NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

OPTIMAL GEOGRAPHIC ALIGNMENT OF U.S. ARMY RECRUITING COMMAND RESOURCES TO REDUCE MISSION RISK

by

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June 2023

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REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC, 20503.				
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2023	**3. REPORT TYPE AND DATES COVERED** Master's thesis		
4. TITLE AND SUBTITLE OPTIMAL GEOGRAPHIC ALIGNMENT OF U.S. ARMY RECRUITING COMMAND RESOURCES TO REDUCE MISSION RISK				**5. FUNDING NUMBERS**
6. AUTHOR(S) Garrett S. Johnson				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000				**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Army Recruiting Command, Fort Knox, KY 40121				**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.				**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

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14. SUBJECT TERMS			**15. NUMBER OF PAGES**
Army recruiting, U.S. Army Recruiting Command, USAREC, districting, geographic optimization			107
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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OPTIMAL GEOGRAPHIC ALIGNMENT OF U.S. ARMY RECRUITING COMMAND RESOURCES TO REDUCE MISSION RISK

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Submitted in partial fulfillment of the
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MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
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U.S. Army Recruiting Command (USAREC) is comprised of over 7,000 recruiters spread across 1,300 stations with the mission to enlist more than 60,000 young people into the U.S. Army annually. USAREC groups its stations into companies to balance span of control responsibilities and minimize its risk of mission failure. Currently, company enlistments are imbalanced—USAREC relies on a small number of companies to produce an outsized portion of its enlistments, exposing the command to mission failure if a single company fails to meet recruitment goals. The author previously worked on this problem during an assignment in USAREC Market Analysis Division in 2019. We implement a local search algorithm to conduct station-company exchanges and systematically explore station-company realignments that reduce this risk. Our algorithm operates on a spatial network of USAREC stations to realign stations to companies while reducing enlistment imbalance and retaining contiguity of company regions. We study new station-company alignments for the entire USAREC command and for each major enlistment region (brigade). Results show that local search can produce station-company alignments that significantly reduce mission risk. However, efficacy of results is limited as new alignments will increase other span of control metrics, namely region compactness and the number of markets per company.

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LIST OF ACRONYMS AND ABBREVIATIONS

COA	courses of actions
CBSA	Core-Based Statistical Area
SME	subject matter experts
QMA	Qualified Military Available
USAREC	U.S. Army Recruiting Command

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EXECUTIVE SUMMARY

U. S. Army Recruiting Command (USAREC) is tasked with enlisting over 60,000 young people into the United States Army each year. With its force of over 7,000 full-time recruiters, located in over 1,300 stations across the country, USAREC leaders are faced with a unique challenge on how best to manage its human resources and reduce risk of mission failure. USAREC stations are organized into recruiting companies managed by senior recruiting leaders which provide direct management to their assigned stations. Due to geographic conditions and demographic changes over time, USAREC companies have become imbalanced in terms of their span of control responsibilities, such as the number of their assigned recruiters and stations as well as their share of the USAREC recruiting mission. Now, a relatively small portion of USAREC companies produce an outsized share of enlistments. This imbalance exposes USAREC to increased mission risk – when a single, critical company fails to meet its enlistment goals, other companies may not be able to increase their recruitment numbers to meet mission requirements. The author has extensive prior experience with this problem, having worked in USAREC Market Analysis Division between 2017 and 2020. During that time our division analyzed and recommended changes to USAREC's geographic command structure, in order to improve organizational efficiencies and reduce mission risk.

This thesis seeks to develop feasible courses of action (COAs) that reduce company enlistment imbalance (i.e., reduce company enlistment variance) and reduce mission risk. We focus on creating new station-company alignments as one way to achieve this goal. Specifically, we hypothesize that realigning stations from one company to another will reduce enlistment variance across USAREC, in turn reducing the likelihood that any single company missing its enlistment goals will result in mission failure.

We leverage research on districting problems to develop an algorithm that produces feasible, lower-risk station-company alignments. Our algorithm takes a geospatial network of contiguous USAREC stations and their current company alignment as input, and outputs in a new alignment with lower company variance by conducting station-company switches (i.e., adding or removing a station from a given company, and vice versa). Explicitly, for each company n in the network, the algorithm attaches each adjacent station i to n, checks for network continuity, and calculates variance. If the exchange reduces variance, the new network structure is saved in a heap, ranking each new network by lowest variance. The next iteration starts with the best network from the previous iteration and continues until no station-company alignments can reduce variance. This process maintains geographic continuity of companies, thus producing actionable station-company alignments and insights for USAREC.

We applied the USAREC station-company redistricting model six different times, first on the overall command (all stations, all companies) and then once for each major recruiting region (brigade). Both the Command model and the Regional models produce a large reduction in company enlistment variance, reducing the coefficient of variance and associated mission risk by roughly 50%. Moreover, each analysis informs different COAs that can reduce mission risk. For example, the Command model shifts companies from regions with lower company enlistment averages to adjacent regions with higher enlistment averages, thus reducing a portion of the inter-regional variance. However, this COA is difficult to implement in practice as maintaining brigade alignment is a current USAREC requirement. Hence, Regional model results provide COAs that reduce variance less for the entire command, but may be easier to implement in practice.

Despite favorable results, there are limitations with the current COAs and model that need to be addressed before real-world use. The districting model's objective ignores important USAREC span of control metrics, including company region compactness and enlistment market factors. Resulting COAs reduce enlistment variance at the expense of producing companies that are stretched out geographically and spread across multiple different markets (called the gerrymandering effect). Moreover, our results are limited by local search sensitivity to input data and geographic boundaries, resulting in poor alignment in regions with prominent peninsulas (e.g., Florida, Michigan). Future research should focus on reducing these limitations by implementing additional constraints and objectives that manage span of control metrics and/or use heuristic techniques to overcome sensitivity to input data.

ACKNOWLEDGMENTS

A huge thank you goes to my advising team, Dr. Daniel Eisenberg and LTC (Dr.) Peter Nesbitt, who gave me the encouragement to pursue this topic, the necessary assistance in building the model, and the constant motivation and draft editing to finally get me over the finish line. Thank you to my wife, Kristi, who put up with me and encouraged me while raising our three young children during the endless hours of COVID-19 ZOOM classes and late-night projects. Thank you to USAREC Market Analysis Division, specifically Mr. Mitch Stokan, for being my first mentor in the ORSA community and who allowed me to lead the analysis on this problem set; it was easily the most interesting and fulfilling professional experience in my 15+ years of service. Finally, thanks to my fellow classmates LCDR Eduardo Castellanos, MAJ Oleg Green, and MAJ Will Brown for their loyal camaraderie and Trident Room patronage.

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I. INTRODUCTION

A. UNITED STATES ARMY RECRUITING COMMAND OVERVIEW

USAREC is responsible for recruiting and enlisting around 60,000 young people into the United States Army every year. USAREC divides the United States and its territories into over 1300 geographically contiguous districts called recruiting stations. Based on the qualified military available (QMA) youth population and previous years' military enlistment production within recruiting stations boundaries, stations are allocated a proportion of USAREC's authorized recruiter positions. Each year, stations are assigned an enlistment goal (i.e., the annual recruiting mission) based on USAREC analytical models and the number of assigned recruiters. Recruiters utilize a commercial store-front facility and generally operate within their recruiting station boundaries to meet their assigned annual recruiting goal.

USAREC uses a standard Army command structure. Recruiters and their stations are grouped into geographically contiguous companies, which are then grouped into battalions and finally brigades. USAREC has five brigades, 38 battalions, and 235 companies geographically aligned as seen in Figure 1 (Stokan 2021). Brigades are large regional headquarters, whereas battalions and companies are localized headquarters, in which their commanders and senior leaders are responsible for facilitating recruiting operations by engaging directly with state, community, and school leaders. Generally, the number of subordinate units and geographic markets determines the workload of the local battalion and company commanders. If recruiting battalions and companies are either too geographically or demographically large, command and staff teams are unable to effectively manage their recruiters and engage community leaders. Correspondingly, if recruiting battalions and companies are too geographically or demographically small, the assigned commanders and staff personnel will be under-utilized. USAREC unit alignment to natural markets is also critical to effective community engagement; if there are too many units assigned to a geographic market, commanders and staff will potentially disrupt the initiatives and operations of their adjacent units operating within the same markets (Stokan 2019).

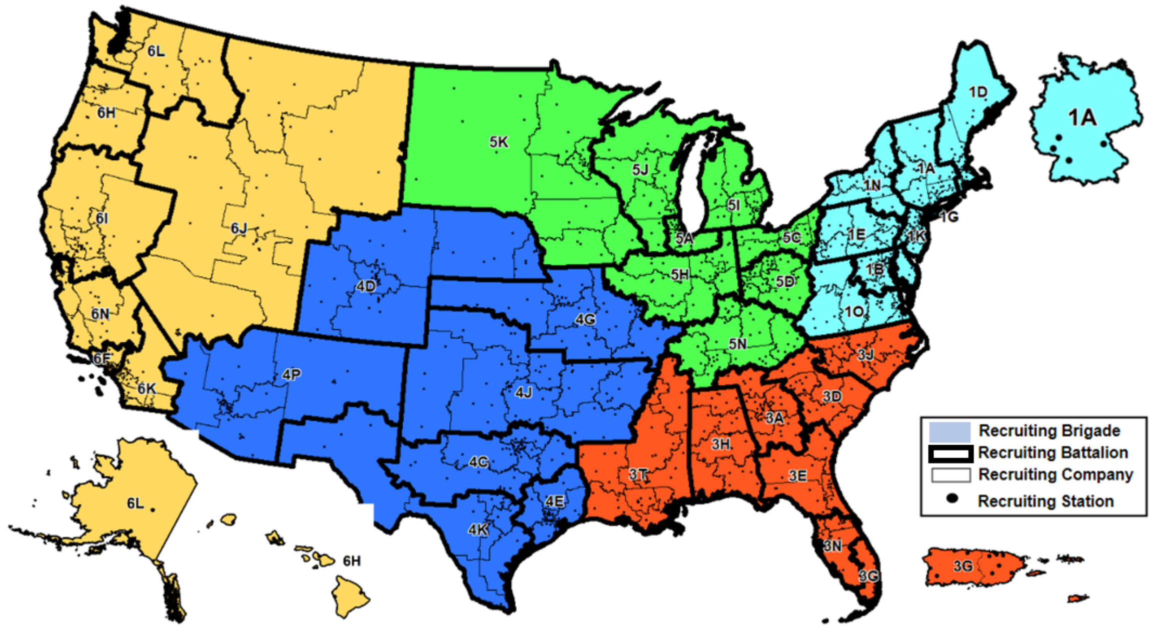

Figure 1. USAREC Area of Operations—Colors represent USAREC Brigades/Regions (author generated map from Stokan 2021 data)

Since the demographics and geography of a region often make standardized force structure impossible, USAREC utilizes span or control metrics to manage the relative responsibility and risk of its subordinate units. Primary responsibility metrics for each headquarters includes the number of subordinate units, number of authorized recruiters and, the number of assigned markets. The risk span of control metric measures the statistical variance in subordinate units' assigned enlistment missions. Over time, normally a result of relative regional demographic growth or decline, some recruiting units' span of control metrics will either get too large or small when compared to their surrounding units. When this occurs USAREC initiates a process to realign stations between companies, or companies between battalions, in order to regionally rebalance the span of control force structure (Stokan 2019).

While assigned as a Market Analyst in United States Army Recruiting Command (USAREC) Market Analysis Division from 2017–2020, I led a team of analysts that were tasked to analyze this thesis' problem in 2019. The tasking was a result of USAREC failing its recruiting mission in 2018, and Army senior leaders began asking USAREC leaders what it could do to improve its organizational efficiencies and reduce mission risk. Our research primarily focused re-balancing company span of control metrics, by manually re-districting station-company assignments. The manual process was extremely slow and difficult to replicate, but I did not have to professional tools to develop a programmatic solution to re-balancing USAREC's force structure. This thesis is an expansion of that original research question, but using a programmatic approach.

B. RECRUITING MISSION ALLOCATION AND RISK MITIGATION

The Army recruiting mission is distributed annually to the station level using previous year's enlistment production and the number of recruiters assigned to the station. Since station demographics change slowly and additional recruiter assignments do not make immediate impacts (market learning curve), a station's mission is largely inflexible in the short-term (less than 3 years). As a result, the only way to balance span of control metrics and statistically reduce recruiting company and battalion enlistment mission variance is to realign the stations that companies and battalions are assigned (Stokan 2019).

USAREC's missioning philosophy is as follows: if a station in a given company ($i \in S_c$) fails its annual mission by x_i enlistment contracts, all other stations in the company (sister stations, $j \in S_c \ i$) are required to each make their own enlistment mission ($reqenlist_j$) and produce additional enlistment contracts to make up the shortfall, ($\sum_{j \in S_c \setminus i} \left(enlist_j - reqenlist_j \right) \geq x_i$). If its sister stations fail to each achieve their own missions and produce the additional contracts, the company ($c \in C_b$) fails its mission. This company mission failure cascades upwards to the battalion level ($b \in B_r$), and the sister companies ($d \in C_b \ c$) are expected to make up the enlistment shortfall. If this cascade continues, USAREC risks failing its mission if the enlistment of a brigade ($r \ \in R$) cannot be met by sister brigades ($q \ \in R \ r$) (Stokan 2019).

