SUPREME COURT OF THE STATE OF NEW YORK
COUNTY OF NEW YORK

PAUL NICHOLS, GAVIN WAX, and GARY GREENBERG

Petitioners,

v.

GOVERNOR KATHY HOCHUL, SENATE MAJORITY LEADER AND PRESIDENT PRO TEMPORE OF THE SENATE ANDREA STEWART-COUSINS, SPEAKER OF THE ASSEMBLY CARL HEASTIE, NEW YORK STATE BOARD OF ELECTIONS, and THE NEW YORK STATE LEGISLATIVE TASK FORCE ON DEMOGRAPHIC RESEARCH AND REAPPORTIONMENT,

Respondents.

Index No. 154213/2022

AFFIDAVIT OF DR. JEANNE CLELLAND

Jeanne N. Clelland, Ph.D., affirms under penalty of perjury:

BACKGROUND AND QUALIFICATIONS

1. I received my B.S. (summa cum laude, 1991), M.A. (1993), and Ph.D. (1996) degrees in Mathematics from Duke University.

2. I currently am a Full Professor in the Department of Mathematics at the University of Colorado Boulder, where I have been on the faculty since 1998. Prior to that I was a National Science Foundation Postdoctoral Research Fellow at the Institute for Advanced Study from 1996 - 1998. My research has been supported by grants from the National Science Foundation and the Simons Foundation at various times throughout my career.

3. I am the author of a graduate-level textbook and 29 peer-reviewed journal articles, with 3 more articles currently submitted and under review.

4. 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. Items (1) and (2) under "Peer-reviewed articles" on my CV are related to this work.

5. My CV is attached to this report, and it contains a list of all my publications from the past 10 years.

6. I served as expert witness for Governor Tony Evers in the case of *Johnson vs. Wisconsin Elections Commissions;* I submitted three expert reports for this case but was not called to give testimony.

SCOPE OF WORK AND COMPENSATION

7. I have been retained by Walden Macht & Haran LLP to analyze the likelihood that the New York State Assembly district plan enacted by the New York State Legislature in January 2022 was drawn to accommodate incumbent residences.

8. Throughout this report, I will refer to this plan as the "2022 Assembly plan," and to the prior decade's district plan as the "2012 Assembly plan."

9. I am being compensated at a rate of $300.00 per hour. My compensation is not contingent in any way upon the substance or conclusions of my expert analysis and/or opinions.

SUMMARY OF OPINIONS

10. I performed two independent and complementary analyses:

- I constructed three large ensembles of valid district plans for New York State Assembly districts based on different districting criteria, and for each plan in the ensembles, I used the addresses of the current incumbent Assembly members to compute the numbers of districts that would contain 0, 1, 2, or 3 incumbents in that plan. I then compared the statistical range of outcomes for these measures to the values for the 2022 Assembly plan.
- I constructed a large ensemble of "theoretical" incumbent addresses by randomly selecting one Census block from each 2012 district to represent the "incumbent" address for that district. For each set of addresses in this ensemble, I computed the numbers of districts that would contain 0, 1, 2, or 3 "incumbents" in the 2022 Assembly plan. I then compared the statistical range of outcomes for these measures to the values for actual incumbent addresses.

11. For both of these analyses, the actual data (i.e., the 2022 Assembly plan for the first analysis and the actual incumbent addresses for the second analysis) is a very extreme outlier compared to the ensembles. Based on the results of these analyses, I consider it almost certain that the 2022 Assembly plan was deliberately designed in part to maximize the number of districts containing a single incumbent Assembly member.

BACKGROUND ON ENSEMBLE ANALYSIS

12. In the years since the last decennial redistricting cycle, there has been much interest in---and litigation around---quantifying and identifying bias of various sorts in district plans. One strategy for quantifying bias that has rapidly been gaining traction is the idea of

"ensemble analysis," in which a particular district plan is compared to a large collection of randomly generated, legally valid plans, referred to as an "ensemble" of plans.

13. The fundamental goal of ensemble analysis is to model the political geography of a state in order to better understand what might be expected for a "typical" district plan for the state. Plans may be evaluated with regard to a variety of measures: partisan balance of election results, geographic compactness of districts, competitiveness of district elections, preservation of communities of interest, racial/ethnic population within districts, etc. The main idea is to create a large collection of randomly generated, legally valid plans, referred to as an "ensemble" of plans. Measures of interest are then computed for each plan in the ensemble using real population and voting data. The result is a statistical range of possible outcomes for each measure, to which any proposed plan may be compared. If a proposed plan appears to be an extreme outlier compared to the ensemble, this may suggest that factors not included in the ensemble design may have played an important role in the plan's construction. Such factors may be desirable (e.g., preservation of communities of interest) or not (e.g., partisan gerrymandering).

14. Ensemble analysis does have limitations, and here are some important points to keep in mind:

- **None of the plans in a computer-generated ensemble are intended for adoption.** Redistricting is fundamentally a human endeavor, and there are many important considerations that are difficult or impossible to fully incorporate into a computer-generated ensemble. The ensembles that I will discuss here are intended **only** to provide context to which the 2022 Assembly plan may be compared with regard to specific quantitative measures.

- The goal of ensemble analysis is **not** to identify a single "best" value for any measure (e.g., the number of districts containing a single incumbent, as in the present analysis), but rather to identify a **range** of values that would be reasonably likely for plans drawn without taking any pertinent information (e.g., addresses of incumbent members) into account. This analysis only raises concerns when a proposed plan is an **extreme outlier** relative to the range of values seen in an ensemble.
- Because it is generally not possible to incorporate into an ensemble all considerations that may be taken into account when drawing maps, plans that appear to be extreme outliers compared to an ensemble may in fact have perfectly reasonable explanations for their deviation from the ensemble. In such cases, more information about the design criteria for a plan may be required in order to evaluate the plan on its merits.

DATA SOURCES

15. My analysis is based on data from the following sources:

- ESRI shapefiles for New York State's 2020 Census blocks and Voter Tabulation Districts (VTDs) were downloaded from the Redistricting Data Hub at https://redistrictingdatahub.org/.
- Adjusted population data was downloaded from the New York Legislative Task Force on Demographic Research and Reappointment at https://latfor.state.ny.us/.
- Addresses of incumbent New York State Assembly members were provided by counsel.[1]
- GEOID20 identifiers for Census blocks containing incumbent addresses were obtained via the Census geocoding tool at https://geocoding.geo.census.gov.

[1] Counsel was able to confirm 141 home addresses of incumbent members; for the remaining 9 incumbent members, office addresses were used as a proxy.

METHODOLOGY: OVERVIEW

16. I used two distinct approaches to analyze the likelihood that the 2022 Assembly plan was drawn to accommodate incumbent residences:

17. (1) (Qualitative[2]) I generated three different ensembles of 50,000 district plans each for the New York State Assembly, using a variety of criteria which I will describe more fully below. For each plan in these ensembles, I computed the numbers of districts containing 0, 1, 2, or 3 of the incumbent addresses provided by counsel. Comparing statistics from these ensembles is intended primarily to show how the incorporation of various district plan design criteria might affect the expected outcomes, and how the 2022 Assembly plan compares to the ensembles regarding these criteria as well as the incumbent district counts.

18. (2) (Quantitative [3]) As mentioned above, it is impossible in practice to build an ensemble that incorporates all the factors that map drawers might reasonably take into consideration when drawing a plan. Furthermore, New York's constitutional criteria for district plans are somewhat vague, particularly the requirement that

> *"The commission shall consider the maintenance of cores of existing districts, of pre-existing political subdivisions, including counties, cities, and towns, and of communities of interest,"*

which provides no guidance as to the relative importance of these criteria or how stringently they must be applied in practice.

[2] While this analysis will produce quantitative results, I am describing it as "qualitative" due to the limitations of ensemble analysis described above, some of which will be apparent in the variety of results obtained from different ensembles of district plans constructed with different critera.

[3] I am describing this analysis as "quantitative" because it addresses the primary question more directly and with more statistical rigor than the analysis based on ensembles of district plans.

19. In order to address this issue, I took an alternate approach that only considers the plan that was actually drawn. Instead of an ensemble of district plans, I generated an ensemble of 100,000 sets of "theoretical" incumbent addresses. Each set of addresses was created by randomly selecting one Census block from each district in the 2012 Assembly plan. In order for this process to approximate the random selection of one adult from each 2012 district to represent the "incumbent" from that district, the probability of randomly selecting a particular block was weighted proportionally to the (adjusted) Voting Age Population of that block.[4]

20. Next, for each set of theoretical incumbent addresses constructed in this way, I computed the numbers of districts in the 2022 Assembly plan containing 0, 1, 2, or 3 of the addresses in that set, and I compared these statistics for the ensemble to those for the actual incumbent addresses. If the actual incumbent addresses produce a result that is an extreme outlier relative to the ensemble, this would strongly suggest that the 2012 Assembly plan was drawn in part to accommodate incumbent residences, regardless of what additional considerations may have informed the drawing of the plan.

