Missouri State Legislative Redistricting in 2021 for the League of Women Voters

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This research analysis was conducted as part of the Institute for Computational Redistricting (ICOR) at the University of Illinois at Urbana-Champaign. This activity was conducted in a non-partisan manner, with any political descriptors used reflecting the results of the quantitative analysis, not the opinions of the researchers nor ICOR.
1. Executive Summary

The Institute for Computational Redistricting (http://redistricting.cs.illinois.edu) is a research group at the University of Illinois at Urbana-Champaign. Under the direction of Dr. Sheldon H. Jacobson (http://shj.cs.illinois.edu) and Dr. Douglas M. King, the group focuses on computational methods for redistricting to provide transparency within the redistricting process. In January 2021, the Missouri League of Women Voters (MO-LWV) contacted the group to prepare state legislative district plans (state senate/house) that satisfy the new redistricting criteria amended to the Missouri Constitution in 2020. The new criteria introduces a maximum allowed percent deviation for district populations, and prioritizes compactness and the preservation of political subdivisions over partisan fairness requirements. The goal of this analysis is to examine the physical and partisan characteristics of plans that satisfy the new criteria.

We answer questions such as how many counties can be kept intact under the new population requirement, how many seats each party is expected to win, and how much partisan fairness can be improved (beyond the constitutionally required Efficiency Gap/Shifted Efficiency Gap threshold). For example, the new population requirement affects how many districts can fit inside highly populated counties. Also, prioritizing compactness and preserving political subdivisions over partisan fairness allows Democrats to be packed into urban districts. It is also important to create these district plans by transparent means; with no insight into how a plan was constructed, it is not clear whether undesirable qualities (e.g., packing and cracking, non-competitive districts) are due to gerrymandering or are a natural result of constitutional requirements and political geography.

We use an optimization algorithm to create a collection of district plans that satisfy legal requirements and prioritize different fairness objectives (e.g., compactness, the Shifted Efficiency Gap). Although compactness is prioritized in the Missouri Constitution, focusing on additional aspects of fairness can illustrate the range of partisan outcomes that is possible for Missouri’s legal requirements and political geography. Optimization algorithms promote transparency in each step of the districting process, since they have clearly defined objectives, constraints, and parameters. A discussion accompanies the collection of district plans, including the advantages and disadvantages of each plan, and how legal requirements and political geography impact the redistricting process.
Ultimately, the results show that Missouri’s unique political geography, combined with the constitutional requirements, gives Republicans an inherent advantage. For example, district plans created to solely prioritize compactness tend to pack Democratic votes, since Democrats are heavily concentrated in a few urban centers. Hence, many Democratic votes are considered wasted, since packed Democratic districts tend to have many more votes than are needed to win their elections. In contrast, Republicans are more evenly distributed throughout the state, and hence tend to waste fewer votes than Democrats do and are better able to translate their votes into seats. Preserving political subdivisions (e.g., county lines), as required by the Missouri Constitution, exacerbates this problem. Although there is a constitutionally required threshold for partisan fairness (related to the Efficiency Gap), it has limited impact on the optimized district plans presented in this report; plans that solely prioritize compactness tend to satisfy this loose threshold even when the threshold is not enforced.

As we improve a plan’s partisan fairness (as measured by various voting-based metrics), its districts tend to become longer and tend to cross county lines in order to gather a more politically diverse collection of voters. Hence, partisan fairness cannot be substantially improved without violating compactness and/or the preservation of county lines. Although substantial improvement would be ideal, moderate improvement can still be made to partisan fairness while reasonably maintaining compactness and preserving county lines. In particular, plans that prioritize the Shifted Efficiency Gap and compactness have compactness scores comparable to plans that solely prioritize compactness, but their Shifted Efficiency Gap values are moderately better (decreased by 3-5%).
2. Introduction

Missouri has changed its redistricting requirements twice since the last redistricting cycle in 2011 (Mo. Const. art. III, §3). While the 2018 redistricting amendment prioritized partisan fairness (i.e., the Efficiency Gap), the 2020 redistricting amendment prioritizes compactness and the preservation of political subdivisions (e.g., counties). The 2020 amendment also defines a maximum allowed percent deviation for district populations. The Missouri League of Women Voters (MO-LWV) contacted the Institute for Computational Redistricting (ICOR) to construct state legislative district plans that satisfy the new requirements.

This report provides the MO-LWV with a diverse collection of state senate/house district plans. The plans are constructed with an optimization algorithm to promote transparency in the districting process. To assess the preservation of political subdivisions, we examine how many districts can fit inside highly populated counties under the new population requirement, and how many counties must be split. Some plans presented in this report prioritize compactness, while others prioritize partisan aspects of fairness (e.g., the Shifted Efficiency Gap). Although the 2020 redistricting amendment prioritizes compactness, focusing on multiple aspects of fairness allows one to examine how constitutional requirements and political geography affect the level of political fairness achievable for Missouri. Each plan is scored with various fairness metrics, and the advantages and disadvantages between plans are discussed. The results show that district plans that satisfy constitutional requirements have an inherent Republican advantage, likely attributable to the political geography of the state.

This report is organized as follows. Section 3 describes the fairness metrics used to evaluate district plans. Section 4 gives an overview of the optimization method used to construct the plans that optimize these fairness metrics. Section 5 outlines Missouri’s redistricting requirements, data, and geography. Lastly, Section 6 presents the district plans and Section 7 discusses and compares their partisan characteristics.

3. Fairness Metrics

In the context of redistricting, “fairness” can be interpreted in a number of ways. Sometimes fairness focuses on political parties; for example, a district plan could be considered fair if neither party is packed and cracked (i.e., concentrated in a few districts where it wins by overwhelming margins, then diluted among the remaining districts). Fairness can also
mean reasonably shaped districts, or competitive districts. Throughout this report, we refer to metrics that use voting data as partisan fairness metrics; compactness is the only fairness metric considered in this report that is not a partisan fairness metric. Each district plan presented in this report is evaluated with various metrics that quantify these common aspects of fairness. This section gives an overview of each metric.