As a result of this missioning philosophy, USAREC assumes that mission failure risk is best mitigated by spreading the mission as equally as possible across its companies and battalions. For the four years' worth of USAREC company enlistment data received, around 10% of USAREC companies (roughly 25) achieved less than 100% of their assigned mission during each year due to a variety of reasons; these companies are considered to have failed their mission regardless of the magnitude. The magnitude or percentage of mission accomplishment less than 100% varies from less than 1% to over 30%, but on average failing companies miss their mission by roughly 10% (Stokan 2019). By ensuring the variance across span of control metrics is minimized, this reduces the overall likelihood and magnitude of mission failure. For example, in any given year, if the 25 companies that fail their mission have a higher-than-average contract requirement (e.g., $reqenlist$ ~ 350 contracts), this translates into an expected enlistment contract shortfall of 875 contracts (expected shortfall = 0.1 * 350 * 25). In contrast, if all companies that failed their mission had an average required number of contracts (~250 contracts) then the expected shortfall would only be 625 contracts, or a reduction in mission failure of roughly 28.5%.

This reduction in mission risk becomes important at the battalion level. For example, assume there is a battalion with six companies, one company has a mission of 450 contracts and the other five companies are assigned a near average-size mission of 250 contracts. If the large company fails its mission by 20% due to an unexpected leadership failure, the remaining companies need to make up the difference of 90 contracts. If this shortfall is spread equally, the 18 contract increase for each company represents a 7% increase for each sister company (250 to 268). Battalion mission accomplishment is reliant upon the other five companies to each make up that gap. Conversely, if each company is geographically aligned (assigned stations) to receive a more equal share of the battalion mission (283 enlistments per company), a 20% mission failure is only 56 contracts that can be made up by increasing the sister companies' mission from 283 to 294, a 3.8% increase.

The purpose of this work is to study mission risk and determine ways to re-align USAREC stations to minimize variance. Whereas a 250-enlistment contract difference seems small as USAREC's annual mission is typically 60,000 enlistments, a three-percentage point reduction (7% to 3.8%) in enlistment contracts for stations significantly reduces the burden to make up failed enlistments in a given company. This reduction in mission risk is compounded further as companies are grouped into battalions, and then into brigades. Thus, even small reductions in mission risk at the station-level can lead to significant gains across USAREC. Accordingly, a key motivating assumption for this work is:

- **Assumption:** re-aligning stations between company headquarters to reduce company mission variance (i.e., enlistment requirements) will reduce USAREC's overall mission risk.

It is important to note that this assumption is limited and does not consider all factors that determine enlistments. USAREC has control over how enlistment requirements are allocated, but does not control its total enlistment requirements. However, there are numerous local factors that play a role in enlistment (e.g., jurisdictional boundaries, demographics, youth propensity) that USAREC has limited to no control over. There is scant research that determines the importance of these factors to guide USAREC mission alignment for stations. Hence, the effectiveness of using mission risk to guide USAREC decisions requires further analysis that is beyond the scope of this work.

C. PROBLEM DESCRIPTION

USAREC's 235 companies' annual enlistment mission and enlistment contract production are not normally distributed and have a large variance. Figure 2 shows the distribution of USAREC company annual enlistments (four-year average), based on how each of the companies is geographically aligned. *Note:* past enlistment production is a close proxy for annual company missions, since they are closely correlated. Balancing company past enlistments is better than balancing their missions because some companies never reach their mission, while some other companies always exceed their mission. The distribution shows that over 50 companies produce less than 200 enlistments per year, while a similar number produce over 400 enlistments. This right skewed distribution highlights the risk USAREC places on its higher missioned and producing companies, due to the risk that any given year, most of the failing companies could be located in the right tail.

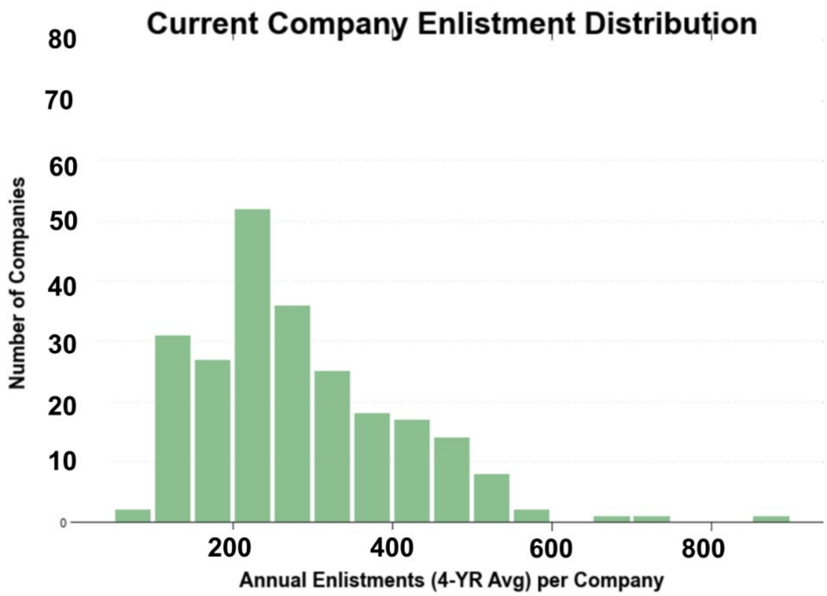

Figure 2. Current Station—Company Alignment: Company Annual Average Enlistments (Figure generated with Stokan 2021 provided data)

USAREC not only faces a large company enlistment variance for all 235 companies, but it also has significant enlistment variances between the five different brigades or regions. Figure 3 highlights that the current Southeast and Southwest region companies, on average, produce a higher number of enlistments per year than the companies in the Northeast, Midwest, and West regions of the United States. For example, the average company in the Southeast produces 400 annual enlistments, while the average Northeast company only produces around 200 annual enlistments. In order to reduce this inter-regional enlistment variance, stations in the Northeast and Midwest regions would need to be consolidated into fewer companies, and those company headquarters would be used to realign the Southeast and Southwest region stations with additional companies.

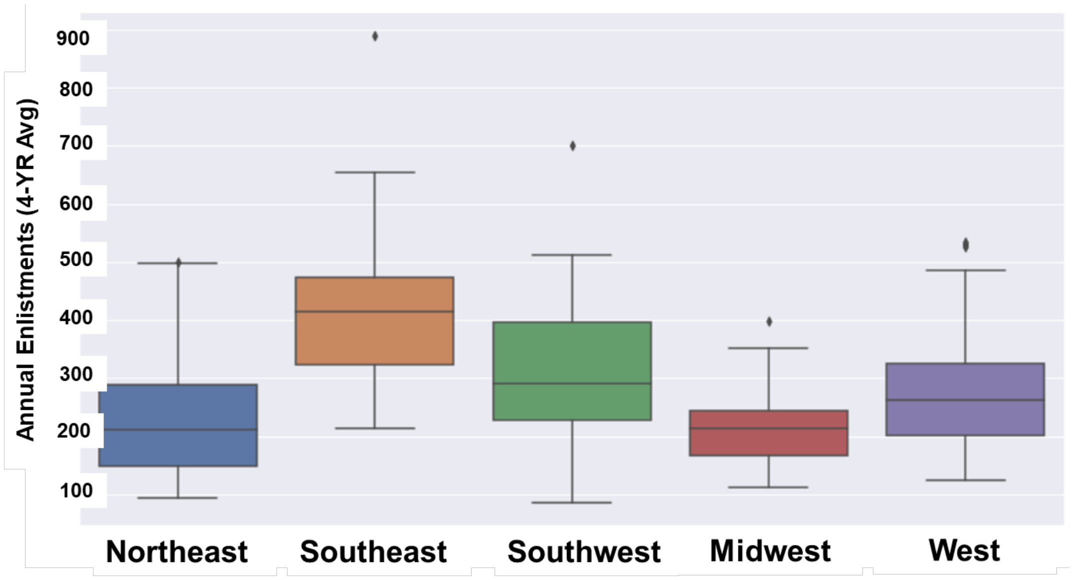

Figure 3. Current Station—Company Alignment: Company Annual Average Enlistments by Region (Figure generated with Stokan 2021 provided data)

As the United States' regional demographics and military enlistment potential continues to slowly change it is important for USAREC to continuously evaluate its command structure to ensure that it has the right number of leaders in the right markets to help balance mission risk, personnel, and engage local leaders. The purpose of this thesis is to assist USAREC by creating a programmatic method to redistrict its stations between companies every 5–10 years in order to reduce company annual enlistment variance.

USAREC rarely redistricts its stations because it is seen as unnecessarily disruptive to current recruiting operations. When attempted, it is done for two primary reasons. First and most common, the regional commander and staff senses their companies are underperforming due to some misalignment or imbalance of span of control responsibilities. Second and less common, USAREC is forced by its higher headquarters to surrender some its leadership position authorizations. Having fewer captain or lieutenant colonel authorizations to distribute across USAREC would likely force the reduction in the number of companies and battalions (Stokan 2019).

Currently, USAREC does not have a programmatic way of redistricting its companies. When it is attempted, a team of battalion, brigade, and USAREC-level subject matter experts (SMEs) use the span of control metrics and heuristics to manually determine the possible station to company alignment. The team builds potential courses of actions (COAs) and compares them utilizing the span of control metrics listed above. The brigade commander selects the best course of action, and the stations are a realigned accordingly (Stokan 2019).

Although USAREC is not currently facing authorization reductions and does not have any reoccurring realignment analyses scheduled, USAREC would benefit from a programmatic approach to redistricting. A programmatic approach would be able to create and compare different, unbiased COAs significantly faster than a team of SMEs. The SMEs would only need to program the algorithm with a commander-determined set of rules and assumptions in order to let the program generate COAs for further exploration.

D. ANALYSIS GOAL

This goal of thesis is to build an algorithm that programmatically partitions or districts existing stations into a set number of companies based on a specified objective function. We refer to this as the USAREC station-company redistricting model. While the ultimate objective function will include multiple and often competing factors and metrics, this thesis's objective function will minimize company enlistment production variance.

While the model built in this thesis will only include one factor and a set number of companies, the algorithm will be expandable to include other important metrics, such as recruiters and markets, and flexible to allow USAREC to consider different starting alignments and numbers of company and battalion headquarters. USAREC will benefit from having a timely and unbiased redistricting solution to utilize as a starting point for all future internally or externally driven station-company-battalion realignment decisions.

Additionally, USAREC will benefit directly from the results of this single-factor model to help consider what is feasible when solely balancing company enlistments versus districting based on multiple factors. Current USAREC companies are based primarily on geographic factors and historic alignment decisions with minimal consideration of current enlistment balance. The immediate results of the model will demonstrate feasible alignments that can reduce USAREC mission risk, which is something to consider in this highly challenging recruiting environment.

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II. LITERATURE REVIEW

A. PARTITIONING OVERVIEW

There is extensive research literature regarding methods and techniques for partitioning and districting algorithms that support developing the USAREC station-company redistricting model, specifically research done on political districting and sales territory. Partitioning is the defined task of separating data observations into one or more groups based on observation characteristics. For the purposes of this thesis, data observations are recruiting stations, which are unique entities with their own associated characteristics (e.g., youth population, past enlistments, number of recruiters, number of markets, number of high schools). Groups are recruiting companies. One requirement common to partitioning problems and this algorithm is the requirement that all data observations are assigned a single group (i.e., data observation cannot be part of two groups). This requirement is referred to as complete and exclusive assignment and relates to the USAREC problem as all recruiting stations are partitioned or assigned a single company (Kalcsics 2015, p. 604).

Methods to partition data observations into groups include supervised techniques such as partition trees or logistic regression or through unsupervised techniques such as clustering (Nasteski 2017, p. 52). Unsupervised statistical methods generally partition data with unknown objectives or relationships *a priori* (Hastie et al. 2001, ch. 14). Often these methods partition data observations with similar features together and a key analysis goal is to determine what these features are. Supervised methods aim to partition data with a measurable objective (e.g., minimizing the maximum differences among data features in a group).

In contrast, when partitioning data with known relationships and goals, mathematical programming and optimization techniques may be more appropriate. An integer programming method to partition data is referred to as an assignment problem and seeks to optimize an objective function by assigning a set of basic observations $J = \{1,....,n\}$ into a set of groups $K = \{1,..., k\}$. Associated binary decision variables, X_{ik}, $= 1$

when unit i is assigned to district k, and = 0, otherwise. Assignment constraints are generally based limiting the total number of members of a group k, or on whether certain units can be grouped together. Assignment problems are common across different applications such as personnel shift scheduling and factory machine allocation (Kalcsics 2015, p. 604). In this work, the objective of the USAREC station-company redistricting model is to minimize enlistment variance across companies. Moreover, a key constraint for partitioning stations is their geographic location, where companies must consist of contiguous land areas.

Graph partitioning is a special subset of the partitioning and linear program assignment problems relevant to this work. In graph partitioning, basic units can only be assigned to the same group if they are connected in the network graph. Graph partitioning is useful in geo-spatial applications where geographically contiguous regions can be represented as a network with regions as nodes and neighboring regions connected with edges. Graph partitioning is usually referred to as a *districting problem* in geo-spatial applications (Kalcsics 2015, p. 617). We focus the remainder of our review on districting problems for their direct relationship to the USAREC problem.

B. DISTRICTING GOALS

Districting is a partitioning task that involves taking contiguous geospatial *regions* with known location and area and assigning them to groups called *districts*. Districting techniques are used for diverse real-world applications, most commonly for political, sales, and logistical districting. Political districts are typically used to divide land into regions such as towns, counties, school districts, and congressional districts that ensure fair demographic representation. Sales districts are designed to give salespeople equal chance for revenue generation. Logistical districts are designed to minimize transportation costs between warehouses and storefronts. While districting goals may be different, assignment to a district is generally made following the same three broad districting objectives: balance, continuity, and compactness (Kalcsics 2015, p. 604).

First, *balance* means districts should have an equal share of a feature. For example, U.S. congressional districts are chosen to contain roughly the same amount of population.