21. A typical conclusion from this analysis might be something like, "The actual incumbent addresses produce more districts containing a single incumbent than X% of the sets of incumbent addresses in the ensemble." This percentage is approximately equal to the likelihood of this outcome occurring by chance if the plan was **not** drawn to accommodate incumbent residences. If this percentage is very small (say, less than 1%), it strongly suggests that the plan **was** drawn to accommodate incumbent residences.[5]

[4] To visualize what this weighting means, imagine putting one ball into a jar for each adult in the district, with each ball labeled with the Census block where that adult lives, and then randomly selecting one ball from the jar to choose a Census block.

[5] One must be careful with statements about conditional probability: The probability of an outcome occurring in the absence of deliberate intent is generally **not** the same as the probability that there was no deliberate intent given that

METHODOLOGY: DETAILS OF DISTRICT PLAN ENSEMBLE GENERATION

22. As described above, the main idea of ensemble analysis for redistricting is to create a large collection of randomly generated district plans, referred to as an "ensemble" of plans. Measures of interest are then computed for each plan in the ensemble, thereby creating a statistical range of possible outcomes for each measure, to which any proposed plan may be compared. If a proposed plan appears to be an extreme outlier compared to the ensemble, this may suggest that factors not included in the ensemble design may have played an important role in the plan's construction.

23. In order to keep computations manageable, all district plans in my ensembles were constructed from whole Voter Tabulation Districts (VTDs). For reference, data from the 2020 Census divides the state of New York into 288,819 Census blocks and 14,191 VTDs. Of the 14,191 VTDs, only 75 were not contained entirely within a single district in the 2012 Assembly plan, although 746 are split between multiple districts in the 2022 Assembly plan.

24. In order to generate my ensembles, I used the Recombination ("ReCom") method developed by the MGGG Redistricting Lab in 2018.[6] For this method, the VTD map is modeled by a mathematical object called a **dual graph**, where each VTD is represented by a point called a **vertex**, and two vertices are connected by an **edge** if the VTDs that they represent share a

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the outcome occurred. Because of this asymmetry, it is generally not possible to accurately compute a quantitative probability that there was, in fact, deliberate intent. This is a well-known issue in statistical analysis, and the standard approach is exactly that taken here, namely, to estimate the probability of the outcome under the assumption of the "null hypothesis." A result is often considered "statistically significant" if this probability is less than 5%, meaning that it would occur by chance only 1 time out of 20 if the null hypothesis were true. The smaller this probability is, the more significant the result is considered to be.

[6] Details and Python source code are available at https://github.com/mggg/GerryChain.

geographic boundary of positive length. A map of New York's 2020 VTDs and its dual graph are shown in Figure 1.

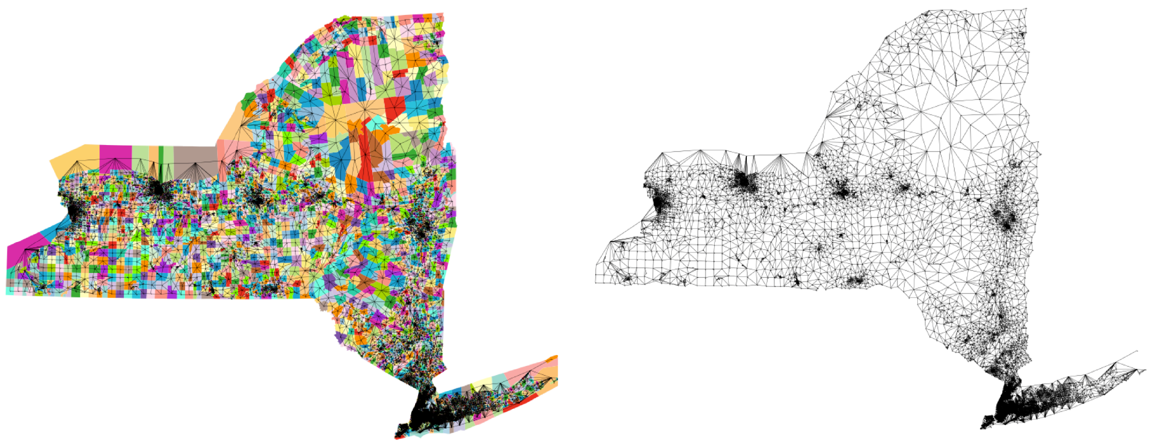

Figure 1: New York 2020 VTD map and dual graph

25. A district plan is then represented by a partition of the dual graph into connected subgraphs, one for each district. A partition is **valid** if it represents a legally valid district plan; at a minimum, the districts in the plan should be contiguous and have (approximately) equal population.

26. An ensemble starts with one valid district plan, called the "seed plan." The ensemble is then constructed by a mathematical process called a **Markov chain**, in which each new plan is created by applying a random process to modify the previous plan in some way. For the ReCom method used to build our ensembles, this random process works as follows: At each step, the algorithm randomly selects a pair of adjacent districts and merges the two subgraphs corresponding to these districts into a single graph. Next, it generates a **spanning tree** for the

merged graph---i.e., a subgraph consisting of all the graph's vertices and a subset of its edges, with the property that this subgraph is contiguous and has no closed loops---chosen randomly from the set of all spanning trees of the merged graph. Finally, it looks for an edge to cut in order to create two new districts that each satisfy the population constraint. (District contiguity is automatic with this method.) This process is illustrated in Figure 2.[7]

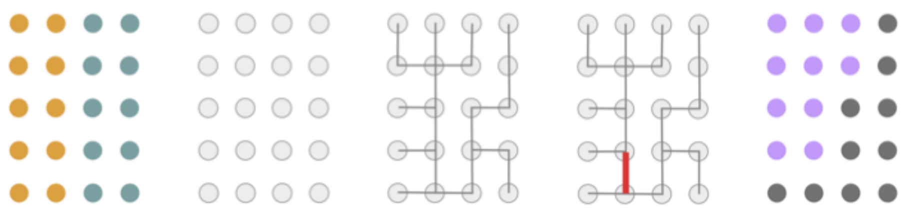

Figure 2: One step in a ReCom chain

27. Part of the appeal of the Markov chain approach is a well-developed theory and a long history of applications of Markov chain sampling methods.[8] In particular, a sufficiently long Markov chain is theoretically guaranteed to produce an ensemble that accurately represents a specific probability distribution on the entire space of valid district plans. In general, this probability distribution is difficult to determine explicitly, but for the ReCom method there is good heuristic and experimental evidence indicating that the probability of any particular plan appearing in the ensemble is closely related to a natural discrete measure for district

[7] Image taken from Daryl DeFord, Moon Duchin, and Justin Solomon, *Recombination: A family of Markov chains for redistricting*, arXiv e-prints (2019), arXiv:1911.05725; used with permission.

[8] See, e.g., Persi Diaconis, *The Markov chain Monte Carlo revolution*, Bull. Amer. Math. Soc. (N.S.) **46** (2009), no. 2, 179–205.

compactness. In practice, this means that this method is strongly biased towards plans with relatively compact districts and has no other detectable bias towards any particular type of plan.

28. The question of how long is "sufficiently long" for a Markov chain to produce a representative sample of plans is usually answered heuristically, by running chains until statistics of interest appear to stabilize in a way that is not dependent upon the choice of seed plan. This stabilization is referred to as "convergence" of the statistics being measured.

29. A variation of this method may be employed to incorporate information about geographic units (e.g., counties and/or municipalities) and attempt to minimize the number of such units that are split across multiple districts in each plan. In this version, the random choice of edges to form the spanning tree is more heavily weighted towards intra-unit edges, so that the resulting spanning tree contains relatively few edges connecting VTDs in different units. When the tree is cut, it is less likely to produce districts that split units. This version is referred to as "region-aware ReCom."

30. For my analysis, all districts in each ensemble were constrained to have (adjusted) total population between 95% and 105% of the ideal district population of 134,626.[9] I constructed three separate ensembles of district plans, each using the same seed plan and one of three region-aware constraints.

31. To construct the seed plan, I started with the 2012 Assembly plan. District populations for this plan are outside the acceptable range, so I first ran a short ReCom chain with a constraint to reduce the population deviation at each step, until a plan was produced with all district populations in the acceptable range. This plan was then used as the seed plan.

[9] For the 2022 Assembly plan, district populations range from a low of 127,923 (95.02% of the ideal population) to a high of 141,348.(104.99% of the ideal population).

32. The three different region-aware constraints are as follows:

- No region-aware constraints;
- County and municipality-aware constraints, with higher priority placed on minimizing municipal splits and secondary priority on minimizing county splits;
- 2012 Assembly district-aware constraints, as a means of minimizing "core population movement," i.e., the number of persons moved from one 2012 district into a different 2022 district.