- **Compactness**: A district is compact if it has a simple shape (such as a circle or square, as in Figure 1b), as opposed to a convoluted shape (as in Figure 1a). Simple shapes are preferred, since convoluted district shapes can be a result of intentional boundary manipulation for political gain. For example, the infamous salamander-shaped Massachusetts district that inspired the term *gerrymander* was constructed to pack Federalist voters (Massachusetts Historical Society). There are several ways one could quantify district compactness (Young 1988); we choose to measure compactness as the sum of all district perimeters (reported in miles). We exclude perimeter segments that coincide with Missouri’s state boundary, since the state boundary will always overlap with district perimeter segments for any district plan. A district with an irregular shape (as in Figure 1a) has a larger perimeter than a district with a simpler shape (as in Figure 1b), which means that smaller values of this metric indicate more compact districts.

![Figure 1](image.png)  
(a) A non-compact district with a perimeter of 197 miles  
(b) A compact district with a perimeter of 94 miles  

Figure 1  Two examples of district shapes (for roughly the same district population). Figure 1a shows a non-compact district and Figure 1b shows a compact district.

- **Efficiency Gap**: The Efficiency Gap aims to quantify packing and cracking. A packed party wastes votes because it wins districts by overwhelming margins; a cracked party wastes votes because it narrowly loses many districts. Hence, “wasted votes” are votes cast for a district’s losing party, or votes cast for a district’s winning party in excess
of the 50% needed to win the election. The Efficiency Gap measures the difference in wasted votes between both parties and reports this difference as a percentage of the total votes cast for these two parties (Stephanopoulos and McGhee 2015). Smaller values of this metric indicate that both parties waste a similar number of votes, which means both parties are packed and cracked to a similar degree. For example, the vote-share scenario in Figure 2a has a large Efficiency Gap because Republicans are cracked, and therefore waste many votes; the vote-share scenarios in Figures 2b, 2c, and 2d have small Efficiency Gap values, because both parties waste votes equally.

- **Shifted Efficiency Gap:** The Shifted Efficiency Gap (referred to as “Competitiveness” in the Missouri Constitution (Mo. Const. art. III, §3)) examines how the Efficiency Gap changes with small shifts in voter preferences. The Efficiency Gap relies on voting data from previous elections, and voting behavior might change in future elections. Consider a scenario with multiple very competitive districts (as in Figure 2c); Democrats might narrowly win all the districts in one election, then narrowly lose them all in the next election. Democrats waste many more votes for the latter outcome than the former, even though the change in voter preference is small. To capture the robustness of a district plan, the Shifted Efficiency Gap calculates the maximum Efficiency Gap value for scenarios in which the statewide vote-share shifts 1-5% in favor of either party (uniformly among all districts). Smaller values for this metric indicate that both parties waste a similar number of votes, even with small shifts in voter preference. For example, the vote-share scenario in Figure 2b has a better Shifted Efficiency Gap than Figure 2c because the seat outcome does not dramatically change with small vote-share shifts.

- **Partisan Asymmetry:** Partisan Asymmetry observes to what extent both parties receive different seat outcomes for the same vote-share scenarios (Grofman and King 2007). Similar to the Shifted Efficiency Gap, Partisan Asymmetry compares the rate at which both parties win/lose seats as the statewide vote-share shifts uniformly among all districts. As the vote-share for one party gradually increases to 100% or decreases to 0%, we can observe how many seats that party would hypothetically win for each of those vote-share scenarios. For example, Figure 3 shows the number of seats each party would hypothetically win for vote-shares from 0-100% in two example district plans (these plots are called vote-seat curves). The more space exists between the two
(a) Democrats win five seats and Republicans win one seat. Five seats are competitive. The Efficiency Gap is bad because Republicans are cracked. The Shifted Efficiency Gap is bad because small changes in vote-share could dramatically alter the seat outcome. Partisan Asymmetry is good because the district vote-shares are mostly symmetrically distributed.

(b) Democrats and Republicans each win three seats. No seats are competitive. The Efficiency Gap is good because both parties waste votes equally. The Shifted Efficiency Gap is good because increases/decreases in vote-share for either party do not dramatically alter the seat outcome. Partisan Asymmetry is good because the district vote-shares are symmetrically distributed.

(c) Democrats and Republicans each win three seats. All seats are competitive. The Efficiency Gap is good because both parties waste votes equally. The Shifted Efficiency Gap is bad because small changes in vote-share could dramatically alter the seat outcome. Partisan Asymmetry is good because the district vote-shares are symmetrically distributed.

(d) Democrats and Republicans each win three seats. Two seats are competitive. The Efficiency Gap is good because both parties waste votes equally. The Shifted Efficiency Gap is bad because small changes in vote-share could either change the seat outcome or indicate packing/cracking. Partisan Asymmetry is bad because the district vote-shares are asymmetrically distributed.

Figure 2  Example vote-share scenarios for six districts. Although the overall vote-share is split 50-50 (assuming equal turnout in all districts), there are a number of different ways the voters can be grouped into districts. Democratic fractions are shown on the bottom in blue and Republican fractions are shown on the top in red.

curves, the more asymmetry is present in the district plan. For the plan in Figure 3a, if Democrats and Republicans were to both win 50% of the votes, they would win 40% and 60% of the seats, respectively. However, for the plan in Figure 3b, Democrats and Republicans each win 50% of the seats for 50% of the votes. In general, there is a large amount of space between the two curves in Figure 3a, while the curves in Figure
3b are nearly identical. Therefore, the plan in Figure 3b is more symmetric than the plan in Figure 3a. The Partisan Asymmetry metric value is calculated as the area between both parties’ vote-seat curves (Grofman 1983). This metric typically takes on values between 0.00 and 0.11. The minimum value of zero occurs when the vote-seat curves are exactly the same; however, sometimes factors such as political geography or number of districts can prevent a state from achieving a value of zero. Similarly, the largest value achievable varies slightly from state to state. As a rough guideline, smaller values up to 0.01 indicate very symmetric plans, while larger values such as 0.08-0.11 indicate very asymmetric plans.

As additional examples, the vote-share scenarios in Figures 2b and 2c have small Partisan Asymmetry values because the vote-shares are symmetrically distributed (i.e., both parties are spread evenly across the districts). The vote-share scenario in Figure 2d has a large Partisan Asymmetry value because the vote-shares are asymmetrically distributed.