In sales territories, districts contain a similar number of customers. Hence, balance is achieved through an objective that minimizes differences in predetermined features across regions. For the USAREC problem, companies desire balanced districts that can produce similar numbers of recruits (on average). With balanced districts, each company leader assumes similar amounts of risk and responsibility (Kalcsics 2015, p. 605).

Second, *continuity* means districts are comprised of regions that are geographically contiguous, i.e., regions within a district border each other. In the U.S. congress, only adjacent census blocks are grouped together in order to form voting districts. The USAREC problem also requires continuity when assigning stations to companies. Continuity is achieved through model constraints that limit districts to only include adjacent regions. Essentially all districting problems require both continuity constraints and balance objectives (Kalcsics 2015, p. 606).

Finally, *compactness* is the idea that districts should conform to a particular shape or land area while achieving balance and continuity. Districting based only on balance and continuity can lead to districts with non-uniform topography that does not conform district needs or expectations. For example, U.S. congressional districts that are balanced but not compact are typically referred to as gerrymandered, a term coined in the 1800s to reflect district boundaries that were drawn specifically to achieve a political objective. Gerrymandered districts tend to comprise oblong or non-unform physical space that do not match expectations. Accordingly, non-compact districts also impact organizational efficiency because they typically do not minimize transportation costs as districts weave through different markets (towns, cities, counties).

From the modeling perspective, these districts tend to be sparsely connected where each region is only adjacent to one other region within the same district. In contrast, a compact district is one where regions tend to be well-connected and/or conforms to a known shape (e.g., are square or circular). Hence, compactness can be included in constraints or objectives for districting problems. For example, compactness may be modeled via constraints that require all districts to meet a minimum level of compactness. Compactness can also be an objective, often competing with balance—compact districts may have poor balance, and vice versa. USAREC ideally wants both balance and compact companies because of the requirement that company leadership teams physically visits their stations; non-compact companies increase transportation time and the number of unique markets in the company (Kalcsics 2015, p. 609). However, USAREC currently has no minimum standards for compactness to aim for, meaning it should be included as an objective in our model, rather than as a constraint.

C. DISTRICTING APPROACHES

It is widely understood that large districting problems with multiple objectives are NP-hard, which means they are computationally intensive and nearly impossible to generate a globally optimal solution. The top algorithms are only able to solve simplified models with up to 150 basic units (e.g., regions) (Ríos-Mercado and López-Pérez 2013, p. 529). Since this model is districting over 1330 recruiting stations into 235 companies a different approach is necessary. Towards this end, we leverage heuristic methods to build sub-optimal solutions utilizing techniques such as local search algorithms and relaxed aggregation methods. While heuristic methods cannot guarantee global optimality, we anticipate their use for the USAREC problem will still generate better company districts than are currently used by the organization.

Ricca and Simeone used heuristic methods for political districting. The authors compared the multi-objective (compactness and balance) results of four different local search algorithms on redistricting Italian political districts(Ricca and Simeone 2008, p. 1414). Starting with an initial, random, and feasible (contiguous) solution the researchers used the Descent, Tabu Search, Simulated Annealing (SA), and Old Bachelor Acceptance (OBA) methods to determine the best approach when considering simultaneous and oft-competing objectives. Since the initial solution was geographically contiguous (feasible), the resulting solutions were contiguous since the algorithms only made districting changes that retained feasibility. Comparing the other methods to the benchmark Descent method, they found that all other methods were superior in the following ways. OBA was superior in compactness, whereas Tabu and SA were superior in balance. SA was notably poor in its compactness results. The Descent method was the worst performer. Overall, their study shows that a programmatic districting algorithm can produce numerous fast and impartial solutions that can be further refined by subject matter experts for building the final districting plan.

King et al. 2018 applied districting methods in the United States. In the U.S., each state creates congressional districts by grouping contiguous census blocks into population-balanced districts. Since the most populous states have over 100,000 census blocks, King et al. 2018 reiterates that "political districting is an intractable discrete optimization problem" and NP-hard (King et. al 2018, p. 40). This paper uses steepest descent local search algorithm on an initially feasible and imbalanced solution to build locally optimal solutions. In addition to required population balance objective, the algorithm's secondary objective is to minimize network-edge cuts as the way to maximize compactness. Since each census block is connected to its adjacent blocks via an edge, a non-compact or gerrymandered congressional district would have a large number of census block edge cuts and blocks would be sparsely connected. Compact districts would have few edge cuts, since districts would be made up of census blocks that were largely connected their surrounding census blocks.

Each iteration of the King et al. 2018 algorithm considers current districting, adds adjacent census blocks to the district (and subtracts the block from its current district), then determines if the change improved the objective function. If the change improves the solution it is saved in a list and then only the best (steepest) change is implemented on next iteration of the districting plan. This process is repeated until no improvement is made. The authors find this local search method improves balance, maintains continuity. However, the final solutions are largely based on the initial feasible solution, such that starting with a completely different initial, feasible solution would completely change the final results.

Whereas compactness is considered tertiary to balance and contiguousness in the previous models, Validi and Buchanan focus on compactness in their model. The authors explore how minimizing the network's basic unit edge cuts maximizes district compactness. The authors utilized a mixed-integer program (MIP) to create compact districts while satisfying the other two districting requirements (Validi and Buchanan 2022, p. 12). This approach may be helpful for the USAREC problem as the resulting districts will have lower costs associated with transportation and market assignment overlap.

Incorporating compactness into a USAREC districting model is critical, but this thesis focuses on exploring improvements in district balance at the expense of compactness.

Local search algorithms are not the only method of solving this NP-hard problem. Ríos-Mercado and López-Pérez developed a relaxed aggregation method to determine the commercial territory design for a beverage distribution company. Instead of an initial feasible solution of units and districts, this algorithm starts off only with a set of K (# of districts) "headquarters" units that will "anchor" the districts final set of units. The other algorithm input is a set of basic units that are within three arcs of each headquarters units. With the limited number of basic units, the algorithm then calculates optimal, non-contiguous districting plan using the optimization function. Since this initial, optimal districting plan is not feasible (non-contiguous) the algorithm iterates backwards until the less-optimal districts are contiguous (Ríos-Mercado and López-Pérez 2013, p. 529).

D. SOLUTION TECHNIQUE

Districting is essentially an integer linear program with a multi-objective function to maximize balance (minimize variance) and compactness (minimize network edges cuts), while constraining for network continuity. A linear optimization formulation for solving this problem will be outlined in Figure 4 in Chapter III Section D, but solving was not attempted using a solver such as "cplex" or "cbc." All cited literature, specifically King, 2012 conclude that traditional linear optimization is not feasible as constraints "increase exponentially with the number of units, making it intractable for large problems" (King et. al 2012, p. 1215). In its place this thesis will build on King et al. and use a local search algorithm that maximizes balance and implements constraints for network continuity (King et al. 2018, p. 40). The USAREC station-company redistricting model will not control for compactness since this model wants to explore what, if any balance improvements are achievable while only controlling for continuity. USAREC currently focuses its station-company alignment heavily on compactness and market alignment, so studying enlistment balance is an approach that has not been conducted. This thesis will use the current districting alignment as the initial feasible solution and the local search algorithm will iterate through potential changes until a local optimal solution is found. Future work should include using this algorithm on a different starting solution and comparing the differences in the program's results.

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III. METHODOLOGY

In support of USAREC, this thesis provides a local search algorithm, USAREC station-company redistricting model, to develop recruiting company districting recommendations considering the balance for one specified metric and continuity constraints. The model can be used on any initial feasible solution (i.e., a districting map) and can redistrict companies so that they have less feature variance than the initial solution. For simplicity and demonstration purposes this model will be built and demonstrated using a single metric, enlistments, to firmly validate the algorithm's variance minimization function. With a slight modification, the model can be updated to balance multiple metrics relevant to USAREC, including enlistments, stations, recruiters, markets, and square-miles (e.g., compactness).

A. MODEL INPUTS

There are three primary model inputs: stations, their current assigned companies, and the USAREC network graph. Additionally, since this thesis is focused on balancing company enlistment contracts it is important to note that USAREC has averaged 66,500 contracts per year during the past four years. With 235 continental U.S. (CONUS) companies, this makes the average company contract production 283 contracts per year (Stokan 2021). The goal of the model is to assign each company a combination of contiguous stations that give them approximately 283 contracts.

The station input is set of all 1330 CONUS recruiting stations and their associated recruiting features i.e., number of enlistment contracts, qualified military available (QMA), high schools, markets, square miles, etc. For analysis, we assign each station a unique identification code which is based on their currently assigned company, battalion, and brigade. For example, the station in Times Square, New York City is identified as 1G2M, "1" to identify that they are in the 1st Recruiting Brigade, "G" to identify the New York City Recruiting Battalion, "2" to identify the Manhattan Recruiting Company, and "M" to identify their unique station. During the past four years, this station averaged 45 contracts per year with 3 assigned recruiters.

Stations are assigned to one of 235 CONUS recruiting companies. We assume that this number of companies will not change before and after districting. Figure 1 (Chapter I) shows the aggregation of currently assigned stations and companies into battalions. For example, if company 1G2 in Manhattan is currently assigned the following stations: 1G2M with 45 contracts, 1G2F with 95 contracts, 1G2N with 83 contracts, 1G2Q with 58 contracts, 1G2M would have a total 281 enlistment contracts. This number of contracts is slightly lower than the USAREC average of 283, so the goal of the USAREC station-company redistricting model would be to assign all 235 companies a set of contiguous stations that gets them as close to 283 contracts as possible. Ultimately, the model may assign 1G2 a set of stations that does not even include any of the starting four stations.

Lastly, the USAREC network graph is a dictionary of how stations are connected geographically to other recruiting stations. We construct the USAREC network based on data provided by the organization. The resulting network graph has 1330 nodes and 7234 arcs. With these edges, the USAREC station-company redistricting model will determine which company groupings are feasible.

B. MODEL CONSTRAINTS

USAREC did not impose any specific guidelines or restrictions on the model's construction or internal constraints; however, USAREC typically does impose district rules during any manual redistricting process. For example, the main districting rule USAREC typically imposes is that companies will have between 3 and 8 stations. This model will not impose any constraints other than continuity, so it is possible that the model recommends recruiting companies with one station or 20 stations depending on the input data (Stokan 2021).

C. MODEL ASSUMPTIONS

There are a couple of keys assumptions required for understanding this model and its results. First and foremost, this model assumes that USAREC has the correct number of recruiting stations spread across the United States. Secondly, the model assumes that the station's geographic boundaries are correct. Slightly modifying station boundaries may change the geographic borders between stations and thus change then network structure and ultimately the local search algorithm's potential results in each iteration.

D. MODEL

We develop a local search model to redistrict USAREC stations into companies. An individual recruiting station is part of the set of 1330 stations, mathematically notated as $i \in I$. Each station has a set of features, historical and current data such as past enlistments and QMA; these individual attributes make up a set of attributes, mathematically notated $j \in J$. Since this model is only trying to balance company enlistments, only one j will be considered. It is important to note that this model can be modified to include multiple data attributes. An individual recruiting company is part of a set of 235 companies, mathematically $n \in V$, where the number of elements N is the cardinality of V. The last model element is the network graph linking geographically contiguous stations. The resulting graph, $(i, k) \in G$, sparse by not including self-edges and only including edges among contiguous stations.

In Figure 4, we formulate a linear optimization problem using Naval Postgraduate School format. Our objective function (1) minimizes enlistment variance for the set of companies or sub-graphs in the network. The company enlistment mean, mathematically notated, $\overline{d}_j = \frac{\sum_i^I d_{ij}}{N}$, is the sum of station enlistments that all companies are attempting to approach through local search exchanges. Our objective function will always maintain the same number of companies or districts N (2) as it begins with. The function requires that each station is assigned only one company (3), and that it is a binary decision variable (5). Finally, our optimization function requires that stations within the same company (sub-graph) are connected in the network (4) (King et.al 2012, p 1215).

$$min\,Z = \sum_{n}^{V}\left[\sum_{i}^{I}(x_{in} * d_{ij}) - \bar{d_J}\right]^2 \quad (1)$$

$$\text{s.t.} \sum_{n\in V} x_{nn} = N \quad (2)$$

$$\sum_{n\in V} x_{in} = 1 \; \forall i \in V \quad (3)$$

$$Connected(n) \; \forall n = 1,2,3,\ldots,\mathrm{V} \quad (4)$$

$$x_{\mathrm{in}} \in \{0,1\} \; \forall i, n \in V \quad (5)$$

Figure 4. Optimization Problem Formulation

Since solving this optimization function is infeasible due to the large number of stations and companies, we construct a greedy heuristic algorithm to attempt to find a local optimal solution.