33. I did not attempt to impose all constraints simultaneously, because the more constraints that are built into an ensemble, the more difficult it is for the Markov chain to make significant changes to districts at each step and thereby to produce a wide variety of district plans. Each Markov chain was run for 500,000 steps, and since each step makes changes to only 2 of the 150 districts, I collected data for the current plan at every 10th step of the Markov chain, for a total of 50,000 plans in each ensemble. For each of these plans, I collected the following data:

- the numbers of "counties split" and "munis split," which count the numbers of counties and municipalities split across multiple districts, respectively;[10]
- the numbers of "total county splits" and "total muni splits," which count the numbers of times counties and municipalities are split, respectively. (So, e.g., if a county is divided between three districts, this counts as one split towards the "counties split" measure and two splits towards the "total county splits" measure);
- the total core population movement as a percentage of the (adjusted) total population;

[10] For purposes of these computations, the municipality to which each Census block belongs was determined from the value in the COUSUB field for that block in the 2020 Census block shapefile.

- the numbers of districts containing 0, 1, 2, or 3 incumbent addresses.

METHODOLOGY: DETAILS OF INCUMBENT ENSEMBLE GENERATION

34. I generated an ensemble of 100,000 sets of locations for "theoretical" incumbent addresses, as follows. In order to model the idea of selecting one adult uniformly at random from each 2012 Assembly district to represent the "incumbent" from that district, I selected a Census block from each 2012 district at random, with the probability of randomly selecting a particular block weighted proportionally to the (adjusted) Voting Age Population of that block. This process was repeated for each 2012 Assembly district to create a set of "incumbent" addresses, and then the entire process was repeated 100,000 times to create an ensemble of theoretical incumbent addresses.

35. For each set of theoretical incumbent addresses, I collected the following data:

- A list of the Census blocks for the "incumbents;" this data was used to compute how often each Census block was selected over the course of the entire ensemble and to verify that each block occurred with frequency approximately proportional to its (adjusted) Voting Age Population.
- the numbers of districts in the 2022 Assembly plan containing 0, 1, 2, or 3 of the addresses in that set.

ANALYSIS: QUANTITATIVE FINDINGS

The 2012 and 2022 Assembly Plans - Baseline:

36. Table 1 shows some baseline statistics for both the 2012 and 2022 Assembly plans regarding county and municipal splits, as well as core population movement for the 2022 Assembly plan relative to the 2012 Assembly plan.[11]

Table 1: Baseline Statistics for Assembly Plans

	2012 Assembly Plan	2022 Assembly Plan
Counties split	39	44
Munis split	38	45
Total county splits	166	179
Total muni splits	129	137
Core population movement	N/A	12.87%

37. According to the incumbent addresses provided by counsel, there were 5 incumbents (out of 150 total) whose district numbers changed from the 2012 Assembly plan to the 2022 Assembly plan; the old and new district numbers for these incumbents are shown in Table 2.

[11] With the official district numberings in the Assembly plans, the core population movement---i.e., the percentage of the population whose district number changed from the 2012 Assembly plan to the 2022 Assembly plan---is actually 13.76%. However, if numberings of Districts 121 and 122 are exchanged in the 2022 Assembly plan, this figure drops to 12.87%, and this slightly altered district numbering minimizes the core population movement over all possible district numberings,. This minimum value is the statistic that I computed for plans in the district ensembles, so it is the appropriate value for comparing the 2022 Assembly plan to the ensembles.

Table 2: Incumbent Districts That Changed in 2022 Assembly Plan

2012 Assembly District	2022 Assembly District
65	61
110	111
101	122
121	101
122	121

38. Observe that the incumbents in 2012 Districts 121, 122, and 101 simply rotated their district numbers in the 2022 Assembly plan, while each remaining as the sole incumbent in their district in the new plan.[12] Thus the 2022 Assembly plan contains:

- 2 districts with 0 incumbents (Districts 65 and 110);
- 2 districts with 2 incumbents (Districts 61 and 111);
- 146 districts with 1 incumbent.[13]

Results from district plan ensembles:

39. As described above, I constructed three ensembles of 50,000 district plans each, with three different levels of region-aware constraints:

- No region-aware constraints ("Unconstrained");
- County and municipality-aware constraints ("County/muni-constrained");
- 2012 Assembly district-aware constraints, as a means of minimizing core population movement ("Core pop movement-constrained").

[12] Additionally, if the optimal district numbering described in the previous footnote had been used, the incumbent in 2012 District 122 would have remained in the same district in the 2022 Assembly plan.

[13] Due to the uncertainty mentioned in Footnote 1 on p. 5 regarding 9 of the 150 incumbent addresses, it is possible that these numbers are slightly inaccurate. I will address the implications of this uncertainty in my analysis of the results below.

40. In order to illustrate how these various constraints played out in the ensemble generation algorithm, the following tables and histograms illustrate the observed ranges for county and municipal splits and core population movement for these ensembles. Values for the 2012 and 2022 Assembly plans are included where appropriate for comparison.

Table 3: Ensemble ranges for counties split

Counties split	Mean	Middle 50%	Middle 99%
Unconstrained ensemble	58.6	58 - 60	55 - 61
County/muni-constrained ensemble	34.9	33 - 36	31 - 44
Core pop movement-constrained ensemble	42.3	42 - 42	41 - 51

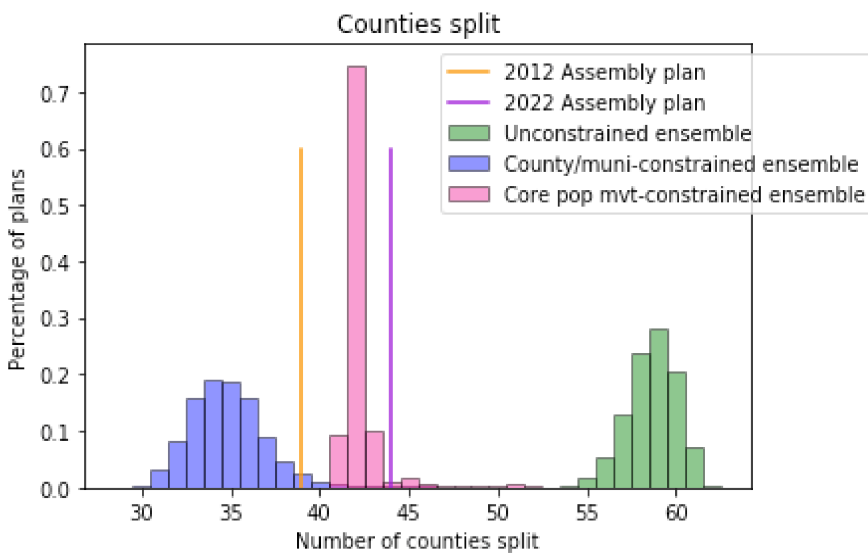

Figure 3: Ensemble histograms for counties split

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Table 4: Ensemble ranges for municipalities split

Municipalities split	Mean	Middle 50%	Middle 99%
Unconstrained ensemble	225.9	219 - 232	201 - 252
County/muni-constrained ensemble	36.0	34 - 38	29 - 47
Core pop movement-constrained ensemble	44.8	41 - 46	37 - 105

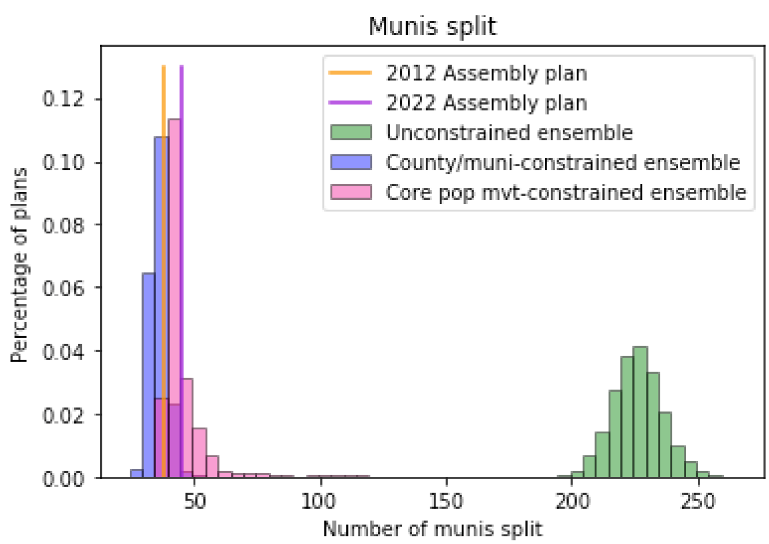

Figure 4: Ensemble histograms for municipalities split

Table 5: Ensemble ranges for total county splits

Total county splits	Mean	Middle 50%	Middle 99%
Unconstrained ensemble	252.9	249 - 256	239 - 267
County/muni-constrained ensemble	140.8	138 - 143	134 - 163
Core pop movement-constrained ensemble	176.9	175 - 178	173 - 192