![Vote-seat curves for Democrats and Republicans. The curves in Figure 3a are for an asymmetric district plan and the curves in Figure 3b are for a symmetric district plan.](image)

- **Competitiveness:** Maintaining competitive districts can encourage voter turnout, reduce district packing, and discourage candidate complacency (Hirano and Snyder 2012, McCarty et al. 2009, Tapp 2018). To assess the competitiveness of a district plan, we display the Democrat/Republican vote-share in each district and report the number of districts within a 10% margin of victory. For example, the vote-shares scenarios in Figures 2a and 2c have many competitive districts, while the scenario in Figure 2b has no competitive districts.
4. Optimization Method

This section describes how the optimization algorithm constructs district plans. In general, the algorithm aims to find a district plan with the best fairness metric value, within the constraints of legal requirements. The algorithm is a local search method, meaning it starts with a given district plan (e.g., the plan currently in place, or another proposed plan) and improves it by making a sequence of small changes to district boundaries. While a single small change might not drastically transform the plan, performing thousands of them can lead to a significant improvement as the algorithm continues to run. The basic steps of the algorithm, based on a method from DeFord et al. (2019), are listed below.

1. Choose an initial district plan, a fairness metric to improve (e.g., compactness, Efficiency Gap), and constraints to enforce (e.g., roughly equal district populations).
2. Randomly choose two neighboring districts.
3. Erase the boundary between these two districts and randomly draw a new boundary that maintains contiguity. Note that this action only affects the two chosen districts.
4. Check whether this new boundary satisfies the constraints chosen in Step 1. If it does not, return to Step 3. If it does, continue to Step 5.
5. Check whether this new boundary improves the chosen fairness metric. If it does not, return to Step 3. If it does, continue to Step 6.
6. Record this boundary. Repeat Steps 3-5 to create a collection of viable new boundaries.
7. From the collection of viable boundaries, select the boundary that yields the greatest improvement in the fairness metric. Update the district plan accordingly. Repeat Steps 2-6 as needed.

Figure 4 shows an example sequence of changes to improve compactness in a four-district plan, using counties as district building blocks. The initial plan (Figure 4a) has convoluted districts with long tendrils. Each algorithm step makes the boundary between two districts less convoluted. After four steps, there are no tendrils and the districts all have simple shapes (Figure 4e).

Section 5 outlines redistricting constraints from the Missouri Constitution. Section 6 briefly discusses how these steps are applied to construct the district plans, and Appendix A provides additional details for algorithm application (including parameter choices and number of iterations).
5. Redistricting in Missouri

This section describes how state legislative redistricting is conducted in Missouri. We discuss Missouri’s geography, the data sources used for our experiments, and the redistricting requirements in the Missouri Constitution.

5.1. Missouri Geography

The discussion of district plans in Section 6 includes references to certain Missouri counties and cities by name, so we provide a brief overview here. Missouri has 114 counties and one independent city (St. Louis City, which we treat as a county in this report), but we mainly discuss the seven most populated counties. Figure 5 shows where these counties are located within the state. Jackson County and Clay County are in the west; these counties contain most of Kansas City. Greene County is in the south; this county contains the city of Springfield. St. Charles County, Jefferson County, St. Louis County, and St. Louis City are in the east.

5.2. Data Sources

Redistricting requires data describing state geography, population, and election results. The data sources used to create district plans for this report are listed below.
Figure 5  Missouri counties. The seven most populated counties are highlighted using insets. To the west, there is Jackson County and Clay County (the Kansas City area); to the south, there is Greene County (containing the city of Springfield); to the east, there is St. Charles County, Jefferson County, St. Louis County, and St. Louis City (the St. Louis area).

- **State geography:** Districts are constructed using geographic units, such as census blocks, census block groups, census tracts, and counties. The 2010 U.S. Census provides spatial data for these units (U.S. Census Bureau 2010). With spatial data, we can determine which units are neighbors (to enforce district contiguity) and the length of shared borders between neighboring units (to calculate district perimeters for compactness).

- **Population:** In addition to spatial data, the U.S. Census also provides population counts for geographic units (U.S. Census Bureau 2010). Population data are needed to ensure that all districts have roughly equal populations. Since the 2020 population data are not yet available, the plans in this report use the 2010 population data (U.S. Census Bureau 2010).

- **Election results:** While compactness can be calculated with spatial data (i.e., state geography data), the other fairness metrics in Section 3 rely on voting data from past elections. The Missouri Constitution requires the use of voting data averaged from governor, United States Senate, and Presidential races for the past three general
elections (Mo. Const. art. III, §3). While this data is readily available at the county level for 2016, 2018, and 2020 (Missouri Secretary of State 2021), it is not readily available at the precinct level for 2018 and 2020. To construct districts using finer census units (e.g., census tracts), voting data must be disaggregated from the county or precinct level to the finer level. In this report, we disaggregate voting data from the precinct level; since precincts are smaller than counties, disaggregating voting data from the precinct level creates a more accurate approximation of finer-level (e.g., tract-level) voting behavior. To illustrate the impact of disaggregating from precinct and county level data, Figure 6 displays two voting data approximations at the census block level for the Kansas City area. Figure 6a uses voting data at the county level (averaged from the 2016, 2018, and 2020 races), distributed proportionally to the block level, while Figure 6b uses voting data at the precinct level (averaged from the 2016 races), distributed proportionally to the block level. For Figure 6b, the Democratic blocks are concentrated in the city and spread over three counties. For Figure 6a, the blocks in Jackson County are homogeneously Democratic because the county is Democratic overall; similarly, the other two counties are homogeneously Republican because those counties are Republican overall. Therefore, to more accurately reflect Missouri’s voter distribution, we construct and analyze plans using the available precinct-level voting data from the governor, United States Senate, and Presidential races in the 2016 election (OpenPrecincts 2020).

With voting data, we can also examine Missouri’s political geography. According to this set of data, Missouri is roughly 45.3% Democrat and 54.7% Republican. Figure 7 shows how voters are distributed throughout the state. Democratic voters are concentrated in urban centers (such as Kansas City and St. Louis), while Republicans are spread throughout the state. As we discuss in Section 6, this distribution of voters causes compact district plans to pack Democratic voters into urban districts.

5.3. Constitutional Requirements

This section excerpts relevant text from the Missouri Constitution describing the redistricting requirements (Mo. Const. art. III, §3), and discusses how these requirements are reflected and implemented within our algorithm. The plans in this report satisfy these requirements to the extent possible.
(a) Voting data for Kansas City using county-level data distributed proportionally to the block level.
(b) Voting data for Kansas City using precinct-level data distributed proportionally to the block level.