E. LOCAL SEARCH ALGORITHM

We implement the local search algorithm of King et al. (King et al. 2018, p. 40) for the USAREC problem. The local search algorithm starts with a feasible, initial solution and then conducts iterations until a better solution is not found. In each iteration, the model looks at all 235 companies and iterates through all their geographically bordering stations by adding one station at a time to the gaining company and detaching the station from the losing company. It then checks to ensure that the losing company is still contiguous, and if contiguous it calculates the enlistment variance for the gaining and losing companies. If the station-company switch results in less variance than the current iteration's variance, the switch is stored in a heap, sorted by which switch reduces the variance the most. After all station switches for all 235 companies are considered the best possible switch (top of the heap) is chosen as the starting point for the next iteration of the algorithm. The pseudo-code is listed below:

```
Local Search Algorithm

Input: Starting graph G0 = (V,E,S,Z) where V is the set of
stations, E is the station geographic borders (edges), S is
the company (sub-graph) that each station is assigned, and
Z is the initial company enlistment variance

Output: Locally optimal, station-company alignment
```

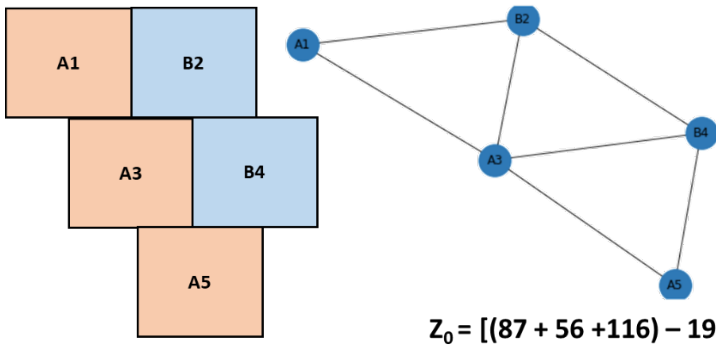
Iterative

```
    i = 0 Iteration Count
    j = 0 Station – Company Exchange ID
    H = empty graph

    Repeat
        Heap ⇒ Ø
        Zi = Z(G0)
        For all Sub-graphs {Sn} of G0
            For all Sub-graphs {xjk S'n} and {xjk ∈ Sn}
                Sn ⇒ Sn ∪ xjk
                S'n ⇒ S'n \ xjk
                H(j) = (V,E) with Sn and S'n
                If H(j) Connected
                    Calculate ZH(j)
                    If ZH(j) < Zi
                Save H(j) in Heap
        If Heap ≠ Ø then
            i = i + 1
            Gi = H with min Z in Heap
    Until Heap = Ø
    Return Gi
```

F. EXAMPLE OF MODEL OUTPUT

To demonstrate our model, we test its performance on a simplified districting problem with similar features to the USAREC problem. Figure 5 shows our simple problem; it mimics USAREC's organizational structure, but with only five stations (nodes) which are currently assigned to one of two companies, "A" and "B," orange and blue, respectively. The nodes are given example enlistment data d_i and their node adjacencies is based on geographic borders.



i	d_i	Adj
A1	87	B2, A3
B2	56	A1, A3, B4
A3	43	A1, B2, B4, A5
B4	92	B2, A3, A5
A5	116	A3, B4

$$Z_0 = [(87 + 56 + 116) - 197]^2 + [(56 + 92) - 197]^2 = 4802$$

Figure 5. Example Problem Initial Network Alignment, Node Attributes, and Variance Objective Function

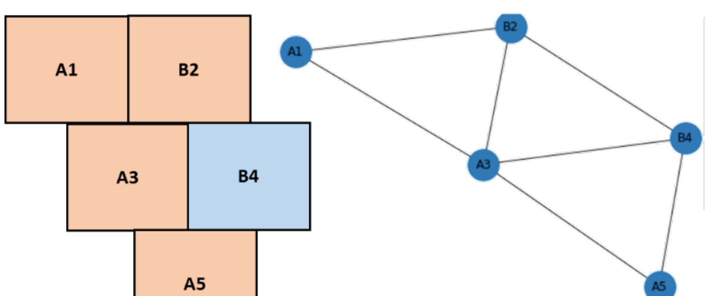
The model's first step is to calculate the current company enlistment variance in order to determine the baseline for all future potential improvements. To begin the model must calculate the company enlistment mean $\sum d_i$ / N where N equals the number of companies (87 + 56 + 43 + 92 + 116) / 2 = 197. To calculate the total variance for the current company alignment the model adds all the Company "A" $d_i s$ and subtracts the company enlistment mean and then squares the difference $[(87 + 43 + 116) - 197]^2 = 2401$. It does the same calculation for Company "B" $[(56 + 92) - 197]^2 = 2401$, adds "A" and "B" together and calculates the current company alignment variance as 4802. From this starting point the algorithm begins its local search as described above.

The local search considers each company subgraph S_n and determines their neighboring stations $V_i \sim S_n$. In the example problem, Company "A" is adjacent to stations B2 and B4, and Company "B" is adjacent to stations A1, A3, and A5. In the first swap calculation Company "A" adds station B2 and Company "B" is deducted B2. The algorithm checks to see if all of Company "B"'s remaining stations are contiguous, and if they are then it calculates the variance function $[(87 + 56 + 43 + 116) - 197]^2 + [92 - 197]^2 = 11025 + 11025$. Since this value is greater than 4802, the algorithm discards this COA and does not save it in the heap as highlighted in Figure 6. After considering the only remaining possible Company "A" move of adding B4, it moves onto evaluating Company "B"'s potential moves.

When considering adding A3 to Company "B" the algorithm determines that Company "A" loses its continuity since A1 and A5 are not geographically contiguous and therefore the solution is infeasible, and it does not calculate the variance function, as highlighted in Figure 7.

Ultimately, the USAREC station-company redistricting model finds only one COA that improves the variance by adding A1 to Company "B." A1 to Company "B" is $[(43+116) - 197]^2 + [(87+56+92) - 197]^2 = 1444 + 1444 = 2888$. This COA is saved into the heap and since it is the best possible COA the algorithm starts the second iteration with the following company alignment: Company "A" (A3, A5) and Company "B" (A1, B2, B4) as highlighted in Figure 8.

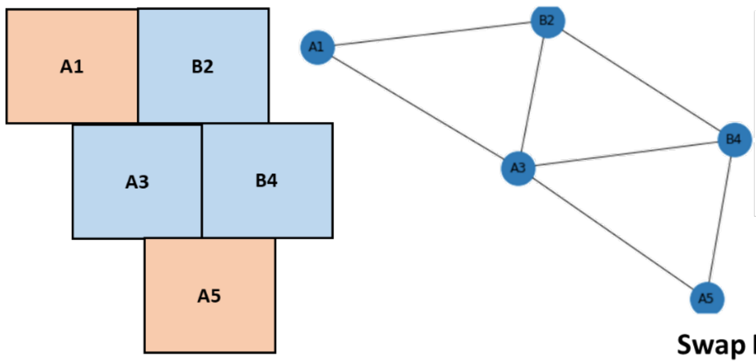
In the second iteration the algorithm conducts the same exhaustive local search but is unable to find an improved solution. The lowest variance in this iteration is adding B4 to Company "A" $[(43+116 + 92) - 197]^2 + [(87+56) - 197]^2 = 2916 + 2916 = 5832$, but since this is not lower than the variance of the previous iteration (2888), the algorithm terminates and returns the final alignment from the iteration 1: Company "A" (A3, A5) and Company "B" (A1, B2, B4) as highlighted in Figure 9.



i	d_i	Adj
A1	87	B2, A3
B2	56	A1, A3, B4
A3	43	A1, B2, B4, A5
B4	92	B2, A3, A5
A5	116	A3, B4

$$Z_{11} = [(87+56+43+116) - 197]^2 + [92-197]^2 = 22{,}050$$

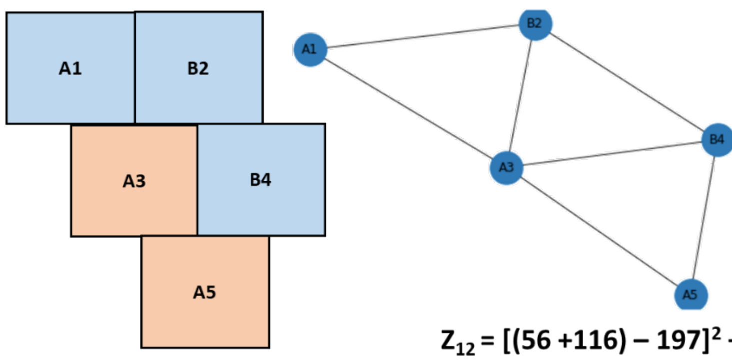
Figure 6. Iteration 1 Station Swap 1 Higher Variance Example (Model generated results hereafter)



i	d_i	Adj
A1	87	B2, A3
B2	56	A1, A3, B4
A3	43	A1, B2, B4, A5
B4	92	B2, A3, A5
A5	116	A3, B4

Swap Infeasible

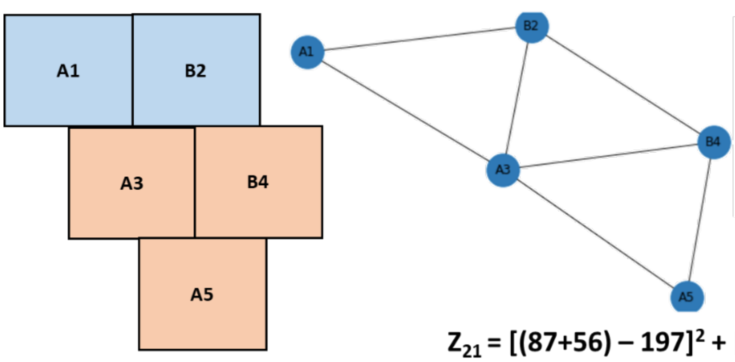
Figure 7. Iteration 1 Station Swap 2 Infeasible Example



i	d_i	Adj
A1	87	B2, A3
B2	56	A1, A3, B4
A3	43	A1, B2, B4, A5
B4	92	B2, A3, A5
A5	116	A3, B4

$$Z_{12} = [(56 + 116) - 197]^2 + [(87+56+92) - 197]^2 = 2888$$

Figure 8. Iteration 1 Station Swap 3 Lower Variance Example

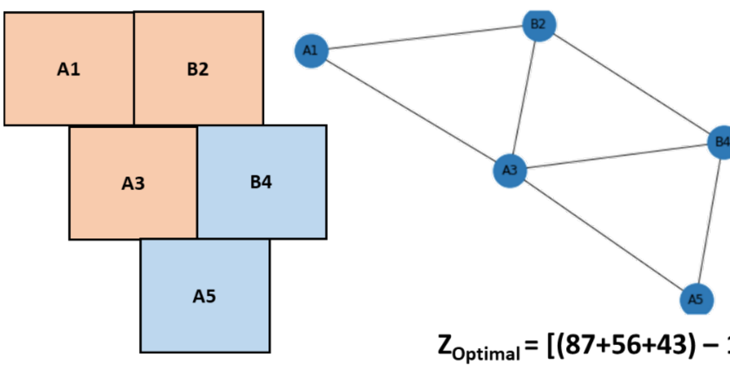


i	d_i	Adj
A1	87	B2, A3
B2	56	A1, A3, B4
A3	43	A1, B2, B4, A5
B4	92	B2, A3, A5
A5	116	A3, B4

$$Z_{21} = [(87+56) - 197]^2 + [(43+92+116) - 197]^2 = 5832$$

Figure 9. Iteration 2 Station Swap 1 Higher Variance Example

It is important to note that this is not the globally optimal solution to this example problem. Optimally when enumerating all feasible options, Company "A" would consist of A1, B2, and A3, and Company "B" would consist of B4 and A5 with a variance of $[(87 + 56+43) - 197]^2 + [(92 + 116) - 197]^2 = 121 + 121 = 242$. As seen in Figure 10, this alignment is at least two iterations away from the starting point since Company A needs to add B2 and lose A5. Unfortunately, if all potential intermediate steps are "uphill" the algorithm would not find the lowest point and it will get stuck or terminate in a local minimum. As previously mentioned, a USAREC station-company redistricting model is not designed to find the global optimal solution, instead it is used to make incremental improvements by considering all possible station to company exchanges and only selecting those that are improvements.



i	d_i	Adj
A1	87	B2, A3
B2	56	A1, A3, B4
A3	43	A1, B2, B4, A5
B4	92	B2, A3, A5
A5	116	A3, B4

$$Z_{Optimal} = [(87+56+43) - 197]^2 + [(92+116) - 197]^2 = 242$$

Figure 10. Globally Optimal Station Company Alignment

As described in Chapter III Section D, in a small districting problem with a handful of basic units and districts, a traditional assignment linear program optimization program could solve this problem without requiring a starting alignment of basic units to districts. A linear program is able to enumerate all ten feasible (Figure 11) station—company alignments, calculate their variances, and determine the optimal solution. In this approach the linear program determines that the example problem's optimal solution is COA 2 with the decision variables $X_{1A}, X_{2A}, X_{3A}, X_{4B}, X_{5B} = 1$ and $X_{1B}, X_{2B}, X_{3B}, X_{4A}, X_{5A} = 0$

COA	CO A	CO B	Variance
1	12	345	5832
2	123	45	242
3	135	24	4802
4	124	35	2888
5	13	245	8978
6	1	2345	24200
7	2	1345	39762
8	3	1245	47432
9	4	1235	22050
10	5	1234	13122

Figure 11. Example Problem COA Enumeration

IV. RESULTS

We run the USAREC station-company redistricting model to determine improved station—company alignment. We study six scenarios. Specifically, we study realignment of the entire command (referred to as the “Command model”), followed by realignment of each of the five USAREC regions (referred to as the “Regional models”).

The purpose of running the model on the entire command is to consider inter-regional company enlistment variance reduction (i.e., the realignment of stations from one brigade to another), which is not possible by studying optimal realignment for each region individually. Since inter-regional variance is significant (see: Ch I., Figure 3), we expect new station—company alignment to occur across brigades. Hence, the regional model allows brigade commanders to explore feasible station—company alignments that reduce mission risk. However, changing the number of companies within each region is very disruptive to USAREC operations. More feasible COAs involve realignment within each region. For individual regions, we assume each brigade has a fixed boundary, and therefore a fixed number of companies, stations, recruiters, and enlistments.

The remainder of Chapter VI is organized as follows: Section A will explore the results of the Command model, while sections B through F will analyze the results of the regional models. Section G will provide comparisons between the command and regional model results on specific geographic areas. Finally, Section H, will recommend initial implementation of the models results.