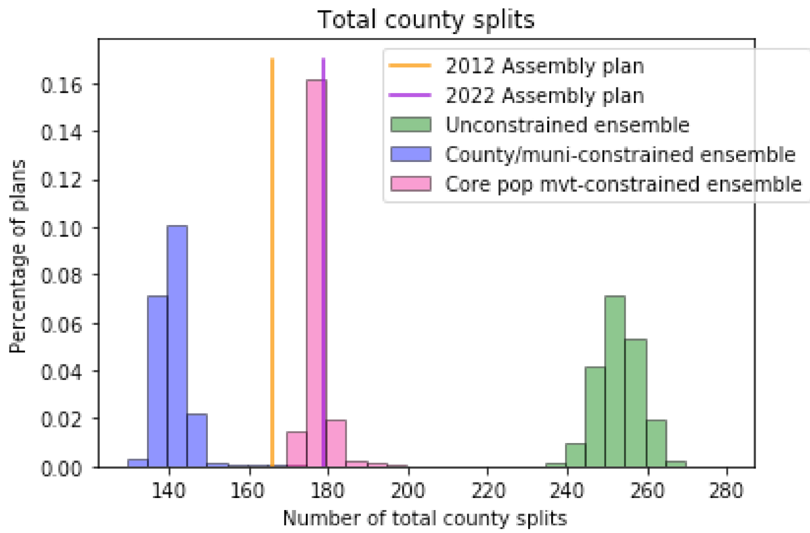

Figure 5: Ensemble histograms for total county splits

Table 6: Ensemble ranges for total municipality splits

Total municipality splits	Mean	Middle 50%	Middle 99%
Unconstrained ensemble	386.0	378 - 394	357 - 418
County/muni-constrained ensemble	105.5	103 - 108	97 - 121
Core pop movement-constrained ensemble	126.5	121 - 128	116 - 198

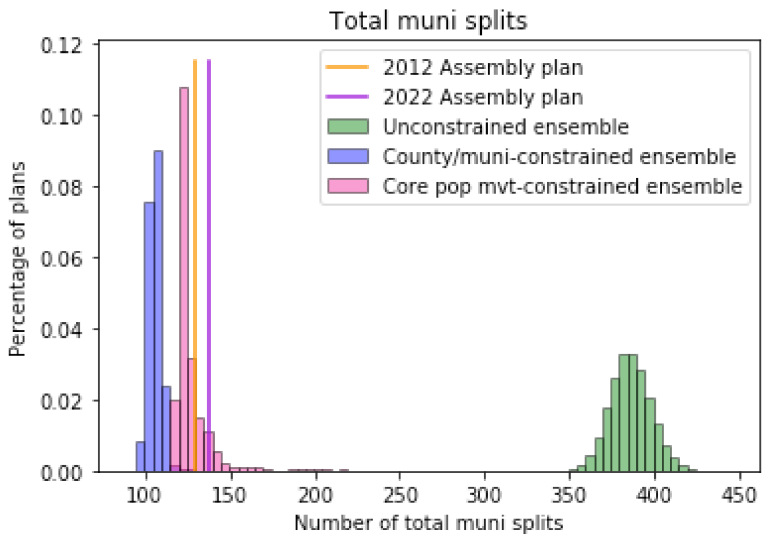

Figure 6: Ensemble histograms for total municipal splits

Table 7: Ensemble ranges for core population movement

Core population movement	Mean	Middle 50%	Middle 99%
Unconstrained ensemble	49.26%	48.53% - 50.03%	46.51% - 52.40%
County/muni-constrained ensemble	45.18%	44.41% - 45.96%	42.46% - 47.88%
Core pop movement-constrained ensemble	4.98%	3.03% - 4.47%	2.41% - 25.67%[14]

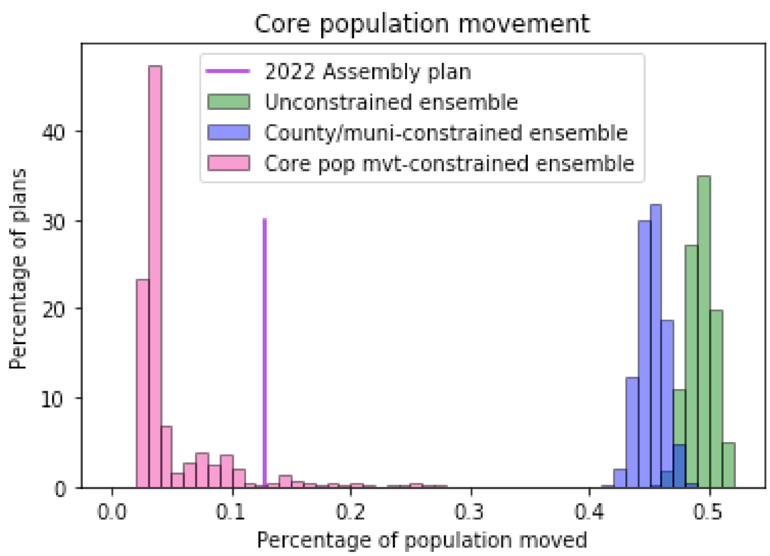

Figure 7: Ensemble histograms for core population movement

41. Some observations regarding these statistics:

- Relative to the unconstrained ensemble, both the county/muni-constrained ensemble and the core pop movement-constrained ensemble were much more effective at constraining county and municipal splits. As might be expected, the county/muni-constrained ensemble was the most effective in this regard, although the core pop movement-

[14] This statistic converged more slowly for the core population movement-constrained ensemble than for the other two ensembles, and the unusual appearance of the mean outside the middle 50% and the high upper range for the middle 99% are artifacts of this relatively slow convergence.

constrained ensemble still achieved values fairly similar to those in the 2012 and 2022 Assembly plans.

- By contrast, the county/muni-constrained ensemble was only slightly more effective than the unconstrained ensemble at constraining core population movement, and core population movement for both of these ensembles was dramatically higher than the value for the 2022 Assembly plan. The core pop movement-constrained ensemble, on the other hand, was extremely effective at reducing core population movement, with a middle 50% range of 3.03% - 4.47% core population movement, compared to the actual value of 12.87% for the 2022 Assembly plan.

42. None of this is particularly surprising: There are an enormous variety of ways to draw plans that keep county and municipal splits to a minimum, most of which may bear little resemblance to the 2012 Assembly plan. However, attempting to minimize core population movement necessitates making minimal changes to the previous districts---and since those districts already contained relatively few county and municipal splits, it is to be expected that the new districts would fare reasonably well by this measure.

43. Now we come to the key statistics: the numbers of districts containing 0, 1, 2, or 3 incumbent addresses. These are shown in the tables and histograms below.

Table 8: Ensemble ranges for number of districts with 0 incumbents

Districts with 0 incumbents	Mean	Middle 50%	Middle 99%
Unconstrained ensemble	40.1	38 - 42	32 - 49
County/muni-constrained ensemble	36.0	34 - 38	28 - 44
Core pop movement-constrained ensemble	6.6	4 - 7	2 - 28

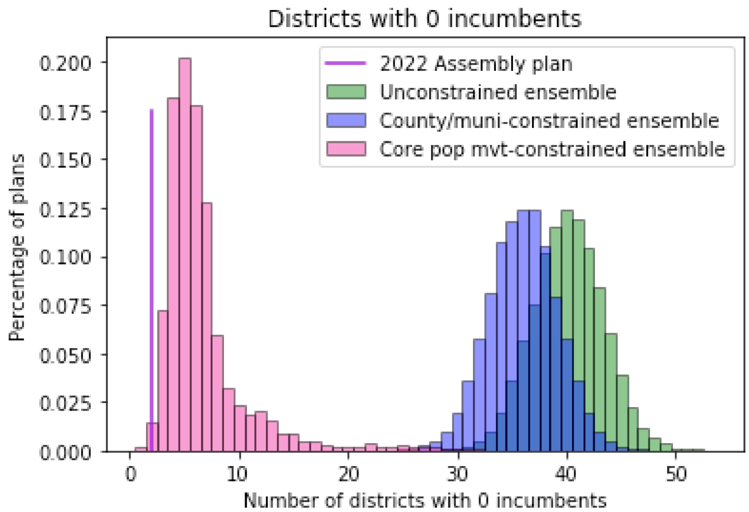

Figure 8: Ensemble histograms for number of districts with 0 incumbents

Table 9: Ensemble ranges for number of districts with 1 incumbent

Districts with 1 incumbent	Mean	Middle 50%	Middle 99%
Unconstrained ensemble	74.1	70 - 78	59 - 89
County/muni-constrained ensemble	80.7	77 - 84	67 - 96
Core pop movement-constrained ensemble	136.8	136 - 142	296 - 146