Figure 6 Two voting data approximations for Kansas City. Democratic blocks are shown in solid blue, Republican blocks are shown in hatched red, and blocks without voters are shown in white.

Figure 7 Voting data for the entire state of Missouri. Democratic blocks are shown in solid blue, Republican blocks are shown in hatched red, and blocks without voters are shown in white. Democratic voters are concentrated in urban centers, while Republicans are more evenly distributed throughout the state.

- Population balance:

Relevant text from the Missouri Constitution: “Districts shall be as nearly equal as practicable in population, and shall be drawn on the basis of one person, one vote. Districts are as nearly equal as practicable in population if no district deviates by more than one percent from the ideal population of the districts, as measured by dividing the number of districts into the statewide population data being used, except that a district may deviate by up to three percent if necessary to follow political subdivision lines […]”

While the Missouri Constitution did require nearly equal district populations in 2010, it did not specify a maximum allowed percent deviation. The current state legislative district plans do not satisfy this new population requirement, since some
districts have a deviation of 3.5-4%. All plans in this report have a maximum 3% deviation from the ideal population. The most notable example of how these new and more restrictive limits on district population affect Missouri redistricting is that Jackson County can no longer contain four whole senate districts, as it does in the current plan.

- **No racial discrimination:**

  Relevant text from the Missouri Constitution: “Districts shall be established in a manner so as to comply with all requirements of the United States Constitution and applicable federal laws, including, but not limited to, the Voting Rights Act of 1965 (as amended). The following principles shall take precedence over any other part of this constitution: no district shall be drawn in a manner which results in a denial or abridgement of the right of any citizen of the United States to vote on account of race or color; and no district shall be drawn such that members of any community of citizens protected by the preceding clause have less opportunity than other members of the electorate to participate in the political process and to elect representatives of their choice.”

  The MO-LWV recommended creating as many competitive districts as possible to avoid racial discrimination, so that minority voters are not packed into safe Democratic districts. As noted in Section 6, we were unable to increase the number of competitive seats while maintaining compactness and preserving the same number of whole counties. However, we provide multiple district plan options for both the senate and house that can be examined further with demographic data.

- **Contiguity and compactness:**

  Relevant text from the Missouri Constitution: “Subject to the requirements of [population balance and no racial discrimination], districts shall be composed of contiguous territory as compact as may be. Areas which meet only at the points of adjoining corners are not contiguous. In general, compact districts are those which are square, rectangular, or hexagonal in shape to the extent permitted by natural or political boundaries.”

  All plans in this report are contiguous; some plans are explicitly optimized for compactness, while others are optimized for different fairness metrics. In the latter cases, compactness is maintained as much as possible.
• Preservation of political subdivisions:

Relevant text from the Missouri Constitution: “To the extent consistent with [population balance, no racial discrimination, contiguity, and compactness], communities shall be preserved. Districts shall satisfy this requirement if district lines follow political subdivision lines to the extent possible, using the following criteria, in order of priority. First, each county shall wholly contain as many districts as its population allows. Second, if a county wholly contains one or more districts, the remaining population shall be wholly joined in a single district made up of population from outside the county. If a county does not wholly contain a district, then no more than two segments of a county shall be combined with an adjoining county. Third, split counties and county segments, defined as any part of the county that is in a district not wholly within that county, shall each be as few as possible. Fourth, as few municipal lines shall be crossed as possible.”

Although this requirement mentions municipal lines, and the MO-LWV expressed a desire to follow school district boundaries as well, we focus on maintaining county lines; too many very specific constraints can make an automated algorithm struggle to find good district plans. Therefore, the plans presented in Section 6 might not follow municipal lines or school district boundaries. For a similar reason, the algorithm does not explicitly enforce the second requirement (which refers to the remaining population of a county that wholly contains one or more districts).

The algorithm uses a few different methods to preserve county lines. First, the plans in this report are constructed using a combination of counties, census tracts, and census block groups. Although district plans are typically drawn using census blocks, the smallest geographic unit for which the census collects information, population balance is still achievable with these larger units. Automatically keeping counties with low population intact helps preserve county lines, and using larger units also helps maintain compact districts.

In addition to using whole counties as geographic units to preserve county lines (when possible), we also rely on numeric “penalties” for districts that cross county lines. These penalties compel the algorithm to view a district that crosses a county line as less compact than a district wholly contained within a county, even if the two
districts have the same perimeter. More details on these numeric penalties are included in Appendix A.

While the Missouri Constitution does not have explicit requirements concerning natural boundaries, there are some sections of the Missouri River that the current senate and house districts do not cross. The MO-LWV was divided on whether districts should be able to cross these sections of the river; to err on the side of the status quo, the plans in this report are designed to have districts that do not directly cross some sections of the river as well. Figures 8 and 9 show the specific sections of the river used for this restriction in the senate and house plans, respectively. Although districts cannot directly cross these sections of the river, they may wrap around them; for example, a district can only have area inside both Jackson and Clay Counties if it also has area outside of those two counties, to serve as a connector.

![Figure 8](image.png)

**Figure 8** Sections of the Missouri River that districts in the senate plan cannot directly cross (shown in black). To the west, there is a section between Jackson and Clay Counties; to the east, there is a section between St. Charles, St. Louis, and Franklin Counties.

- **Partisan fairness:**
  Relevant text from the Missouri Constitution: “*Districts shall be drawn in a manner that achieves both partisan fairness and, secondarily, competitiveness, but [population balance, no racial discrimination, contiguity, compactness, and the preservation of political subdivisions] shall take precedence over partisan fairness and competitiveness* [...]
Figure 9  Sections of the Missouri River that districts in the house plan cannot directly cross (shown in black). To the west, there is a section between Jackson, Clay, Ray, Lafayette, and Carroll Counties; to the east, there is a section between St. Charles, St. Louis, and Franklin Counties; in the middle, there is a section between Callaway and Cole Counties.

“To this end, the average electoral performance of the two political parties receiving the most votes in the three preceding general elections for governor, for United States Senate, and for President of the United States shall be calculated. This index shall be defined as the total votes received by each party in the three preceding general elections for governor, for United States Senate, and for President of the United States, divided by the total votes cast for both parties in these elections. Using this index, the total number of wasted votes for each party, summing across all of the districts in the plan shall be calculated [...] In any redistricting plan and map of the proposed districts, the difference between the two parties’ total wasted votes, divided by the total votes cast for the two parties, shall not exceed fifteen percent.