To compare USAREC station-company redistricting model’s results against the current alignment, Chapter VI sections B thru G’s sub-sections will be organized as follows: Sub-section 1 will display and discuss the current map and regional model’s resulting map. This portion will compare and contrast the resulting geographic boundaries, enlistment variance reduction, and company compactness. This section will also include a “zoomed-in” geographic example in order to highlight some of the mapped results more clearly. Sub-section 2 compares company enlistment variance using side-by-side a bar charts and a summary statistics table. This will highlight the model’s performance of reducing company enlistment variance. Sub-section 3 uses a side-by-side boxplot chart to compare the statistical distribution of each companies' mathematical compactness scores. For this thesis we used the Schwartzberg Compactness score that measures the ratio between a company's area and the length of its perimeter between [0,1]. For example, in Figure 12, company A and B have the same area, but company B has the a smaller perimeter, so it would be considered more compact and receive a Schwartzberg compactness score of 1, whereas company A would receive a lower Schwartzberg compactness score (Schwartzberg 1966).

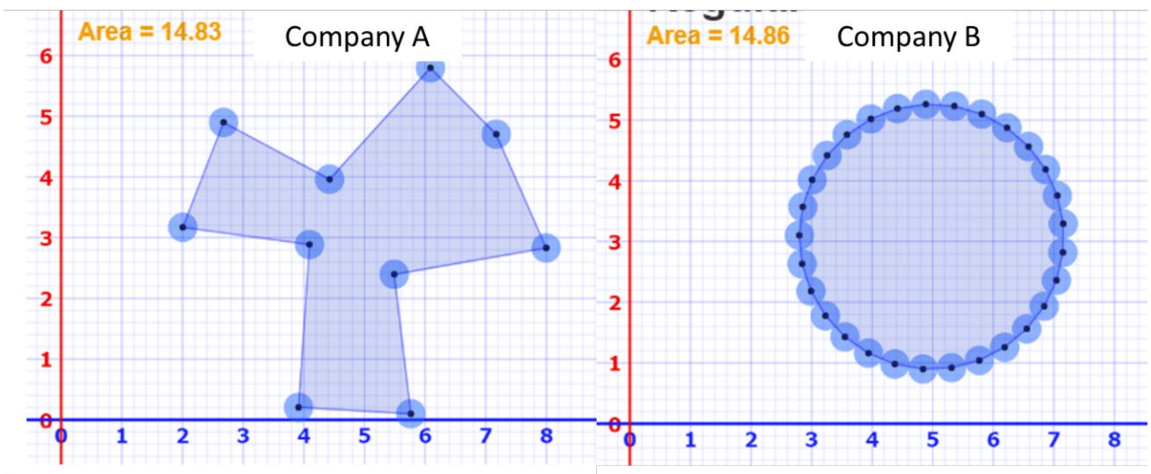


Figure 12. Schwartzberg Compactness: Area vs. Perimeter Example (generated by author)

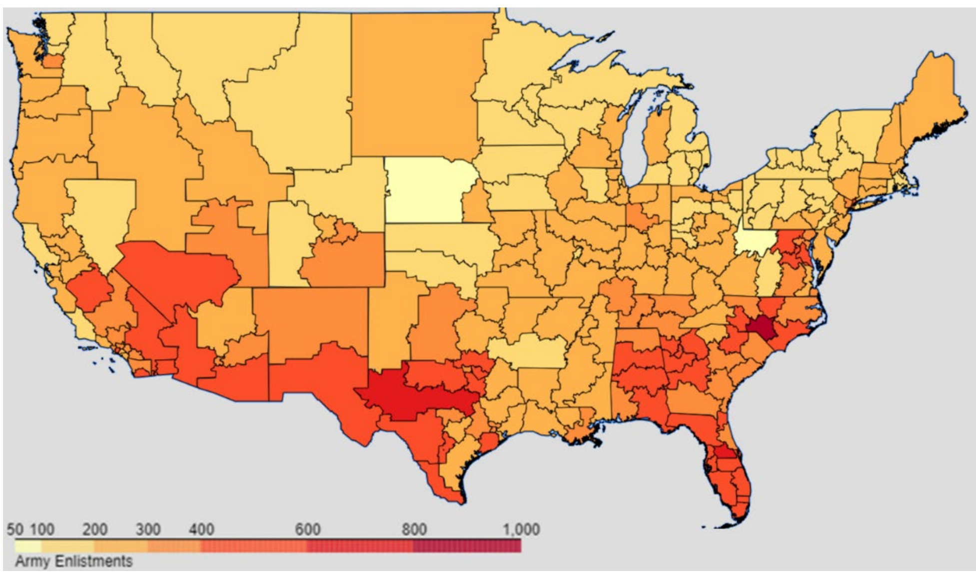
Finally, sub-section 4 uses a side-by-side bar chart to compare the "market integrity" of the current and regional model's resulting companies. There are numerous ways to quantitatively analyze company market integrity, some of which will be discussed in Chapter V, but for this thesis we counted the unique Core Based Statistical Areas (CBSA) that each company had a station located within. CBSAs are formally defined by the U.S. government as groups of U.S. counties that are economically linked to an urban core. There are over 900 CBSAs in the U.S. broken down further into metropolitan and micropolitan statistical areas. Consider an example, where there are two companies that each have six stations, if company A has its six stations located in only one unique CBSAs and company B's six stations that are located in six different CBSAs, then you would consider company A having more market integrity than company B.

Note: Section A's sub-section organization will vary slightly from the template, but they will contain the same items of analysis.

A. ENTIRE COMMAND

A.1. **Current Map**

Current USAREC station—company alignment places a priority on market alignment and compactness and less importance on minimizing company enlistment variance as seen in Figure 13. Figure 13 shows the current territory of the current 235 continental United States (CONUS) recruiting companies without considering current battalion and brigade boundaries.

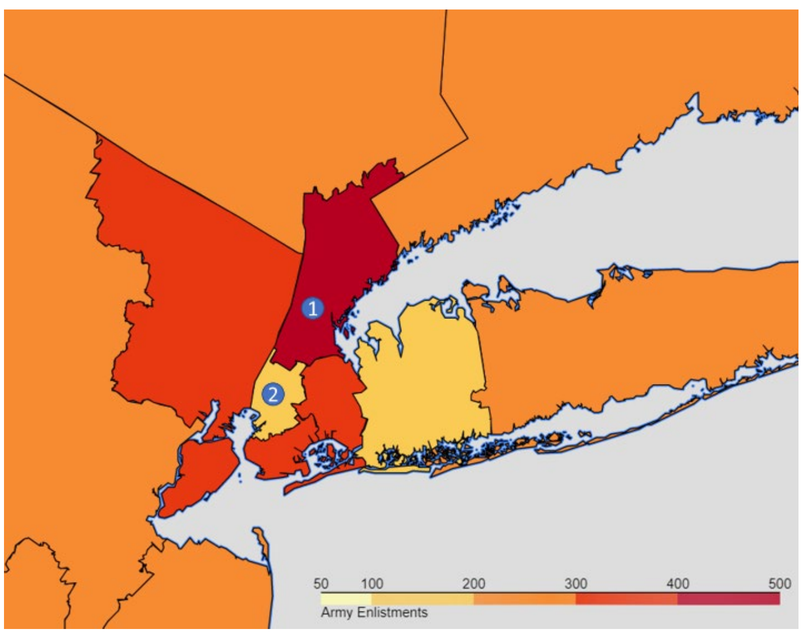


Generated using USAREC provided data (Stokan 2021).

Figure 13. Current Station—Company Alignment (Average Annual Army Enlistments per Company)

Current company boundaries are compact for the reasons discussed in Chapter II, Section B Some are non-compact but are generally elongated along major highway networks to minimize travel times to outlying stations. Both urban and regional companies follow similar rules and are clustered around the largest nearby U.S. CBSA. We find several inefficiencies in this alignment that lead to greater enlistment variance and mission risk.

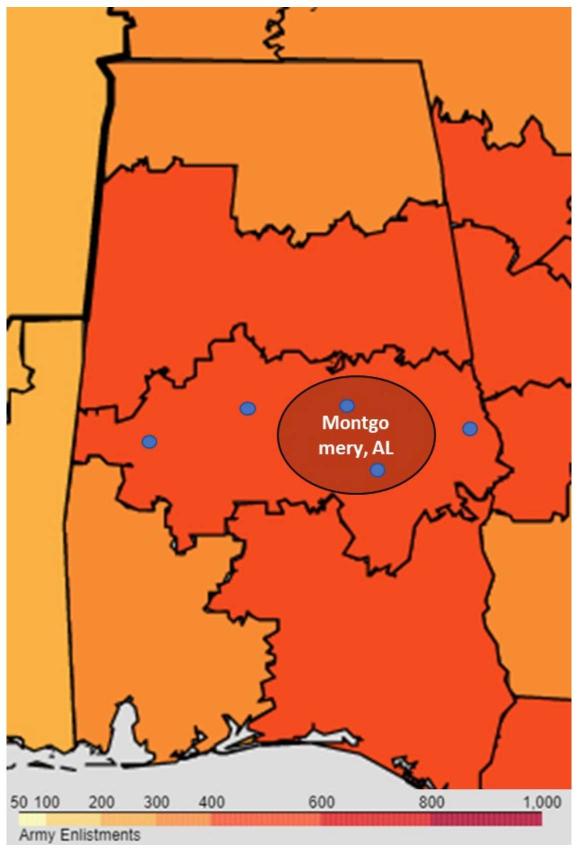
First, urban companies tend to follow local jurisdictional boundaries that increase mission risk. Urban companies, defined as companies where all stations are located within the same CBSA, include very large CBSAs such as New York City or Los Angeles (which have more than five companies) and large CBSAs such as Seattle or St. Louis (which have one to four companies). Urban companies generally follow existing market boundaries such as school districts, counties, and states. Despite the benefits of market integrity and compactness, the company enlistment imbalance within these geographically small areas can be severe as seen in New York City CBSA. Figure 14 shows that stations in neighboring companies in Manhattan (company 2) produces significantly fewer contracts than the stations in the Bronx (company 1). Realigning stations can improve enlistment balance between company 1, company 2, and surrounding companies at the expense of market integrity by disregarding borough and state boundaries.



Generated using USAREC provided data (Stokan 2021.

Figure 14. New York City CBSA Current Company Alignment (Enlistments per Company)

The majority of USAREC companies are regional companies which are headquartered in mid-size CBSAs like Montgomery, AL or Grand Rapids, MI. Regional companies are assigned all of the four or fewer stations within their own CBSA as well as nearby stations in adjacent CBSAs, up to a maximum of eight stations. Figure 15 highlights the state of Alabama's companies, specifically noting the location of Montgomery, AL CBSA and its company's five stations, two of which are located within the CBSA. Since all of these companies are higher enlistment producing than the USAREC average, either adding a sixth company to the state of Alabama or incorporating stations from lower producing adjacent states would reduce company enlistment variance.



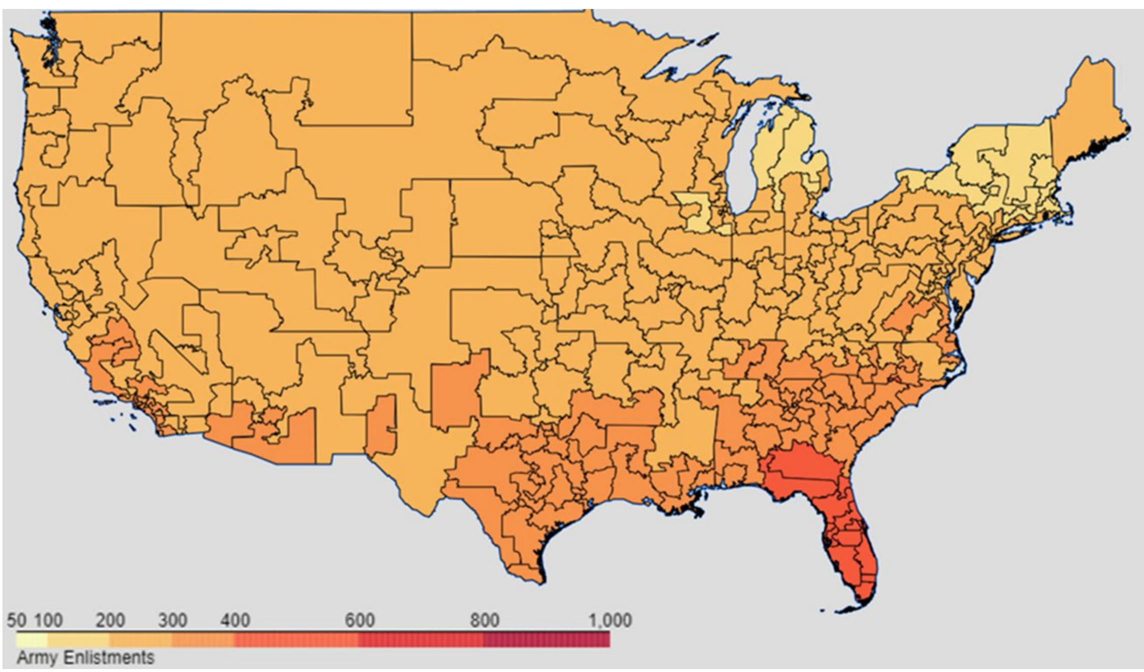
Generated using USAREC provided data (Stokan 2021).

Figure 15. Alabama Current Company Alignment with Montgomery, AL CBSA and Montgomery Company Stations highlighted (Enlistments per Company)

A.2. **Mapped Results**

The USAREC station—company redistricting model was run on the entire command of 235 companies. Each iteration considered each company and exchanging each neighboring station between its current and new company as described in Chapter III, Section E. The model required 514 iterations to produce the following map, Figure 16.