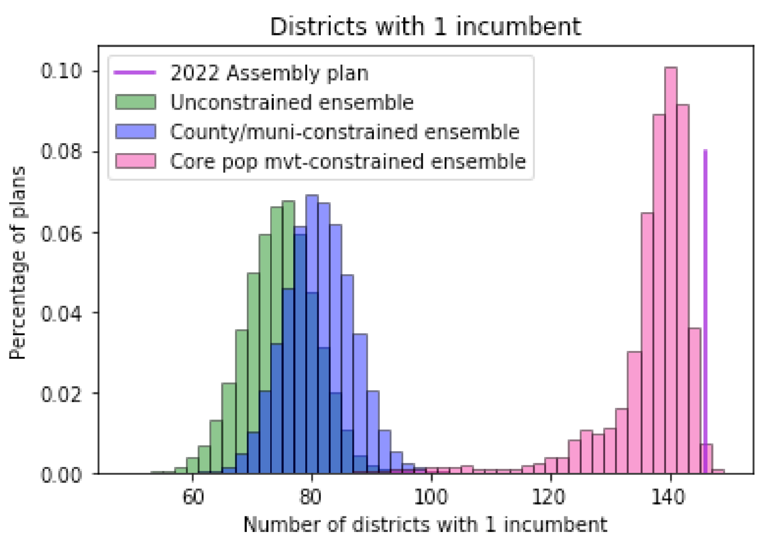

Figure 9: Ensemble histograms for number of districts with 1 incumbent

Table 10: Ensemble ranges for number of districts with 2 incumbents

Districts with 2 incumbents	Mean	Middle 50%	Middle 99%
Unconstrained ensemble	31.4	29 - 34	22 - 41
County/muni-constrained ensemble	30.8	29 - 33	23 - 39
Core pop movement-constrained ensemble	6.5	4 - 7	2 - 26

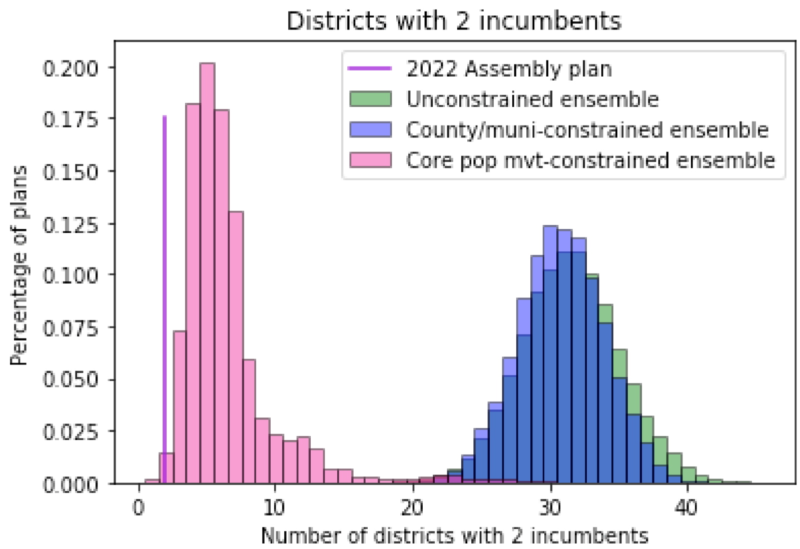

Figure 10: Ensemble histograms for number of districts with 2 incumbents

Table 11: Ensemble ranges for number of districts with 3 incumbents

Districts with 3 incumbents	Mean	Middle 50%	Middle 99%
Unconstrained ensemble	4.1	3 - 5	0 - 9
County/muni-constrained ensemble	2.5	1- 3	0 - 7
Core pop movement-constrained ensemble	0.0	0 - 0	0 - 2

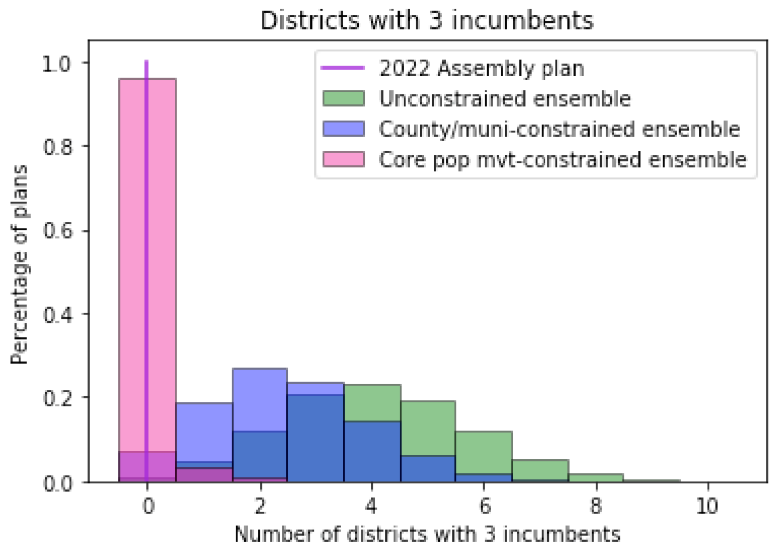

Figure 11: Ensemble histograms for number of districts with 3 incumbents

44. With 2 districts with 0 incumbents, 146 districts with 1 incumbent, 2 districts with 2 incumbents, and 0 districts with 3 incumbents, the 2022 Assembly plan is a **very** extreme outlier with respect to the unconstrained and county/muni-constrained ensembles, and a somewhat less extreme outlier with respect to the core pop movement-constrained ensemble. The most extreme values (i.e., the smallest numbers of districts with 0, 2, and 3 incumbents and largest number of districts with 1 incumbent) observed for **any** of the 50,000 plans in each of these ensembles are shown in Table 12.

Table 12: Most extreme values observed for numbers of districts with 0, 1, 2, or 3 incumbents

	0	1	2	3
Unconstrained ensemble	27	96	18	0
County/muni-constrained ensemble	24	103	18	0
Core pop movement-constrained ensemble	1	148	1	0

45. None of the plans in the unconstrained or county/muni-constrained ensembles have **any** values remotely as extreme as those for the 2022 Assembly plan. For the core pop movement-constrained ensemble, only 1.6% of the plans in the ensemble have 2 or fewer districts with 0 incumbents, 146 or more districts with 1 incumbent, and 2 or fewer districts with 2 incumbents. So even for this ensemble, the 2022 Assembly plan is a fairly extreme outlier.

46. Additionally, it is intuitively clear that the number of incumbents whose district number changes between the 2012 Assembly plan and any potential new plan should be strongly correlated with the proportion of the total population whose district number changes – i.e., with the core population movement of the new plan. When we look at the combination of these two measures, we see that among the plans in the core pop movement-constrained ensemble whose incumbent statistics are at least as extreme as those of the 2022 Assembly plan, the maximum core population movement observed is only 6.23%, whereas the core population movement in the 2022 Assembly plan is 12.87%. Conversely, among the plans in this ensemble with core population movement of 12.87% or greater, the maximum number of districts with 1 incumbent is 130, whereas the 2022 Assembly plan has 146 such districts.

47. These relationships are illustrated graphically in Figure 12, which shows a scatterplot of the relationship between core population movement and the number of districts containing 1 incumbent for all 3 ensembles, with the 2022 Assembly plan shown for comparison. Here we can see that even in the core pop movement-constrained ensemble, the 2022 Assembly plan is a very extreme outlier with respect to the **combination** of core population movement and numbers of districts with 1 incumbent.

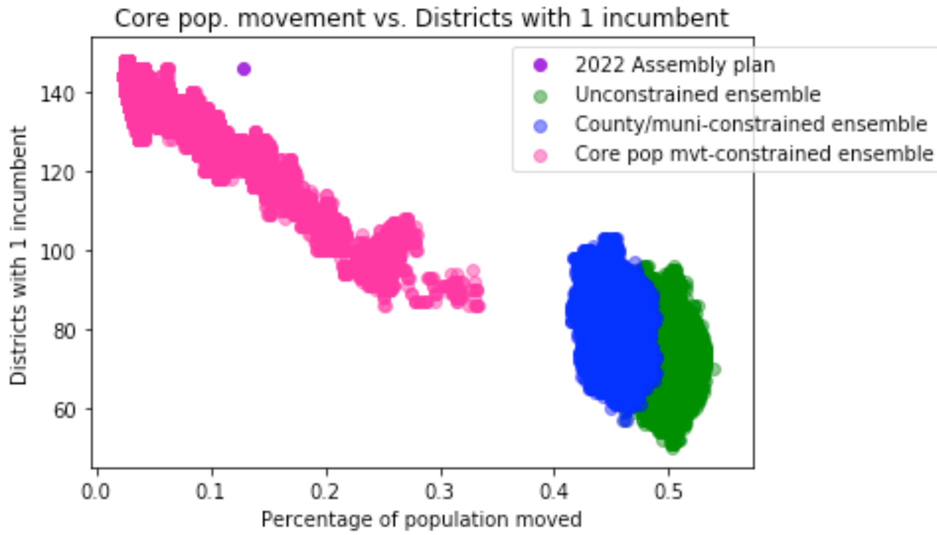

Figure 12: Ensemble scatterplot for core population movement vs. number of districts with 1 incumbent

48. **Conclusion:** By virtue of having the combination of 12.87% core population movement and 146 districts containing exactly 1 incumbent, the 2022 Assembly plan appears to be an extreme outlier compared to all district plans in all three ensembles under consideration. This analysis strongly suggests that some consideration impacting the number of single-incumbent districts other than those used to generate these ensembles played a role in the design of the 2022 Assembly plan. While it is impossible to identify such considerations with absolute certainty, it seems very likely that the plan was deliberately designed to maximize the number of districts containing exactly 1 incumbent.