“To promote competitiveness, the electoral performance index shall be used to simulate elections in which the hypothetical statewide vote shifts by one percent, two percent, three percent, four percent, and five percent in favor of each party. The vote in each individual district shall be assumed to shift by the same amount as the statewide vote. In each of these simulated elections, the difference between the two parties’ total
wasted votes, divided by the total votes cast for the two parties, shall not exceed fifteen percent.”

This requirement states that the plan’s Efficiency Gap and Shifted Efficiency Gap should be below 15%. All plans in this report have an Efficiency Gap/Shifted Efficiency Gap value below 15%, and some plans are explicitly optimized for the Shifted Efficiency Gap. As stated in Section 5.2, we use the available precinct-level voting data from the 2016 general election to calculate these values.

6. District Plans

Here we present a collection of district plans for the state senate and state house in Missouri, following the constitutional requirements discussed in Section 5.3 and optimized for the different fairness metrics discussed in Section 3.

The Missouri Senate consists of 34 districts and the ideal district population is 176,145 people. Only seven of the 115 counties have large enough populations to contain whole districts (St. Louis, Jackson, St. Charles, St. Louis City, Greene, Clay, and Jefferson); these counties are split into census tracts and the remaining counties are kept intact. Hence, we construct the senate plans with a combination of 108 counties and 731 census tracts.

The Missouri House consists of 163 districts and the ideal district population is 36,742 people. The plans are constructed with a combination of counties and census block groups; the 25 least populated counties are automatically kept intact and the rest are split into 4,319 block groups. Note that the final plans have more than 25 counties intact; splitting more counties into block groups at the beginning gives the algorithm more flexibility to find good plans. Since it is more difficult to visually examine how well the house plans preserve county lines, for each plan we report the final number of whole counties and the total number of counties spanned by the districts (for example, a district that lies in three different counties would add three to this total).

The district plans in this section can be categorized in the following manner. For each type of plan, we provide two different options.

- **Compact plans:** These plans were optimized solely for compactness. No effort was made to improve other fairness metrics beyond the 15% Efficiency Gap/Shifted Efficiency Gap requirements.

- **Shifted Efficiency Gap plans:** First, these plans were optimized for the Shifted Efficiency Gap (i.e., the algorithm tries to make this value as small as possible). Once the
plans have a small Shifted Efficiency Gap value, the algorithm maintains this small value while improving compactness.

- **Partisan Asymmetry plans:** Similar to the approach taken to produce the Shifted Efficiency Gap plans, the algorithm first decreases the Partisan Asymmetry value as much as possible, and then improves compactness while maintaining a small value.

Note that we construct some sets of district plans using multiple algorithm phases (i.e., first a plan is optimized for a partisan fairness metric, then the plan is optimized for compactness). Appendix A gives additional details for plan construction, including a discussion of these phases.

Although we ran experiments to optimize senate/house plans for competitiveness, we do not include them in this report. In these experiments, the algorithm was unable to create plans with more competitive districts than the compact/Shifted Efficiency Gap/Partisan Asymmetry plans, while still maintaining the current number of whole counties. Similarly, we ran experiments to optimize house plans for Partisan Asymmetry, but the algorithm was unable to make significant improvement; hence, this report does not present house plans optimized for Partisan Asymmetry.

6.1. **Senate Plans - Compactness**

Figures 10 and 11 display the compact district plans for the senate (Senate-COMP1 and Senate-COMP2, respectively). The districts in these plans are fairly circular/rectangular and most are comprised of whole counties. For both plans, Jackson County completely contains three districts, Clay County contains one, Greene County contains one, St. Charles County contains two, and St. Louis City contains one. St. Louis County contains five districts in Figure 11c, but only contains four districts in Figure 10c (the southernmost district has one tract in Jefferson County). For both plans, the district primarily located in Jefferson County also has one or two tracts in St. Louis County. While the remaining population of St. Louis City is wholly joined in a single district for both plans, the remaining populations of St. Louis County, Jackson County, and Greene County are split between two or three districts.

6.2. **Senate Plans - Shifted Efficiency Gap**

Figures 12 and 13 display the Shifted Efficiency Gap district plans for the senate (Senate-SEG1 and Senate-SEG2, respectively). As with the compact plans, most districts consist
of whole counties; the differences are in the populated areas. While the compact plans divide St. Louis City between two districts, the Shifted Efficiency Gap plans divide the city between three districts. The districts in St. Louis County are also more elongated in these plans than in the compact plans. Figure 12b exhibits the most significant difference from the compact plans, since Clay County no longer contains an entire district; instead, the northern Kansas City population is divided between two districts. These differences may be a result of the algorithm trying to more evenly distribute Democratic voters among the districts.

6.3. Senate Plans - Partisan Asymmetry
Figures 14 and 15 display the Partisan Asymmetry district plans for the senate (Senate-PA1 and Senate-PA2, respectively). The main differences between these plans and the compact/Shifted Efficiency Gap plans are in Kansas City and St. Louis; both Partisan Asymmetry plans have a snake-like district in St. Louis County (Figures 14c and 15c) and elongated districts in Jackson County (Figures 14b and 15b). As with the Senate-SEG1 and Senate-SEG2, these elongated districts may result from the algorithm trying to spread out Democratic voters.

6.4. House Plans - Compactness
Figures 16 and 17 display the compact district plans for the house (House-COMP1 and House-COMP2, respectively). House-COMP1 has more whole counties than House-COMP2, and its districts are divided between fewer counties overall. However, House-COMP2 has more whole districts contained within the more populated counties, such as Clay County (Figure 17b), St. Charles County and St. Louis City (Figure 17c), and Greene County (Figure 17d).