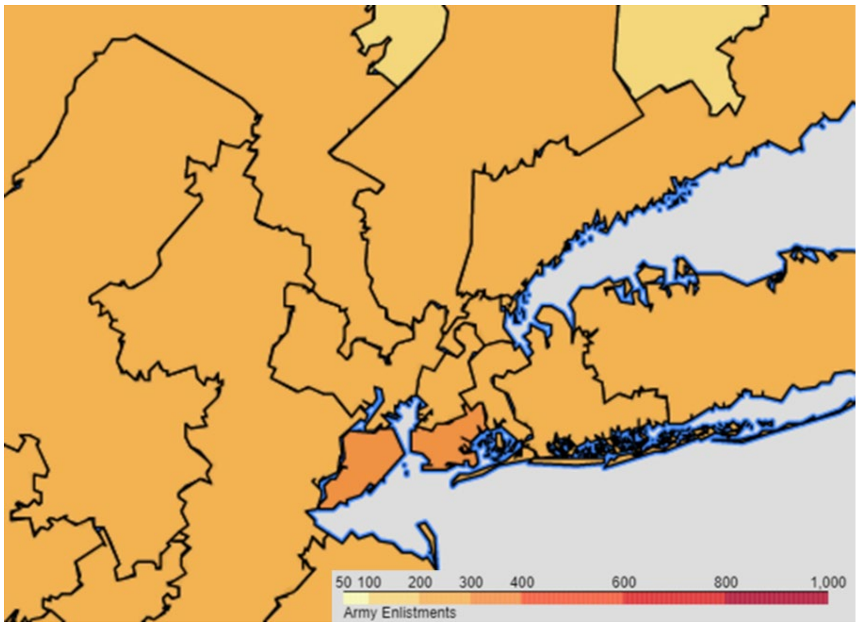
Figure 16 companies achieve lower variance of enlistments but are less compact. Companies stretch across state lines and do not follow traditional road networks since these factors were not included in the model. Interestingly, companies along the U.S. coasts and borders, especially peninsulas of Florida, Michigan, and New England regions, are more likely to have the larger variance than companies located in the U.S. interior. This is likely due to the fact that the USAREC station-company redistricting model only considers switching stations geographically nearby each other. The constrained geography in peninsulas leads to fewer feasible station swaps due to physical (and network) boundary conditions.



Generated using USAREC provided data (Stokan 2021) and model generated results.

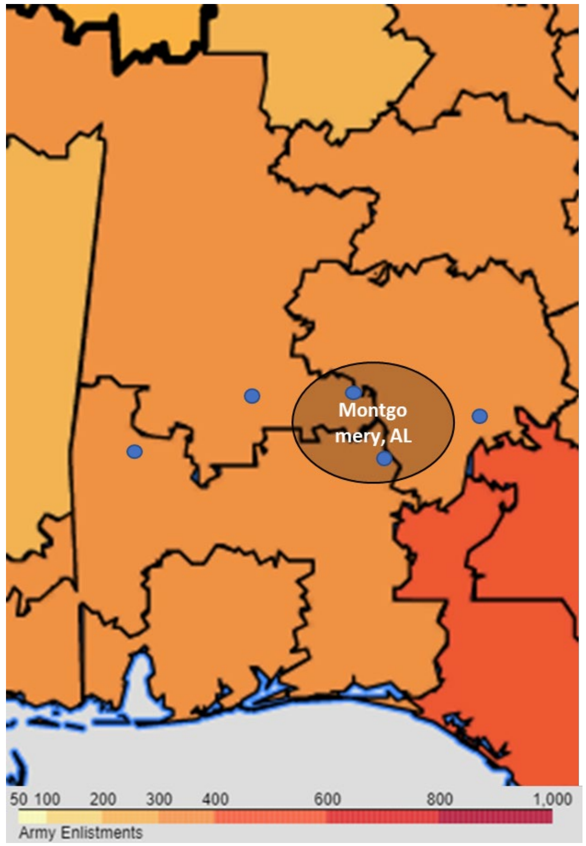
Figure 16. Command Model Station—Company Alignment (Army Enlistments per Company)

Both urban and regional companies saw their enlistment variance decrease, but visually their market integrity decreased as seen in Figures 17 and 18. In Figure 17, NYC state and borough boundaries are no longer identifiable. In Figure 18, Montgomery, AL CBSA two stations are split into different companies, and the other companies incorporated stations in neighboring states.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 17. New York City CBSA Command Model Station—Company Alignment (Enlistments per Company)

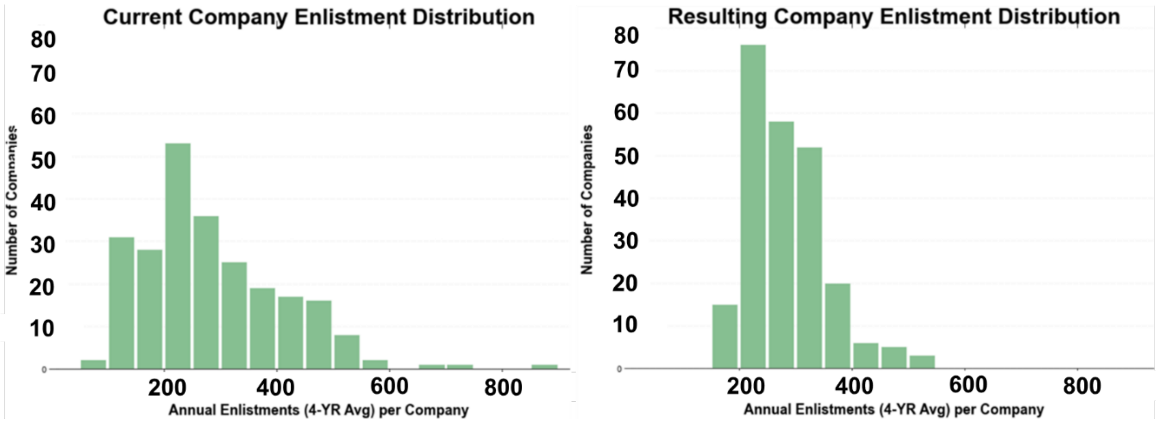


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 18. Alabama Command Model Station—Company Alignment with Montgomery, AL CBSA and Current Montgomery Company Stations highlighted (Enlistments per Company)

A.3. **Span of Control Metrics**

We compare the local search results to the current alignment across the entire command and inter-regionally. Figure 19 compares the enlistments per company in the current command alignment to the enlistment per company from local search results. Table 1 presents the summary statistics for Figure 19. The results highlight the reduction in variance produced by local search. The number of companies producing over 400 enlistments per year reduced from 44 to 14. Moreover, the number of companies producing less than 200 enlistments per year reduced from 60 to 15. The new alignment increases the peak of the distribution, which reduces USAREC mission risk. Table 1 highlights a drop in the enlistment per company standard deviation from 125 to 69, a 44% decrease, with a corresponding decrease in the coefficient of variation (i.e., [standard deviation / mean]) from 0.44 to 0.24.



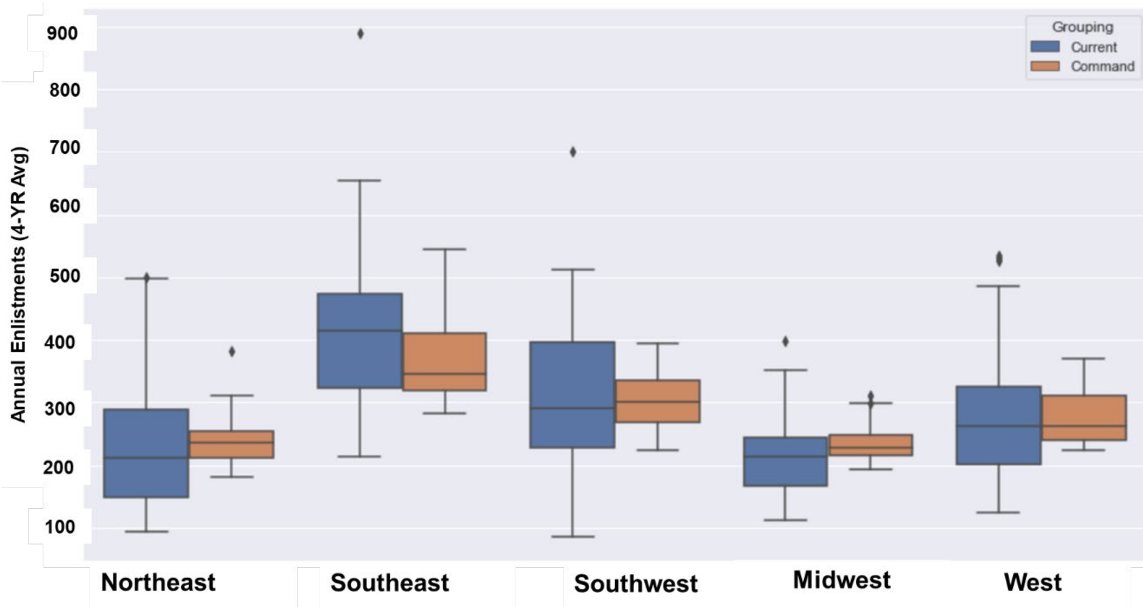
Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 19. Army Enlistments per Company – Current Alignment (left) vs. Command Model (right)

Table 1. Army Enlistments per Company (Current Alignment vs. Command Model)

Summary Stats	Current Alignment	Command Model	Change
Mean	283	283	0
Standard Deviation	125	69	-56
Minimum	86	181	+95
Maximum	889	543	-346
Coefficient of Variation (CoV)	0.44	0.24	- 0.20

Figure 20 highlights the Command model reduction, but not elimination, of inter-regional company enlistment variance. As also seen in Figure 16 (command map), the Southeastern and Southwest region companies maintain higher enlistments averages than the Northeast and Midwest region companies even after realignment, likely due to the limited local search options along the exterior borders. The variance is also due to the inability to fully realign companies that are far away in the network (i.e., graphically). Optimal realignment would likely move more companies from northern regions with fewer total enlistments to southern regions. However, this is unlikely to happen given our USAREC station-company redistricting model and the current company alignment as a starting point. Instead, starting from a different initial alignment (e.g., with more companies in the south) could further reduce variance across low and high enlistment regions.



Generated using USAREC provided data (Stokan 2021) and model generated results.

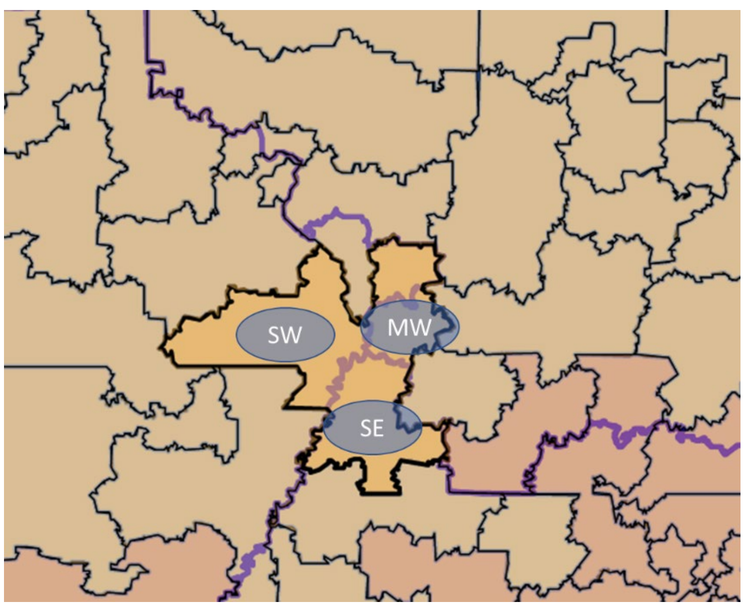
Figure 20. Army Enlistments per Company by Region (Current Alignment vs. Command Model)

The only way to remove inter-regional variance is to change the number of companies per region. The USAREC station-company redistricting model changed the region-company count by eight, as listed in Table 2. The Southeast region gained the most companies by adding four companies to manage its stations. Conversely, the Midwest region saw a significant reduction in companies, losing seven of its original 54 companies to neighboring regions.

Table 2. Companies per Region (Current Alignment vs. Command Model)

Region	Current Companies	Resulting Companies	Change
Northeast	49	48	-1
Southeast	44	48	+4
Southwest	49	51	+2
Midwest	54	47	-7
West	39	41	+2

Figure 21, highlights the difficulty in calculating companies per region since the Command model occasionally assigned stations, orginially located in different regions into the same company. For example the highlighted company includes stations that were originally in the Midwest, Southwest, and Southeast regions. In these cross-regional situations we assign the company to the region based on the current assignment of a majority of its stations. Since the company in the figure included three stations in the Southwest region, two stations from the Southeast region, and one station from the Midwest region, the company was assigned to the Southwest region for analysis in subsequent analysis sections.

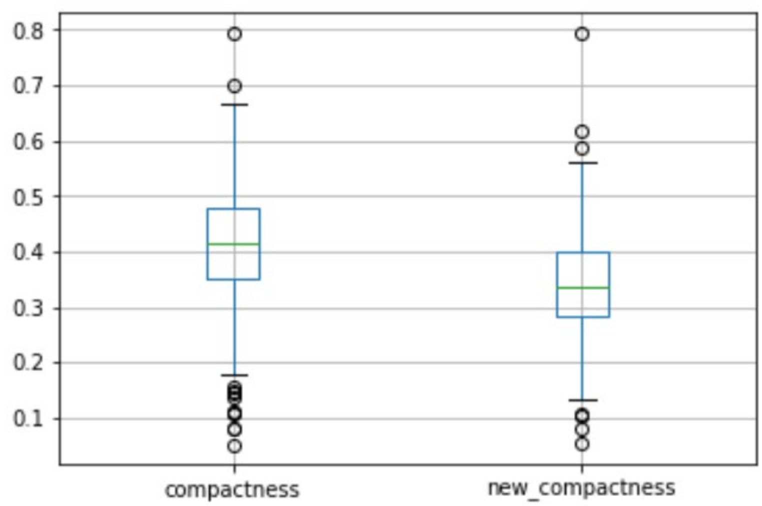


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 21. Cross-Regional Company Example – Command model generated

A.4. Compactness

We estimate the compactness of company realignment using the Schwartzberg Compactness score. As seen in Figure 22, the USAREC station-company redistricting model produces recruiting companies that are 15% less compact than the current alignment with the average compactness score decreasing from 0.41 to 0.34. Additionally, the 25% of companies considered the most compact saw their average compactness decline from 0.6 to 0.5. Still, in terms of percent change, the worsening in compactness was less than the improvement in variance reduction.