Results from incumbent ensemble:

49. As described above, I constructed an ensemble of 100,000 sets of locations for "theoretical" incumbent addresses; each set of addresses was constructed by randomly selecting

one Census block from each 2012 district at random, with the probability of randomly selecting a particular block weighted proportionally to the (adjusted) Voting Age Population of that block.

50. Unlike the Markov chain that was used to generate the district-based ensembles for the previous analysis, this process produces an ensemble that is **independently and identically distributed (i.i.d.).** This means that each set of addresses in the ensemble was selected by the same random process ("identically distributed"), and that the selected sets are not connected to each other in any way ("independent"). This differs from the Markov chain process, where each new district plan is created by making a random modification to the previous plan. For random samples with the i.i.d. property, there are well-developed, standard statistical techniques for estimating the reliability of the results; more details will be given blow.

51. Since each element of the ensemble is a collection of 150 Census blocks, the process of creating the ensemble involved choosing a random Census block 15,000,000 times; thus we might expect each of the 288,819 Census blocks to have been chosen repeatedly. Figure 13 shows a scatterplot with one point for each Census block; the horizontal axis represents the (adjusted) Voting Age Population of each block, while the vertical axis represents the number of times that block was randomly sampled during the construction of the ensemble.[15]

[15] The dataset for the (adjusted) Voting Age Population contains 41 Census blocks whose Voting Age Population is recorded as negative. The scatterplot confirms that these blocks were never selected for inclusion in the ensemble of addresses.

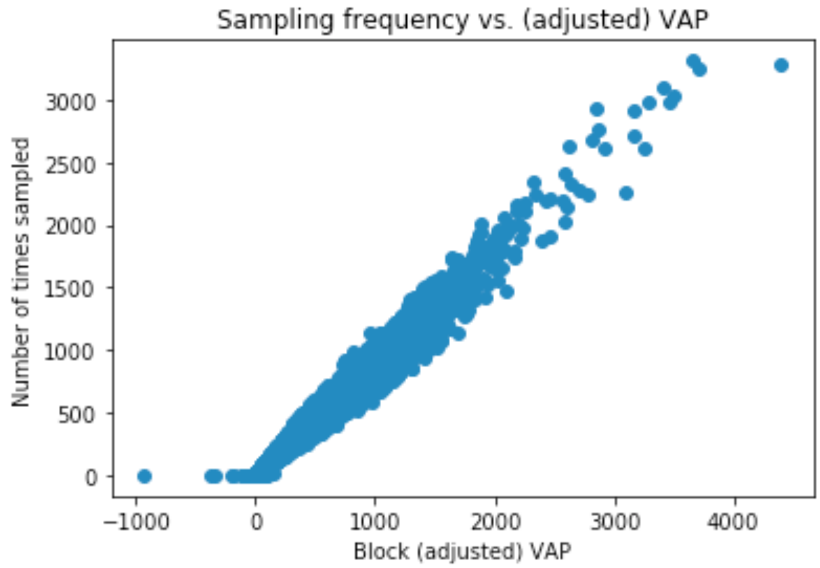

Figure 13: Incumbent ensemble scatterplot for Census block sampling frequency vs. (adjusted) VAP

52. The table and histograms below demonstrate the frequency statistics for the numbers of districts in the 2022 Assembly plan containing 0, 1, 2, or 3 of the addresses in each set of "theoretical" incumbent addresses in the ensemble. The values for the actual incumbent addresses are included in the histograms for comparison.

Table 13: Incumbent ensemble statistics

	Mean	Standard Deviation	Middle 50%	Middle 99%
Districts with 0 incumbents	14.99	2.83	13 - 17	8 - 20
Districts with 1 incumbent	120.62	5.66	117 - 124	106 - 130
Districts with 2 incumbents	13.79	2.83	12 - 16	7 - 19
Districts with 3 incumbents	0.58	0.0	0 - 1	0 - 2

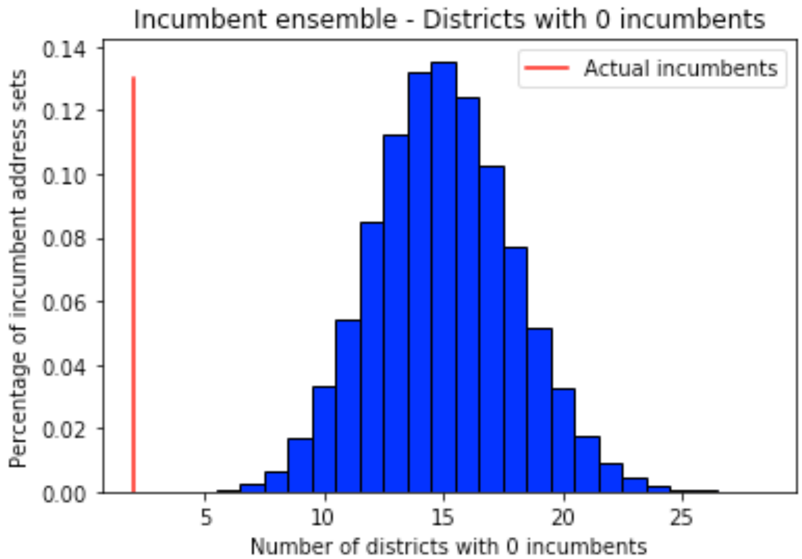

Figure 14: Incumbent ensemble histogram for number of districts with 0 incumbents

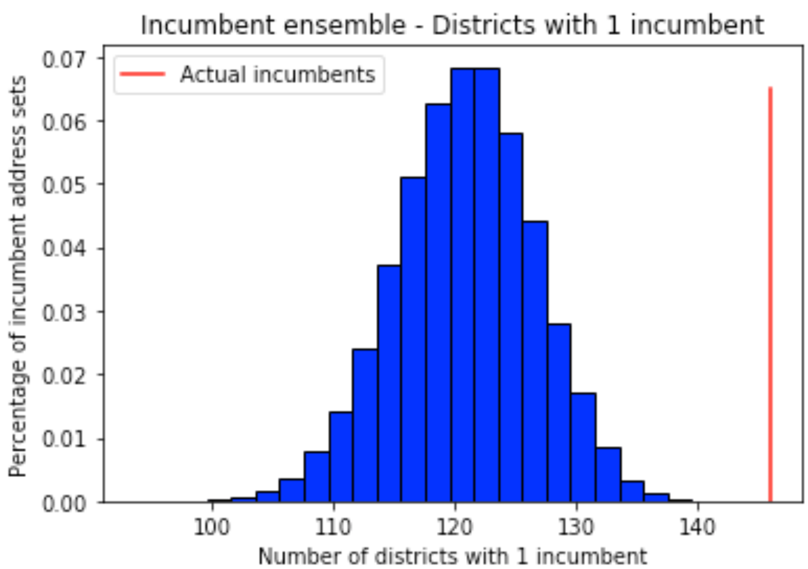

Figure 15: Incumbent ensemble histogram for number of districts with 1 incumbent

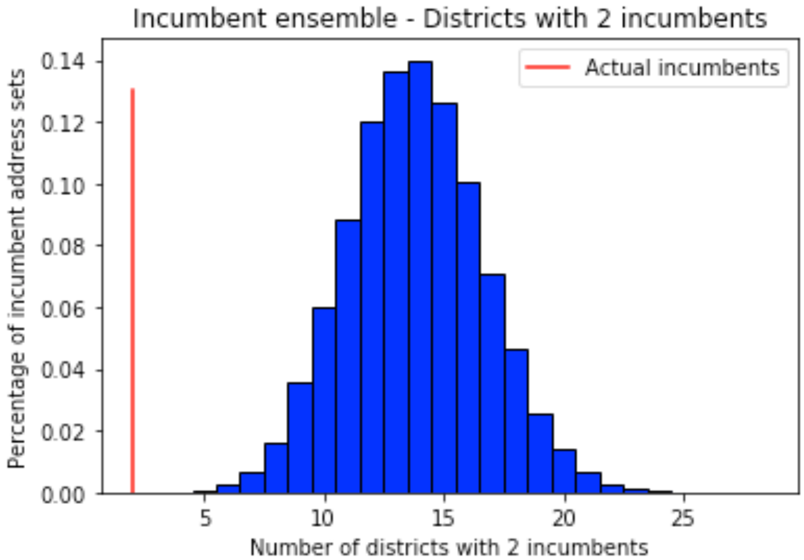

Figure 16: Incumbent ensemble histogram for number of districts with 2 incumbents