6.5. House Plans - Shifted Efficiency Gap
Figures 18 and 19 display the Shifted Efficiency Gap district plans for the house (House-SEG1 and House-SEG2, respectively). House-SEG2 is comparable to House-COMP1/2 with respect to compactness and the preservation of county lines, while House-SEG1 begins to deviate. For example, House-SEG1 has a few snake-like districts in Jackson County (Figure 18b), while House-SEG2 does not (Figure 19b). House-SEG2 also has more districts wholly contained within Jackson and Clay Counties (Figure 19b), and Jefferson County and St. Louis City (19c).
Figure 10  A senate plan optimized for compactness (Senate-COMP1), with a closer view of populated areas. District boundaries are shown in black and county boundaries that do not coincide with a district boundary are shown in white.
Figure 11 A senate plan optimized for compactness (Senate-COMP2), with a closer view of populated areas. District boundaries are shown in black and county boundaries that do not coincide with a district boundary are shown in white.
(a) Senate-SEG1

(b) Jackson and Clay Counties (the Kansas City area)

(c) St. Charles, Jefferson, St. Louis City, and St. Louis Counties (the St. Louis area)

(d) Greene County (Springfield)

Figure 12 A senate plan optimized for the Shifted Efficiency Gap (Senate-SEG1), with a closer view of populated areas. District boundaries are shown in black and county boundaries that do not coincide with a district boundary are shown in white.
Figure 13 A senate plan optimized for the Shifted Efficiency Gap (Senate-SEG2), with a closer view of populated areas. District boundaries are shown in black and county boundaries that do not coincide with a district boundary are shown in white.
Figure 14  A senate plan optimized for Partisan Asymmetry (Senate-PA1), with a closer view of populated areas. District boundaries are shown in black and county boundaries that do not coincide with a district boundary are shown in white.
Figure 15 A senate plan optimized for Partisan Asymmetry (Senate-PA2), with a closer view of populated areas. District boundaries are shown in black and county boundaries that do not coincide with a district boundary are shown in white.
Figure 16 A house plan optimized for compactness (House-COMP1), with a closer view of populated areas. District boundaries are shown in black and county boundaries that do not coincide with a district boundary are shown in white.
(a) House-COMP2

(b) Jackson and Clay Counties (the Kansas City area)

(c) St. Charles, Jefferson, St. Louis City, and St. Louis Counties (the St. Louis area)

(d) Greene County (Springfield)

Figure 17 A house plan optimized for compactness (House-COMP2), with a closer view of populated areas. District boundaries are shown in black and county boundaries that do not coincide with a district boundary are shown in white.
Figure 18  A house plan optimized for the Shifted Efficiency Gap (House-SEG1), with a closer view of populated areas. District boundaries are shown in black and county boundaries that do not coincide with a district boundary are shown in white.
Figure 19 A house plan optimized for the Shifted Efficiency Gap (House-SEG2), with a closer view of populated areas. District boundaries are shown in black and county boundaries that do not coincide with a district boundary are shown in white.
7. Discussion
This section reports the fairness metric values for each plan, examines the trade-offs between plans, and discusses the fairness metric values that are achievable for Missouri given its voter distribution and redistricting requirements.

7.1. Senate Plans
The Senate-COMP1/2 plans in Section 6.1 prioritize compactness, and in doing so prioritize the preservation of county lines; therefore, these plans most effectively follow Missouri’s constitutional requirements (out of the three sets of senate plans in this report). However, it is also important to examine how solely prioritizing compactness affects the partisan characteristics of these district plans. Table 1 shows that the Efficiency Gap/Shifted Efficiency Gap values for both plans are below 15%, but by small margins. Figures 20a and 20b show that Democrats win multiple districts by overwhelming margins, causing them to waste many votes. The Partisan Asymmetry values in Table 1 show that both plans are quite asymmetric; this asymmetry is also evident in Figures 20a and 20b, since the district vote-shares are skewed. These values indicate that Republicans are able to translate their voter support into seats more effectively than Democrats.

<table>
<thead>
<tr>
<th>Plan</th>
<th>Comp</th>
<th>EG</th>
<th>SEG</th>
<th>PA</th>
<th>Cmpttv</th>
<th>Dem/Rep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senate-COMP1</td>
<td>10,857</td>
<td>14.85%</td>
<td>14.85%</td>
<td>0.1060</td>
<td>7</td>
<td>9/25</td>
</tr>
<tr>
<td>Senate-COMP2</td>
<td>10,923</td>
<td>11.59%</td>
<td>12.74%</td>
<td>0.0944</td>
<td>8</td>
<td>10/24</td>
</tr>
<tr>
<td>Senate-SEG1</td>
<td>11,124</td>
<td>7.95%</td>
<td>7.95%</td>
<td>0.0949</td>
<td>7</td>
<td>11/23</td>
</tr>
<tr>
<td>Senate-SEG2</td>
<td>10,874</td>
<td>8.21%</td>
<td>9.50%</td>
<td>0.0965</td>
<td>8</td>
<td>11/23</td>
</tr>
<tr>
<td>Senate-PA1</td>
<td>11,105</td>
<td>4.69%</td>
<td>12.69%</td>
<td>0.0692</td>
<td>5</td>
<td>12/22</td>
</tr>
<tr>
<td>Senate-PA2</td>
<td>10,984</td>
<td>8.16%</td>
<td>12.76%</td>
<td>0.0787</td>
<td>4</td>
<td>11/23</td>
</tr>
</tbody>
</table>

Table 1 The metric values for the senate plans. From left to right, the table lists each plan’s compactness (Comp), Efficiency Gap (EG), Shifted Efficiency Gap (SEG), Partisan Asymmetry (PA), number of seats within a 10% margin of victory (Cmpttv), and number of Democratic and Republican seats (Dem/Rep).

It is certainly possible that Missouri’s unique political geography causes district plans to have pro-Republican biases, even when districting goals are not explicitly political; most Democratic voters are heavily concentrated in urban centers, so optimizing for compactness packs urban districts with Democrats. We investigate this possibility using the additional plans in Sections 6.2 and 6.3 that prioritize the Shifted Efficiency Gap and Partisan
Figure 20 The estimated fraction of votes won by Democrats/Republicans in each district for the senate plans (based on past election results). Democratic fractions are shown on the bottom in blue and Republican fractions are shown on the top in red.

Asymmetry, respectively. These plans demonstrate how much the Shifted Efficiency Gap and Partisan Asymmetry can be improved, while maintaining compactness and preserving county lines as much as possible.