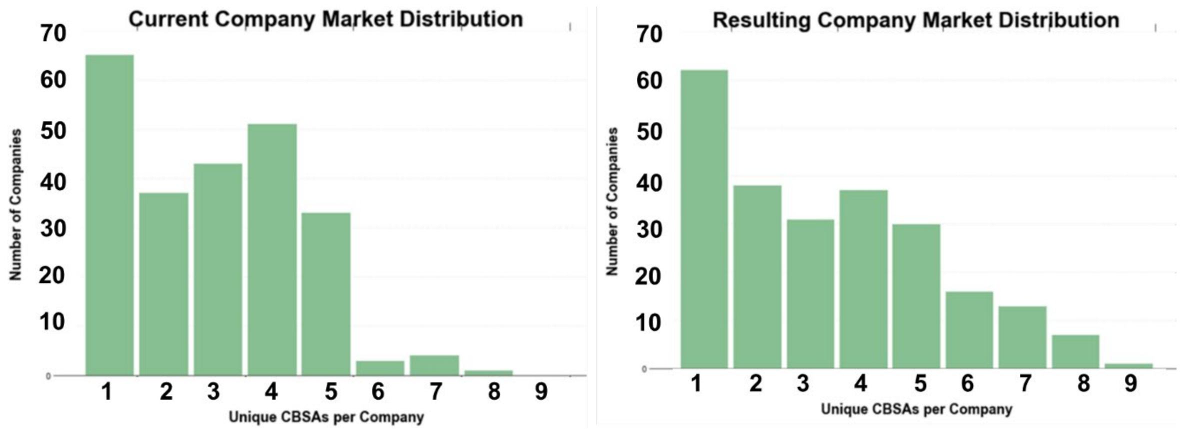


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 22. Company Schwartzberg Compactness (Current Alignment vs. Command Model)

A.5. Market Integrity

A critical measure of market integrity is the number of unique CBSAs that any company is assigned. A CBSA is a U.S. government defined population center and its surrounding, economically linked counties. In order to measure this metric, each station was assigned to one CBSA based on its facility location. Note: Stations can be assigned territory (ZIP codes) in multiple CBSAs, but the facility can only be located within one CBSA. As seen in Figure 23, nearly all current companies are assigned stations in less than six CBSAs. The USAREC station-company redistricting model increased the number of companies with six or more unique CBSAs from less than 10 to over 45.

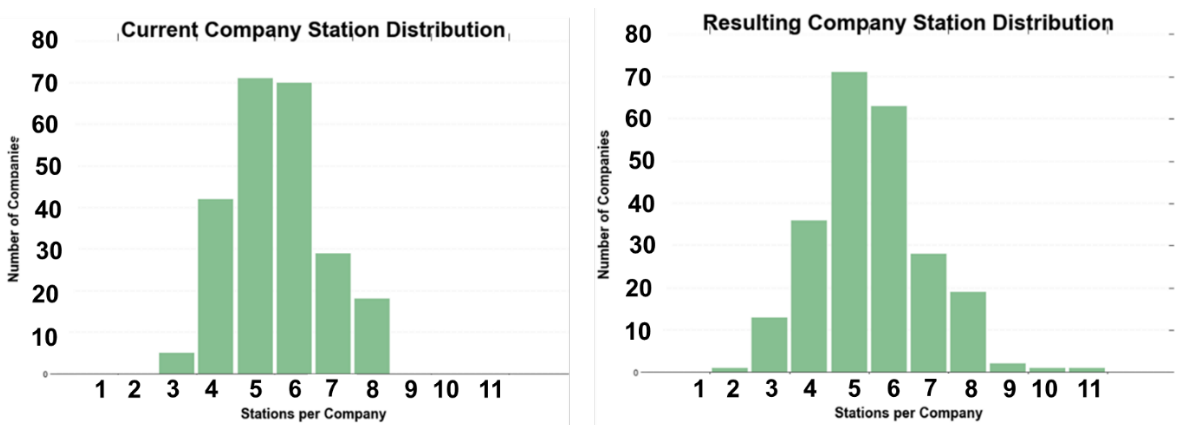


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 23. Unique CBSAs per Company (Current Alignment vs. Command Model)

This result was caused by a two primary reasons, increasing stations per company and the gerrymandering effect. First, in the cases of regional companies with lower enlistment production, the USAREC station-company redistricting model increased the number of stations in a company up to 11, up from a maximum of 8 in the current alignment as seen in Figure 24. Increasing the number of stations in regional companies also increases the number of unique CBSAs that a company is assigned. Secondly, our model causes a gerrymandering effect where companies add stations outside of their primary CBSA in order to decrease variance. For example, most New York City companies are currently assigned stations only within the New York City CBSA, so their unique CBSA count is one. The USAREC station-company redistricting model results in a handful of the "outer ring" New York City CBSA companies gaining stations from adjacent CBSAs in Allentown, PA, Hartford, CT, and Trenton, NJ which increases their unique CBSA count from one to two.

Unfortunately, the impact of gerrymandering is difficult to observe in the CBSA histogram (Figure 23) because of an offsetting effect. While some companies expand outside of their current CBSA, there are companies in higher enlistment producing areas that decrease their unique CBSA count by reducing their number of assigned stations, as seen in the increase of two and three station companies in Figure 24b. This is caused when a higher producing regional company is broken up into two companies to reduce enlistment variance and the resulting companies have roughly half of the stations of the original company. Assuming that most stations in a regional company are in their own CBSA, fewer stations equal fewer unique CBSAs for the company.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 24. Stations per Company (Current Alignment vs. Command Model)

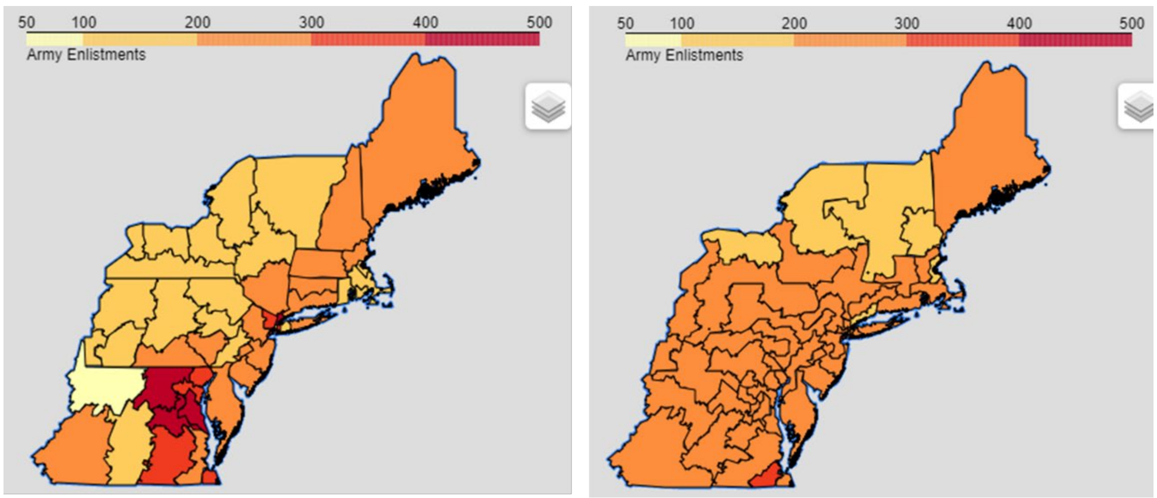
B. NORTHEAST REGION

We consider the USAREC station-company redistricting model results on individual regions. We begin with the Northeast. Changing the company boundaries within each region will highlight what is possible to reduce regional mission risk without disrupting the other regions.

1. Mapped Results

In Figure 25a, current Northeast companies are visually compact, but maintain high enlistment variance between dense urban companies in Washington, DC, and New York City CBSAs and non-urban companies in western portions of the region. Interestingly, counter to other urban companies across the command, the Boston, MA CBSA companies have lower enlistments compared to the regional companies in the rest of the New England area, indicating that the Boston CBSA may have too many companies assigned.

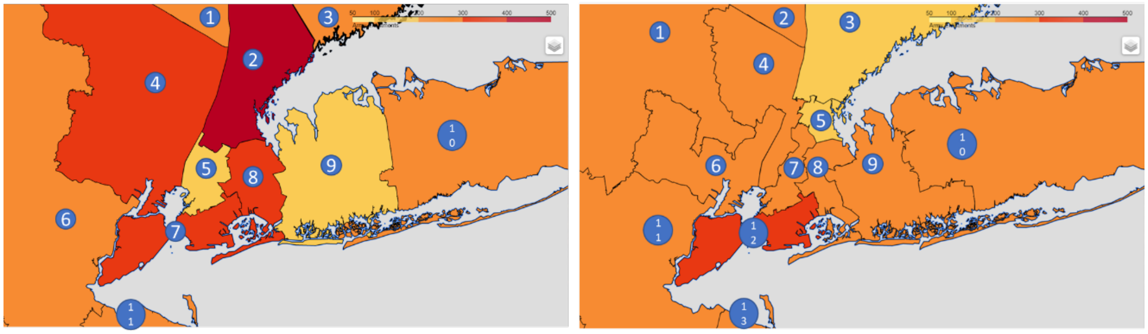
In Figure 25b, the Regional model decreases visual compactness and market integrity, stretching companies in non-compact shapes, across state lines, and splitting CBSA stations into multiple companies. Additional companies were added to the New York and Washington, D.C., CBSAs, while stations in rural areas in upstate New York and western Pennsylvania were consolidated into fewer, larger companies.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 25. Northeast Region—Current Alignment (left) vs. Regional model (right)

Figure 26 compares New York City CBSA's current and Regional model alignment. Since the New York CBSA has a higher-than-average enlistment per company, additional companies are needed to reduce variance. In Figure 26b, a 12th and 13th company are added to the New York CBSA, relocating from other areas within the Northeast region. Specifically, a new company is added to divide the stations currently assigned to company 2, primarily being split into companies 3 and 5, but also portions of companies 4 and 7.

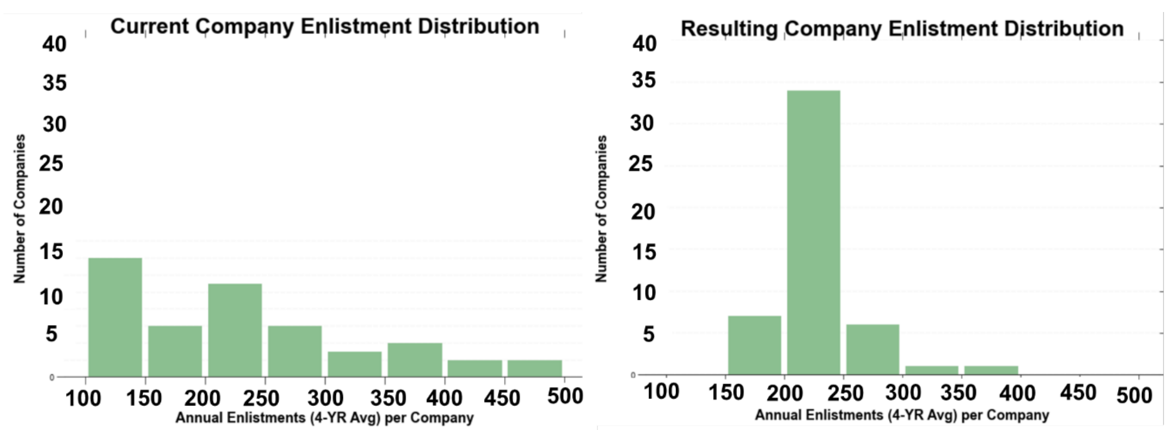


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 26. New York City CBSA Local Example—Current (left) vs. Regional Model (right)

2. Span of Control Metrics

Figure 27a highlights that the Northeast region currently has the highest number of companies in USAREC producing between 100 to 150 enlistments per year, significantly below the average of 283 enlistments. Additionally, the distribution between low and high producing companies was the closest to a uniform distribution in USAREC. In Table 3, we see that despite the region having a higher internal coefficient of variance (CoV) than the overall command (0.45 vs. 0.44), the Regional model performed very well, reducing the regional enlistment CoV by nearly 70% from 0.45 to 0.14.



Generated using USAREC provided data (Stokan 2021) and model generated results.