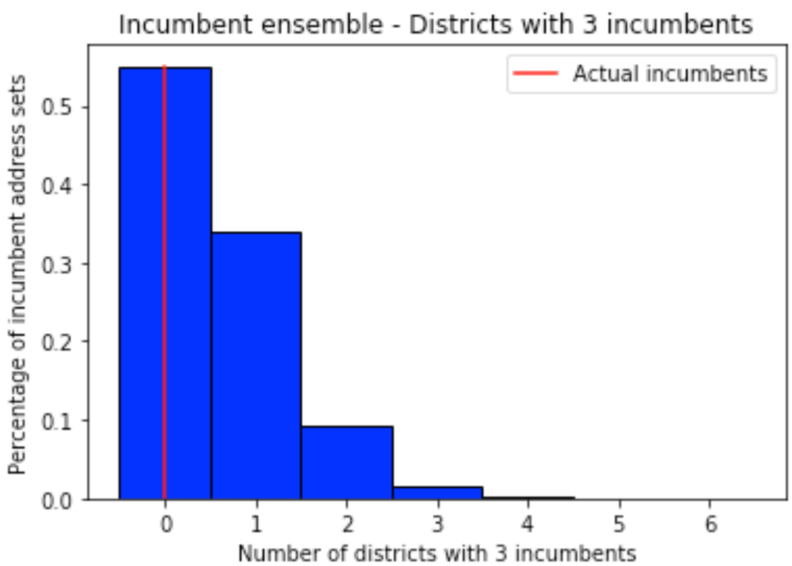

Figure 17: Incumbent ensemble histogram for number of districts with 3 incumbents

53. The shapes of the histograms in Figures 14, 15, and 16 indicate that this data is approximately **normally distributed**. For such data, there is a standard formula for computing a **confidence interval**, which describes how likely it is that the mean value of each statistic computed from the ensemble data is accurate. The input required for this formula is:

- the sample size (in this case, 100,000),
- the sample mean (shown in Table 13 for numbers of districts with 0, 1, or 2 incumbents),
- the standard deviation (shown in Table 13 for numbers of districts with 0, 1, or 2 incumbents),
- the "confidence level," i.e., the desired probability that the true mean value is contained within the computed confidence interval.

54. Using a confidence level of 99.999%, confidence intervals for the mean numbers of districts with 0, 1, and 2 incumbents are shown in Table 14.[16] As this computation shows, the large size of the ensemble results in a very high degree of confidence in the results.

Table 14: Confidence intervals for mean numbers of districts with 0, 1, or 2 incumbents in incumbent ensemble

	Mean	99.999% confidence interval
Districts with 0 incumbents	14.99	14.95 - 15.03
Districts with 1 incumbent	120.62	120.54 - 120.70
Districts with 2 incumbents	13.79	13.75 - 13.83

55. Meanwhile, the values for the actual incumbent addresses---2 districts with 0 incumbents, 146 districts with 1 incumbent, and 2 districts with 2 incumbents---are 4.59 standard deviations below, 4.48 standard deviations above, and 4.17 standard deviations below the

[16] These confidence intervals were computed using the Confidence Interval Calculator at https://www.calculator.net/confidence-interval-calculator.html.

respective mean values for these statistics. The probability of such a result occurring by chance if the 2022 Assembly plan was **not** drawn to accommodate incumbent addresses is less than 0.01%. In fact, these values are so rare that they **never** occurred in the entire ensemble of 100,000 sets of addresses; the most extreme values observed for any set of "incumbent" addresses in the ensemble were:

- 4 districts with 0 incumbents;
- 142 districts with 1 incumbent;
- 3 districts with 2 incumbents.

Furthermore, each of these extreme values occurred only 2 or 3 times in the entire ensemble of 100,000 sets of addresses.

56. As noted in Footnote 1 on p. 5, proxy addresses were used for 9 of the 150 actual incumbent addresses. It is possible some of these incumbents are actually located in other 2022 Assembly districts than I have assumed based on these addresses, and that the actual number of 2022 Assembly districts with 1 incumbent is less than 146. In the worst-case scenario, in which all 9 of these incumbents were located in different districts than these addresses would indicate, the actual number of 2022 Assembly districts with 1 incumbent could theoretically be as low as 137.

57. Table 15 shows, for each possible number of actual districts with 1 incumbent between 137 and 146, the number of standard deviations above the mean that this number represents and the corresponding likelihood that this outcome could have occurred by chance if the plan were not drawn to accommodate incumbent addresses.

Table 15: Probability of numbers of districts with 1 incumbent occurring by chance

	Standard deviations above the mean	Probability
137 districts	2.89	0.19%
138 districts	3.07	0.11%
139 districts	3.25	0.06%
140 districts	3.42	0.03%
141 districts	3.60	0.02%
142 districts	3.78	0.01%
143 districts	3.95	< 0.01%
144 districts	4.13	< 0.01%
145 districts	4.31	< 0.01%
146 districts	4.48	< 0.01%

58. Even under the worst-case scenario of 137 districts with 1 incumbent, the probability of this outcome occurring by chance if the plan were not drawn to accommodate incumbent addresses is less than 1 in 500, and this probability drops rapidly as the number of districts with 1 incumbent increases. For instance, if the plan contained 142 districts with 1 incumbent, the probability of this outcome occurring by chance would be approximately 0.01%, or about 1 in 10,000.

59. **Conclusion:** For the 2022 Assembly district plan, the actual set of incumbent addresses is a very extreme outlier compared to a large ensemble of randomly selected "theoretical" incumbent addresses from each 2012 Assembly district. Notwithstanding the asymmetry of conditional probability (cf. Footnote on p. 7), it is extremely unlikely that this plan was drawn without consideration of the incumbent addresses and a deliberate intention to maximize the number of districts containing exactly 1 incumbent.

SUMMARY OF ANALYSIS

60. In order to address the question of whether the 2022 Assembly plan was deliberately designed to accommodate incumbent addresses, I performed two independent and complementary analyses:

- I constructed three ensembles of 50,000 valid district plans each for New York State Assembly districts, each with a different set of region-aware constraints typically considered in redistricting. For each plan in the ensembles, I used the addresses of the current incumbent Assembly members to compute the numbers of districts that would contain 0, 1, 2, or 3 incumbents in that plan. I then compared the statistical range of outcomes for these measures to the values for the 2022 Assembly plan. The values for the 2022 Assembly plan are a very extreme outlier compared to the statistical ranges of all three ensembles, particularly among plans with similar core population movement, which correlates strongly with the number of districts with a single incumbent across the ensemble.
- I constructed an ensemble of 100,000 sets of "theoretical" incumbent addresses by randomly selecting one Census block from each 2012 district for each set to represent the "incumbent" addresses. For each set of addresses in this ensemble, I computed the numbers of districts that would contain 0, 1, 2, or 3 "incumbents" in the 2022 Assembly plan. I then compared the statistical range of outcomes for these measures to the values for actual incumbent addresses. The actual addresses were a very extreme outlier---more extreme, in fact, than **any** of the sets of addresses in the ensemble. The probability of this outcome occurring by chance if the 2022 Assembly plan had **not** been deliberately

designed to accommodate incumbent addresses is less than 0.01%. Even allowing for possible inaccuracies in the 9 incumbent addresses for which proxy addresses were used, this probability estimate remains accurate even if the actual number of districts with 1 incumbent is as low as 142. Even in the worst-case scenario in which all 9 proxy addresses are located in the wrong 2022 Assembly district, the probability of this outcome occurring by chance remains less than 1 in 500.

61. Based on the results of these analyses, I consider it almost certain that the 2022 Assembly plan was deliberately designed in part to maximize the number of districts containing a single incumbent Assembly member.

Dated: Boulder, Colorado
July 28, 2022

Jeanne N. Clelland, Ph.D.

State of Colorado
County of Boulder

The foregoing instrument was acknowledged before me this 28 day of July, 2022, by Jeanne N Clelland.

Notary Public

08/28/2024
My Commission Expires

ZOE B SCOTT
Notary Public
State of Colorado
Notary ID # 20204030068
My Commission Expires 08-28-2024

CERTIFICATE OF CONFORMITY

STATE OF NEW YORK

COUNTY OF NEW YORK

The undersigned does hereby certify that he is an attorney-at-law duly admitted to practice in the State of New York, and is a resident of Brooklyn in the State of New York that he is a person duly qualified to make this certificate of conformity pursuant to Section 299-a of the Real Property Law of the State of New York; that he is fully acquainted with the laws of the State of New York pertaining to the acknowledgment or proof of deeds of real property to be recorded therein; that the foregoing acknowledgment by Dr. Jeanne Clelland named in the foregoing instrument taken before Zoe B. Scott, a notary public (or other officer) was taken in the manner prescribed by such laws of the State of Colorado, being the state in which it was taken; and that it duly conforms with such laws and is in all respects valid and effective in such state.