The plans optimized for the Shifted Efficiency Gap and Partisan Asymmetry show that partisan fairness can be moderately improved in the senate plans, but not substantially improved; this is likely due to Missouri's unique political geography and constitutional requirements. For example, Table 1 shows that Senate-COMP1/2 have Shifted Efficiency Gap values of 14.85% and 12.74%, while Senate-SEG1/2 have values of 7.95% and 9.50%. Table 1 and Figures 20c and 20d show that Democrats may win a few more seats by narrower margins, causing them to waste fewer votes than they do with the compact...
plans. These improvements are more moderate than extreme, since there are still many wasted votes when the Shifted Efficiency Gap is 8-10%. While Senate-SEG2 (Figure 13) is comparable to Senate-COMP1/2 in terms of compactness and preserving county lines, Senate-SEG1 (Figure 12) begins to deviate from these ideals. Clay County does not contain an entire district (Figure 12b) and one district in St. Louis County is somewhat snake-like (Figure 12c). Improving the Shifted Efficiency Gap any further would require even more crossed county lines and unusual district shapes.

As with the Shifted Efficiency Gap plans, the Partisan Asymmetry plans only show moderate improvement. While the Partisan Asymmetry values for Senate-COMP1/2 are 0.1060 and 0.0944, Senate-PA1/2 have values of 0.0692 and 0.0787. Figures 20e and 20f shows that Democratic voters are slightly more evenly distributed throughout the districts. Even these moderate improvements require a few snake-like/elongated districts (Figures 14c and 15c); additional improvements would violate compactness and the preservation of county lines even further.

From the compact, Shifted Efficiency Gap, and Partisan Asymmetry plans, we conclude that there are limited options for senate plans that strictly adhere to the constitutional requirements. The Shifted Efficiency Gap and Partisan Asymmetry can be moderately improved, but a pro-Republican bias persists due to Missouri’s political geography and the constitutional requirements of compactness and preserving county lines. However, moderate improvement is still improvement; since a moderately improved Shifted Efficiency Gap appears to be compatible with compactness, a senate plan that has a Shifted Efficiency Gap value around 10% (rather than 15%) could strike a better balance between partisan fairness and Missouri’s constitutional requirements.

7.2. House Plans
As with the senate plans, Missouri’s political geography produces an inherent Republican advantage, since Democrats are heavily concentrated in a few urban centers. In the house plans specifically, the districts are too small to be flexible; they cannot stretch between urban and rural areas to achieve a Democrat-Republican balance. The metric values of House-COMP1/2, shown in Table 2, illustrate this pro-Republican bias. Both plans have high Efficiency Gap/Shifted Efficiency Gap values; we can see from Figures 21a and 21b that Democrats waste many votes from winning districts by large margins. Both plans also have high Partisan Asymmetry values; Republicans can translate their votes into seats
more effectively than Democrats, since their votes are more evenly distributed among the districts (as shown in Figures 21a and 21b).

<table>
<thead>
<tr>
<th>Plan</th>
<th>Comp</th>
<th>EG</th>
<th>SEG</th>
<th>PA</th>
<th>Cmpttv</th>
<th>Dem/Rep</th>
<th>Whole</th>
<th>Spanned</th>
</tr>
</thead>
<tbody>
<tr>
<td>House-COMP1</td>
<td>27,726</td>
<td>10.95%</td>
<td>12.94%</td>
<td>0.1032</td>
<td>23</td>
<td>49/114</td>
<td>55</td>
<td>307</td>
</tr>
<tr>
<td>House-COMP2</td>
<td>28,003</td>
<td>10.52%</td>
<td>14.32%</td>
<td>0.1049</td>
<td>22</td>
<td>50/113</td>
<td>46</td>
<td>321</td>
</tr>
<tr>
<td>House-SEG1</td>
<td>29,364</td>
<td>7.84%</td>
<td>8.00%</td>
<td>0.1020</td>
<td>30</td>
<td>53/110</td>
<td>45</td>
<td>326</td>
</tr>
<tr>
<td>House-SEG2</td>
<td>27,839</td>
<td>9.56%</td>
<td>9.74%</td>
<td>0.1020</td>
<td>30</td>
<td>51/112</td>
<td>51</td>
<td>311</td>
</tr>
</tbody>
</table>

Table 2: The metric values for the house plans. From left to right, the table lists each plan’s compactness (Comp), Efficiency Gap (EG), Shifted Efficiency Gap (SEG), Partisan Asymmetry (PA), number of seats within a 10% margin of victory (Cmpttv), number of Democratic and Republican seats (Dem/Rep), number of whole counties (Whole), and number of counties spanned by the districts (Spanned).

Figure 21: The estimated fraction of votes won by Democrats/Republicans in each district for the house plans (based on past election results). Democratic fractions are shown on the bottom in blue and Republican fractions are shown on the top in red.

The additional plans in Section 6.5 demonstrate that the algorithm was able to moderately, if not substantially, improve the Shifted Efficiency Gap. Table 2 clearly shows that House-SEG1 (Figure 18) has a better Shifted Efficiency Gap than House-SEG2 (Figure 19); Democrats may win two seats in House-SEG1 that they lose in House-SEG2, so
House-SEG1 wastes fewer Democratic votes. Both plans have better Efficiency Gap/Shifted Efficiency Gap values than the compact plans; Figures 21c and 21d shows that Democrats waste fewer votes by winning seats with less overwhelming margins. Both plans also have 30 competitive seats, while the compact plans have 22-23. Although House-SEG1 has a lower Shifted Efficiency Gap than House-SEG2, House-SEG2 is more compact, has more whole counties, and its districts span fewer counties.

While the Shifted Efficiency Gap values for House-SEG1/2 are lower than House-COMP1/2, the values are not excellent. Similar to the senate plans, Missouri’s political geography gives Republicans an inherent advantage; even achieving a Shifted Efficiency Gap of 8.00% in House-SEG1 requires convoluted districts. Hence, the house plans reiterate the conclusion of the senate plans: partisan characteristics can only be moderately improved while still maintaining compactness and preserving county lines. Also similar to the senate plans, a house plan with a Shifted Efficiency Gap value around 10% could strike a better balance between partisan fairness and Missouri’s constitutional requirements.

7.3. Limitations
The district plans constructed for this report provide insight into how Missouri’s constitutional requirements and political geography affect the redistricting process. However, there are limitations to consider that impact the optimization algorithm’s ability to fully consider all possible district plans and constitutional requirements in Missouri. Hence, this report should be used as a reference to understand fairness metrics and the affects of political geography and redistricting requirements on partisan fairness, rather than an exact prescription for drawing Missouri districts.

