Keri Kornelson, November 1999
- Member, Qualifying exam committee for Ian Miller, April 2021
- Member, Qualifying exam committee for Zachary Gray (Department of Computer Science), March 2019
- Member, Qualifying exam committee for Albany Thompson, September 2018
- Member, Qualifying exam committee for Braden Balentine, December 2017
- Member, Qualifying exam committee for Carlos Pinilla, May 2016
- Member, Qualifying exam committee for Jonathan Belcher, November 2015
- Member, Qualifying exam committee for Jae Min Lee, September 2015
- Member, Qualifying exam committee for Boramey Chhay, April 2014
- Member, Qualifying exam committee for Pearce Washabaugh, January 2014
- Member, Qualifying exam committee for Chao Ma, October 2010
- Member, Qualifying exam committee for Christopher Seaton, November 2001
- Member, Ph.D. thesis exam committee for Albany Thompson, April 2021
- Member, Ph.D. thesis exam committee for Carlos Pinilla, April 2021
- Member, Ph.D. thesis exam committee for Zachary Gray (Department of Computer Science), October 2019
- Member, Ph.D. thesis exam committee for Pearce Washabaugh, March 2017
- Member, Ph.D. thesis exam committee and second reader for Matthew Krupa, July 2016
- Member, Ph.D. thesis exam committee for John Davenport, October 2007
- Member, Ph.D. thesis exam committee for Christopher Brown, November 2004
- Member, Ph.D. thesis exam committee for William Kirwin, March 2004

• Other departmental committees:
  - Member, Primary Unit Evaluation Committee for Nathaniel Thiem's promotion to Full Professor, Fall 2020
  - Member, Primary Unit Evaluation Committee for Sean O'Rourke's tenure and promotion, Fall 2020
  - Member, Awards Committee, Fall 2018 - Fall 2020
  - Member, First-Year Mathematics Committee, Fall 2018 - Spring 2019
  - Member, Primary Unit Review Committee for Sean O'Rourke's reappointment, Fall 2018
  - Member, Teaching Quality Framework committee, Fall 2017 - Spring 2018
  - Member, Executive Committee, Fall 2011 and Fall 2013 - present
  - Chair, Task Force on Reappointment, Promotion, and Tenure, Fall 2010 - Spring 2012

- Member, Task Force on Reappointment, Promotion, and Tenure, Fall 2007 - Fall 2008
- Member, Primary Unit Review Committee for Stephen Preston's tenure and promotion, Fall 2012
- Member, Primary Unit Review Committee for Stephen Preston's reappointment, Fall 2009
- Member, Computer Committee, Fall 2008 - Fall 2012
- Member, Graduate Committee, Fall 2008 - Spring 2010
- Member, Undergraduate committee, 1998 - 2005
- Member, Math 350 redecoration committee, Spring 2008

Service/Outreach Activities for the University of Colorado:

- Campus sponsor for The Center for Bright Kids Summer Programs, January 2019 - present
- Member, Academic Affairs Advisory Committee, Fall 2017 - Spring 2021
- Gave an interview to U.S. News & World Reports on how incoming freshmen planning to major in math can prepare over the summer, June 2014: http://www.usnews.com/education/best-colleges/articles/2014/06/23/get-a-jump-start-on-college-classes-as-a-stem-major
- Member, Academic Advising Center promotional committee, Fall 2012
- University of Colorado Representative, Rocky Mountain Mathematics Consortium Board of Directors Meeting, New Orleans, LA, January 2007
- Volunteered for Girl Scout Badge Day, sponsored by the Women In Engineering Program at the University of Colorado, October 2006
- Co-organized Department of Mathematics public lecture "Real Estate in Hyperbolic Space: Investment Opportunities for the New Millennium" by Dr. Colin Adams of Williams College, April 2006
- Member, Appeals Committee on Academic Rules and Policies, Fall 2005 - Spring 2006
- Math consultant for "Breaking the Code," a production of the University of Colorado Department of Theater and Dance, October 2005
- Co-organized Department of Mathematics public lecture "Soap Bubbles and Mathematics" by Dr. Frank Morgan of Williams College, April 2004
- Co-organized Department of Mathematics public lecture "Mathemagics" by Dr. Arthur Benjamin of Harvey Mudd College, March 2002
- Consultation regarding a Mathematica computation for Patrick Weidman, University of Colorado Department of Mechanical Engineering, October 2002
- Gave a presentation on utilizing university resources at a CRCW panel discussion, October 2001
- Gave a math presentation for a Brownie troop, November 2000

Service to the National Science Foundation:

- Member, Grant review panel, February 2014, February 2016
- Member, Division of Mathematical Sciences Committee of Visitors, February 2013

Service to the American Mathematical Society:

- Chair, Western Section Program Committee, 2018
- Member, Western Section Program Committee, 2017

Service to the Association for Women in Mathematics:

- Schafer Prize committee, 1999 - 2001 (committee chair in 2000 and 2001)

Conferences/Special sessions co-organized:

- Co-organized special session on "Geometry of Differential Equations" for American Mathematical Society/Mathematical Association of America Joint Meetings, Denver, CO, January 2020
- Co-organized Geometry and Analysis Day, University of Colorado, October 2018
- Co-organized working group in Calibrated Geometry at Women in Geometry conference, Banff International Research Station, Banff, Canada, November 2015
- Co-organized "New Directions in Exterior Differential Systems: a conference in honor of Robert Bryant's 60th birthday," Estes Park, CO, July 2013
- Co-organized Mathematical Sciences Research Institute Workshop on Exterior Differential Systems and the Method of Equivalence in honor of Robert B. Gardner, May 2008
- Co-organized Association for Women in Mathematics workshop at the American Mathematical Society/Mathematical Association of America Joint Mathematics Meetings, New Orleans, LA, January 2007
- Co-organized special session on "Geometry of Differential Equations" for American Mathematical Society Fall Central Section meeting, Lincoln, NE, October 2005
- Co-organized special session on "Geometry of Partial Differential Equations" for American Mathematical Society Fall Central/Western Joint Section meeting, Boulder, CO, October 2003

Manuscripts refereed/reviewed:

- Referee for:
  - **2021:** *CASC-2021 (Computer Algebra in Scientific Computing)*, *Differential Geometry And Its Applications*, *Journal of Geometry and Physics*, *SIGMA (Symmetry, Integrability, and Geometry: Methods and Applications)*, *Computer Algebra in Scientific Computing*
  - **2020:** *The Hokkaido Mathematical Journal*, *Journal of Geometry and Physics*, *Journal of Differential Equations*, *Journal of Mathematical Analysis and Applications*
  - **2019:** *Journal of Nonlinear Mathematical Physics*
  - **2018:** *Applied Mathematics and Computation*, *Communications in Analysis and Geometry*, *The Hokkaido Mathematical Journal*, *International Journal of Geometric Methods in Modern Physics*, *Journal of Geometric Analysis*, *Linear Algebra And Its Applications*, *Reports on Mathematical Physics*
  - **2017:** *Geometriae Dedicata*, *Differential Geometry and its Applications*, *Journal of Geometric Analysis*
  - **2016:** *Applied Mathematics and Computation*, *Journal of Geometry and Physics*

- **2015:** *Communications in Analysis and Geometry*, *Proceedings of the Royal Society of Edinburgh, Series A*
- **2014:** *Communications in Analysis and Geometry*, *Differential Geometry And Its Applications*, *ICMS Proceedings* volume on "Differential Geometry and Continuum Mechanics," *Journal of Differential Equations*, *Journal of Nonlinear Science*, *SIGMA (Symmetry, Integrability, and Geometry: Methods and Applications)*
- **2013:** *Brazilian Journal of Physics*, *Canadian Mathematical Bulletin*, *Differential Geometry and its Applications*, *Journal of Geometry and Physics*, *Journal of Mathematical Analysis and Applications*, *Mathematical Communications*
- **2012:** *Differential Geometry and its Applications*, *Journal of Geometry and Physics*, *Journal of Mathematical Analysis and Applications*, *Letters in Mathematical Physics*, *Mathematical Communications*, *SIGMA (Symmetry, Integrability, and Geometry: Methods and Applications)*
- **2010:** *Mathematical Communications*, *Journal of Geometry and Physics*, *Journal of Mathematical Analysis and Applications*, *Osaka Journal of Mathematics*
- **2009:** *Communications in Analysis and Geometry*, *Duke Mathematical Journal*, *Journal of Lie Theory*
- **2008:** *Advances in Mathematics*, *Differential Geometry and its Applications*, *Journal of Lie Theory*
- **2007:** *Duke Mathematical Journal*
- **2006:** *Foundations of Computational Mathematics*, *Journal of Mathematical Analysis and Applications*, *Journal of Zhejiang University Science*
- **2005:** *Journal of Differential Equations*
- **2003:** *Proceedings of the American Mathematical Society*, *Transactions of the American Mathematical Society*
- **2002:** *Canadian Journal of Mathematics*, *Journal of Differential Equations*
- **1999:** *Transactions of the American Mathematical Society*
- **1998:** *Differential Geometry and Control*, Proceedings of Symposia in Pure Mathematics

- Reviewer for *zbMATH*, May 2018 - present
- Reviewer for *Mathematical Reviews*, January 2016 - present
- Reviewer for *Zentralblatt*, January 2013 - September 2014

Grant proposals reviewed:

- Reviewer for Banff International Research Station workshop proposal, November 2017
- Reviewer for Natural Sciences and Engineering Research Council of Canada grant proposal, December 2010
- Reviewer for National Science Foundation grant proposals, January 2001, July 2013

External Ph.D. theses reviewed:

- External Reviewer for Ph.D. thesis of Sara Froehlich, McGill University, November 2016
- External Reviewer for Ph.D. thesis of Sunita Vatuk, Princeton University, July 2009
- External Reviewer for Ph.D. thesis of Dennis The, McGill University, July 2008

Miscellaneous outreach activities:

- Gave an interview about Project NExT for Science's NextWave, Science magazine's career-oriented online publication, March 1999

PROFESSIONAL DEVELOPMENT ACTIVITIES:

- Leadership Education for Advancement and Promotion (LEAP) workshop participant, 2005
- Project NExT (New Experiences in Teaching) fellow, Mathematical Association of America, 1998-2000
- Area Teaching Scholars Program participant, University of Colorado, 1998-1999
- Teaching workshop participant, Princeton University Department of Mathematics, January 1998

PROFESSIONAL AFFILIATIONS:

- American Mathematical Society (AMS)
- Mathematical Association of America (MAA)
- Association for Women in Mathematics (AWM)
- MGGG Redistricting Lab