Dated: New York, New York
August 2, 2022

Peter A. Devlin

Sworn and subscribed to me
before this 2nd day of August 2022

Notary Public

TERESA P LAMBE
NOTARY PUBLIC, STATE OF NEW YORK
Registration No. 01LA5024673
Qualified in Kings County
Commission Expires March 14, 2022

JEANNE NIELSEN CLELLAND
Department of Mathematics, 395 UCB
University of Colorado
Boulder, CO 80309-0395
(303) 492-7083
e-mail: Jeanne.Clelland@colorado.edu
July 28, 2022

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) 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.

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

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

Peer-reviewed Book:

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

Preprints:

(34) J. Clelland. N. Bossenbroek, T. Heckmaster, A. Nelson, P. Rock, and J. VanAusdall, "Compactness statistics for spanning tree recombination," https://arxiv.org/abs/2103.02699.

(35) J.N. Clelland and P.J. Vassiliou, "Strings attached: New light on an old problem," https://arxiv.org/abs/1302.6672.

Reports:

(36) J. Clelland, "Response Report in Support of Governor Evers's Proposed District Plans," submitted to the Wisconsin Supreme Court, December 15, 2021. Available online at https://www.wicourts.gov/courts/supreme/origact/2021ap1450.htm.

(37) J. Clelland, "Expert Report in Support of Governor Evers's Proposed District Plans," submitted to the Wisconsin Supreme Court, December 30, 2021. Available online at https://www.wicourts.gov/courts/supreme/origact/2021ap1450.htm.

(38) J. Clelland, D. DeFord, B. Malskog, and Flavia Sancier-Barbosa, "Ensemble Analysis for 2021 State Legislative Redistricting in Colorado, Part 2: Comparison of Final Approved Plans to Ensembles" submitted to the Colorado Independent Legislative Redistricting Commission, October 21, 2021. Available online at https://coloradoincontext.wordpress.com/.

(39) J. Clelland, D. DeFord, B. Malskog, and Flavia Sancier-Barbosa, "Ensemble Analysis for 2021 Congressional Redistricting in Colorado, Part 2: Comparison of Final Approved Plan to Ensembles," submitted to the Colorado Independent Congressional Redistricting Commission, October 4, 2021. Available online at https://coloradoincontext.wordpress.com/.

(40) 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/.

(41) 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:

(42) 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/.

(43) 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/.

(44) 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:

(45) 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:

(46) 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.)

CONSULTING WORK:

- Ensemble analysis consultant to the Colorado Independent Legislative Redistricting Commission, August 2021 - October 2021
- Consulting expert for The Brennan Center For Justice regarding The Ohio Organizing Collaborative, et. al., vs. Ohio Redistricting Commission, et. al., October 2021
- Testifying expert for Governor Tony Evers regarding Johnson vs. Wisconsin Elections Commissions, November 2021 - January 2022

LECTURES AND PRESENTATIONS:

Invited conference talks:

(1) "Redistricting and gerrymandering: When is a district map "fair"?" Invited talk at 2nd Annual Conference in Mathematics and Politics, Institute for Mathematics and Democracy, May 2022

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

(3) "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

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

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

(6) "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

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

(8) "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

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

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

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

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

(13) "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

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

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

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

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

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

(19) "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

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

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

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

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

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

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

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

(27) "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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Invited seminar talks:

(45) "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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Invited colloquium talks:

(64) "Gerrymandering: What is it, how can we measure it, and what can we do about it?" Calvin University, February 2022

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

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

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

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

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

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

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

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

Invited talks for students:

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

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

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

(76) "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

(77) "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

(78) "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/presentations:

(79) "Gerrymandering: What is it, how can we measure it, and what can we do about it?" Duke Nashville/Duke Colorado Alumni Fireside chat, January 2022

(80) "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

(81) "Assessing Partisan Bias in Redistricting Using Ensemble Analysis" (joint with Beth Malmskog), presentation to the Colorado Independent Congressional Redistricting Commission, August 2021

(82) "Assessing Partisan Bias in Redistricting Using Ensemble Analysis" (joint with Beth Malmskog), presentation to the Colorado Independent Legislative Redistricting Commission, June 2021

(83) "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.

(84) "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

(85) "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.

(86) "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.

(87) "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:

(88) 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:

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

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

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

Ph.D. students supervised:

- Peter Rock, Ph.D. student 2019 - present
- Boramey Chhay, Ph.D. student (secondary advisor) 2015 - 2016
- Pearce Washabaugh, Ph.D. student (secondary advisor) 2015 - 2016
- Mason Pelfrey, Ph.D. student 2014 - 2017
- Taylor Klotz, Ph.D. student 2015 - 2020 – Ph.D. received August 2020
  Dissertation: *Geometry of Cascade Feedback Linearizable Control Systems*
- Matthew Stackpole, Ph.D. student 2008 - 2011 – Ph.D. received May 2011
  Dissertation: *Dynamic equivalence of control systems via infinite prolongations*
- Christopher Catone, Ph.D. student 2000 - 2006 – Ph.D. received August 2006
  Dissertation: *Projective equivalence of Finsler and Riemannian surfaces*

M.A./M.S. students supervised:

- Brendt Gerics, M.A. student 2017 - 2018 – M.A. received May 2018
- Rachel Benefiel, M.A. student 2016 - 2017 – M.A. received May 2017
- Jessica Burkhart, M.A. student 2012 – M.A. received August 2012
- Nathaniel Bushek, M.A. student 2009 - 2010 – M.A. received May 2010
- Jason Boisvert, M.S. student 2005 - 2006 – M.S. received December 2006
- Anne Cervino, M.A. student 2002 – M.A. received May 2002

Undergraduate research projects supervised:

- Catherine Brennan, Maxwell Fogler, Robi Huq, and Xianoming Wang, Undergraduate Research Opportunities Program (UROP) project on Mathematical Analysis of Redistricting in Colorado and Massachusetts, Fall 2021.
- Nicholas Bossenbroek, Thomas Heckmaster, Adam Nelson, and Jade VanAusdall, Undergraduate Research Opportunities Program (UROP) project on Mathematical Analysis of Legislative Redistricting in Colorado, Fall 2019.
- Nicholas Bossenbroek, Thomas Heckmaster, Adam Nelson, and Jade VanAusdall, 6 week summer REU project on Discrete Geometry and Applications to Redistricting, Summer 2019.

Undergraduate honors theses supervised:

- Catherine Brennan, *An Analysis of Gerrymandering on Single and Multi Member Legislative Districts*, *summa cum laude* honors, Fall 2021
- Peter Rock, *Uses of Mathematics in Computer Animation and 3D Rendering Software*, *summa cum laude* honors, Spring 2018
- Jonah Miller, *A characterization of affine minimal and affine flat surfaces*, *summa cum laude* honors, Spring 2013
- Brian Carlsen, *The Geometry of Null Surfaces in Minkowski Space*, *summa cum laude* honors, Spring 2012

Independent study courses supervised:

- James Stephan (undergraduate), Lie groups and Cartan's method of moving frames, Spring 2018
- Peter Rock and James Stephan (undergraduates), Lie groups and Cartan's method of moving frames, Fall 2017
- Brendt Gerics (M.A. student), Lie groups and Cartan's method of moving frames, Spring 2017
- Duff Baker-Jarvis, Akaxia Cruz, Rachel Helm, Peter Joeris, and Joshua Karpel (undergraduates), Lie groups and Cartan's method of moving frames, Spring 2013
- Edward Estrada, Molly May, and Jonah Miller (undergraduates), Lie groups and Cartan's method of moving frames, Part 2, Spring 2012
- Edward Estrada, Molly May, Jonah Miller, and Sean Peneyra (undergraduates), Lie groups and Cartan's method of moving frames, Fall 2011
- Brian Carlsen (undergraduate) and Michael Schmidt (M.A. student), Lie groups and Cartan's method of moving frames, Fall 2010
- Bryan Kaufman (undergraduate) and Nathaniel Bushek (M.A. student), Lie groups and Cartan's method of moving frames, Fall 2009
- Sam Galler (Boulder High School student), Geometry of Curves and Surfaces, Spring 2007

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 - August 2020
- 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:
  - **2022:** *Election Law Journal*
  - **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)*
  - **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:

- Co-leader of Voting Methods Team of the League of Women Voters of Boulder County, January 2022 - present
- 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
- Institute for Mathematics and Democracy, Wellesley College