First, there are limitations related to the data we use to construct plans. We construct plans with census tracts and census block groups, rather than census blocks. Although population balance is achievable with tracts and block groups, using blocks could provide more district plan options. As discussed in Section 5.2, we only use election data from 2016, rather than data from 2016, 2018, and 2020 (as required by the Missouri Constitution). If voting behavior from 2016 differs substantially from voting behavior in 2018 and 2020, a different set of data could alter the metric values from Tables 1 and 2, and possibly change what metric values are achievable for Missouri plans. Section 5.2 also discusses how we distribute precinct-level election data proportionally to census blocks/block groups/tracts; this assumes that Democratic and Republican voters are spread evenly throughout the
voting precincts, which might not be the case. Although it is a more accurate approximation than using county-level election data, it is still an approximation that could possibly misrepresent the true voter distribution. Lastly, Section 5.2 mentions that we use population data from the 2010 census, since the 2020 population data is not yet available. Shifts in population could affect how many legislative districts fit in certain counties and how many counties are split.

Second, there are limitations regarding the redistricting requirements that the algorithm enforces. As Section 5.3 discusses, we do not analyze our plans with demographic data; hence, there is a chance that plans in this report might unintentionally weaken the voting power of a particular minority. Section 5.3 also mentions that we do not attempt to preserve municipal lines or school district boundaries. Similarly, we do not explicitly enforce the requirement that the remaining population of a county that contains one or more districts should be wholly joined in a single district. These limitations mean that the district plans in this report might require manual adjustment to reduce racial discrimination and adequately preserve political subdivisions.
Appendix A: Additional Technical Details

In this appendix we discuss some of the technical details for creating district plans with the optimization algorithm. As mentioned in Section 4, the algorithm we use is based on a method from DeFord et al. (2019). Their paper fully explains the mechanics behind how to alter the boundary between two districts in each step of the algorithm. While their goal is to create a large sample of legal district plans for statistical analysis, our goal is to iteratively find better and better plans (with respect to some fairness metric) until there is no more room for significant improvement.

The algorithm steps from Section 4 are applied in multiple phases; these phases are distinguished by the initial plan the algorithm uses, the metric the algorithm improves, and the redistricting constraints the algorithm enforces. Note that the basic steps of the algorithm from Section 4 do not change between phases. Figure 22 outlines these phases and the following paragraphs provide additional details.

For both senate and house plans, we begin with an approximation of the plan currently in place. Since the current plans are drawn at the census block level, some census tract/block groups are split. For the senate/house, we assign split tracts/block groups to the district in which they have the most area. Next, we optimize these plans for population balance (this is Phase 1 in Figure 22); the algorithm transitions between contiguous plans with smaller and smaller population deviations until the 3% population balance requirement is satisfied. The algorithm alternates between two methods to choose which two districts to modify during an iteration. For the first method, the algorithm first chooses the district with the largest population deviation, then chooses a random neighboring district. For the second method, the algorithm first chooses a district at random, then chooses a random neighboring district. We alternate between these methods to prevent the algorithm from getting stuck in a local minimum; improving population balance throughout the state creates more opportunities to shift population to/from the district with the largest population deviation. Achieving population balance takes roughly 350 iterations for the senate and 2000 iterations for the house. We collect 3-10 senate/house plans that satisfy population balance to serve as initial plans for the compactness plans. Section 6 then presents only the best two plans for each metric.

First, we optimize plans solely for compactness (this is Phase 2 in Figure 22). The algorithm begins with the population-balanced plans, then transitions between contiguous, population-balanced plans with better and better compactness scores until the the scores appear to plateau. For these plans, and for the remaining experiments, the algorithm chooses which two districts to modify at each iteration in the following manner. First, the districts are listed in a random order. At each iteration, the algorithm chooses the next district in this list, then chooses a random neighboring district. When the algorithm has completed enough iterations to finish the list (i.e., has completed a cycle), a new list of districts is created, in a new random order. Cycling through the districts ensures that all areas of the state are changing at the same pace. Improving compactness takes roughly 50-70 cycles.

As mentioned in Section 5.3, to preserve county lines we add numeric penalties to a plan’s compactness score when districts cross county lines. District perimeter segments that do not coincide with county lines receive a penalty; the length of these perimeter segments are multiplied by 1.25 when added to the sum of all district perimeters. District perimeter segments that do coincide with county lines receive no penalty;
the true length of these perimeter segments are added to the sum of all district perimeters. Note that this penalty system does not penalize districts comprised of multiple whole counties. More extreme penalty multipliers were tested (such as 2, 3, 4, and 5), but these frequently caused misshapen districts; the extreme penalties encouraged districts to cling to county lines, even if doing so created long tendrils or thin connecting segments.

Next, we optimize plans for the Shifted Efficiency Gap (this is Phase 3 in Figure 22). The algorithm begins with the compactness plans, then transitions between contiguous, population-balanced plans that satisfy a compactness threshold and gradually improve the Shifted Efficiency Gap. The compactness threshold is set as 1,000-3,000 miles above the initial plan’s perimeter sum (which is usually around 11,000 miles for senate
plans and 28,000 miles for house plans). The algorithm is run until the Shifted Efficiency Gap falls below a certain threshold; we test different thresholds from 6-12%. The lower values of 6-7% are achievable, but we were unable to recover a reasonable level of compactness while maintaining these low values. Plans with values of 11-12% can be made reasonably compact, but these values are not significantly better than the values of plans optimized for compactness. Therefore, Section 6 presents plans created with 8-10% thresholds. Once the desired threshold is achieved, the algorithm optimizes the plans for compactness, while maintaining a Shifted Efficiency Gap value below the threshold (this is Phase 4 in Figure 22). Improving the Shifted Efficiency Gap takes roughly 30-50 cycles, then improving compactness takes roughly 40-60 cycles.

Lastly, we optimize plans for Partisan Asymmetry in a manner described for the Shifted Efficiency Gap (using the appropriate Phases 3 for Partisan Asymmetry in Figure 22). We test thresholds from 0.06-0.08. Although a value below 0.06 is possible, we were unable to recover a reasonable level of compactness while maintaining this low value. Section 6 presents plans with 0.07-0.08 thresholds. Once the desired threshold is achieved, the algorithm optimizes the plans for compactness, while maintaining a Partisan Asymmetry value below the threshold (this is Phase 4 in Figure 22). Improving Partisan Asymmetry takes roughly 30-50 cycles, then improving compactness takes roughly 40-60 cycles.
References
Mo Const art III, §3.