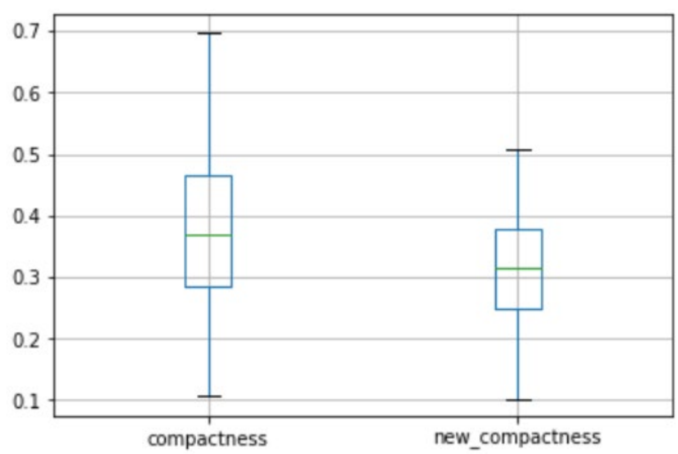
Figure 27. Northeast Region Army Enlistments per Company (Current Alignment vs. Regional Model)

Table 3. Northeast Region Army Enlistments per Company (Current Alignment vs. Regional Model)

Summary Stats	Command	Region	Regional Model	Change
Mean	283	228	228	0
St Dev	125	103	32	-71
Minimum	86	93	182	89
Maximum	889	499	382	-117
CoV	0.44	0.45	0.14	-0.31

3. Compactness

The Regional model significantly worsened the compactness scores for the Northeast region, as shown in Figure 28. The model reduced the company average compactness from 0.37 to 0.32, but for the most compact 25% of companies, their average compactness dropped from roughly 0.6 to 0.45, a larger drop than in the Command model. This means while company enlistment variance plummeted, compactness also dropped, albeit not as significantly.

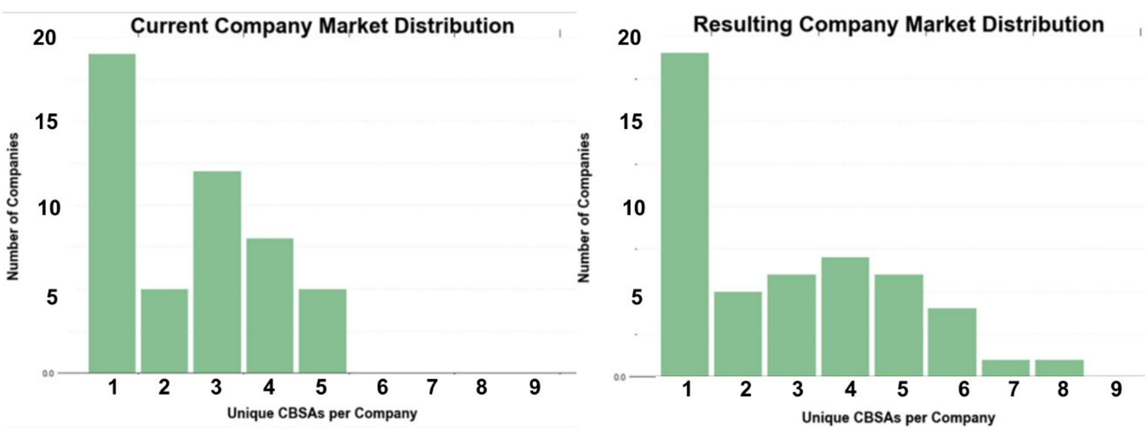


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 28. Northeast Region Company Geo-Compactness (Current vs. Regional Model)

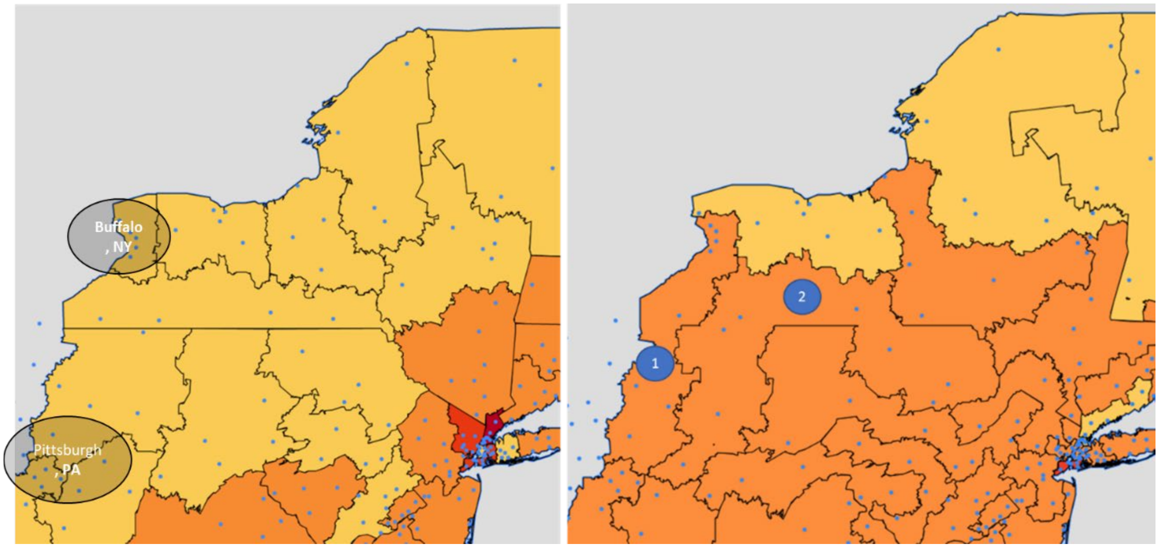
4. Market Integrity

Figures 29 compare the number of unique CBSAs that each company is assigned. The Regional model increased the number of companies responsible for stations located in six or more unique CBSAs from 0 to 6. These results are caused by both the gerrymandering effect and the station growth effect. In Figure 30, we see an example of each. First, Company 1 highlights the gerrymandering effect, where companies break market integrity to reduce enlistment variance. Company 1 contains 4 of 5 Buffalo, NY CBSA stations, and then instead of including the fifth station it stretches south into the Pittsburgh, PA CBSA, including its northernmost station. Secondly, company 2 in Western Pennsylvania and New York is an example of company station growth. In the current alignment this area's stations were part of four smaller, lower enlistment companies each with five or fewer stations. In order to increase company enlistments in this rural area, eight stations from multiple companies were consolidated into a large company that stretches across both states.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 29. Northeast Region Unique CBSAs per Company (Current vs. Regional Model)



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 30. Gerrymander Effect (Current vs. Regional Model)

Overall, the Northeast Regional model moved several companies into the dense urban corridor that stretches from Washington, D.C., to Boston, MA. This shift in leadership resources allows commanders to better balance mission risk by spreading the urban core's higher enlistment missions over more companies. Consequently, commanders would be required to consolidate the more rural, regional stations into fewer companies, leaving these commanders with a higher station management workload, by increasing their responsibilities from 4 to 5 stations to 6 to 9 stations.

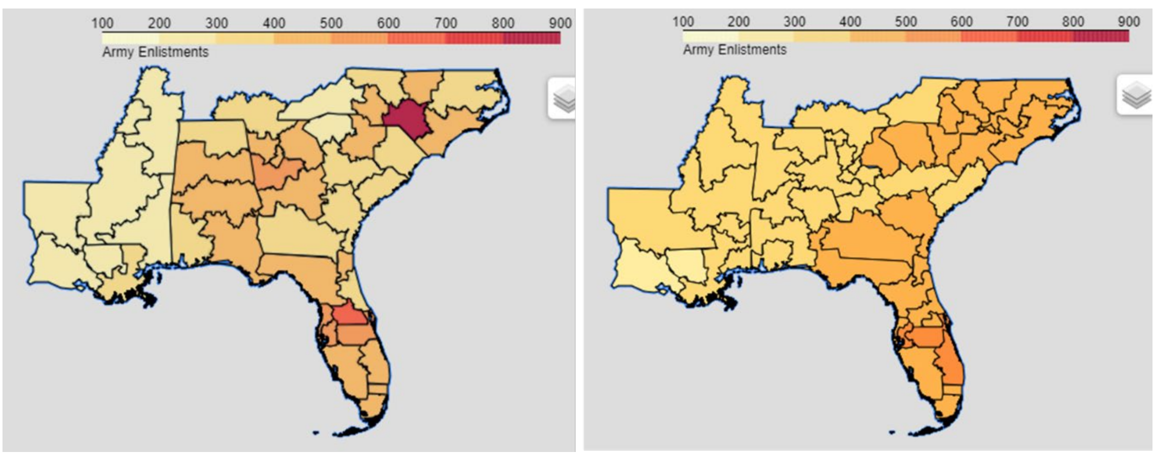
C. SOUTHEAST REGION

The Southeast region is the highest enlistment production region in the command with an average of 404 annual enlistments per company, compared to the command average of 283. In the Command model we saw that the region gained four companies from other regions, but in the Regional model the region redistributed its 44 companies to determine what internal mission risk reduction measuses are feasible.

1. Mapped Results

In Figure 31a, we see that nearly all current Southeast companies are regionally aligned companies, that are compact surrounding medium and large CBSAs. This regional alignment focus has created noticable company enlistment variance. Even when excluding the outlying company, the dark red company encompassing the Fayetteville / Fort Liberty, NC CBSA, we see significant enlistment variance when comparing regional companies in Louisiana and Mississppi where a majority produce 100–300 enlisments per year, against Alabama companies where a majority produce over 400 contracts per year.

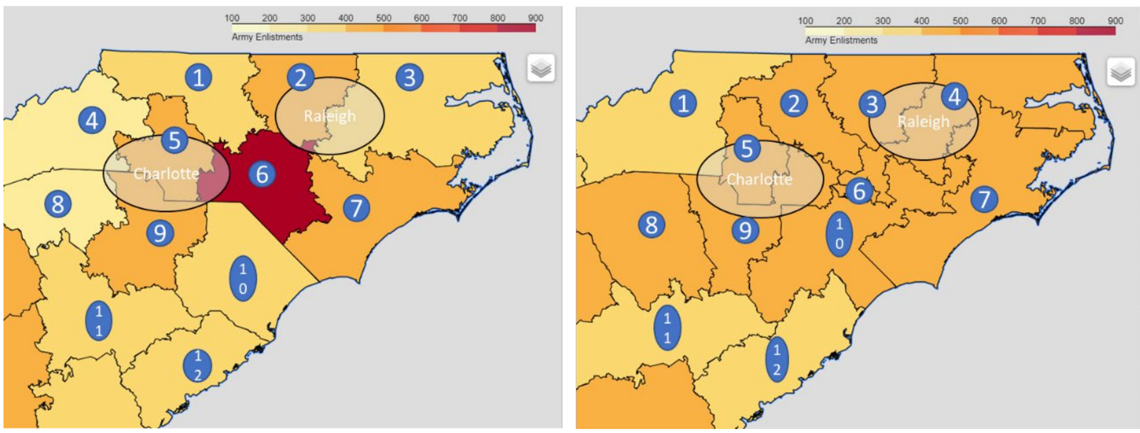
As seen in Figure 31b, the Regional model visually decreases the regional company compactness, creating gerrymandered companies. For example, the model resulted in companies ignoring state boundaries and stretching between Mississippi and Alabama in an attempt to reduce the current enlistment variance. Interestingly, the Florida companies look relatively similar to the their current aligment, likely due to the previously mentioned issue with local search on pennisulas.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 31. Southeast Region (Current Alignment vs. Regional Model Results)

Taking a closer look at North and South Carolina in Figure 32a, we see that companies are regionally aligned around large CBSAs such as Charlotte and Raleigh-Durham, while the Fayetteville / Fort Liberty, NC company (# 6) heavily skews enlistment production in the region. In Figure 32b, we see that this area of the Southeast region keeps its 12 current companies, indicating the area does not have too many or too few companies than the rest of the Southeast. Importantly, the model breaks the Fayetteville, NC company into a two-station company #6, and the remainder of its six stations are assigned to surrounding companies in Greensboro, NC, Raleigh, NC, Columbia, SC, and Florence, SC (#1, #4, #9, and #10, respectively). Geographically this alignment increases the travel and time burdens for commanders gaining these formerly Fayetteville company stations, but for that battalion commanders managing these companies and the region as a whole, the overall mission risk is more effectively reduced.

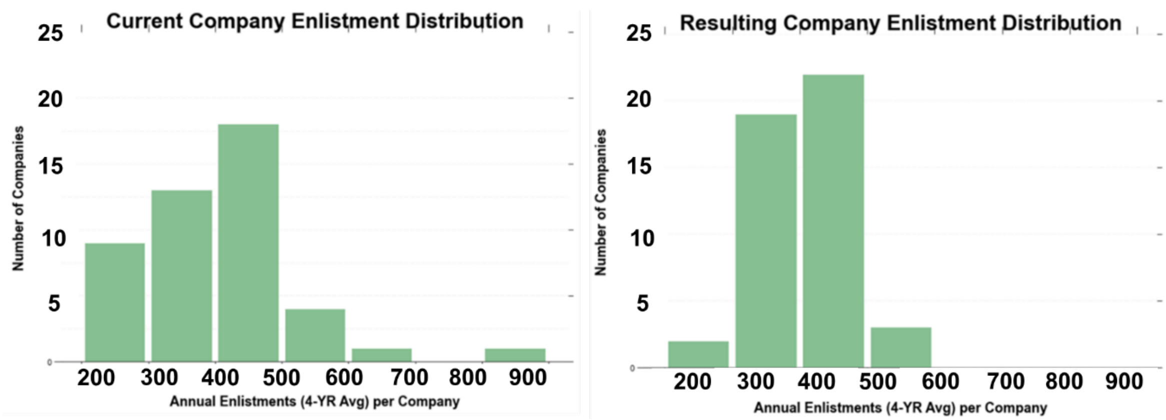


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 32. North and South Carolina Local Example (Command vs. Regional Model Results)

2. Span of Control Metrics

Figure 33, we highlight the current and resulting company enlistment distribution. Noticeably the current alignment companies have a similar right skew to the command's distribution, with a relatively smaller number companies producing greater than the average of 404 enlistments per year.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 33. Southeast Region Army Enlistments per Company (Current Alignment vs. Regional Model)

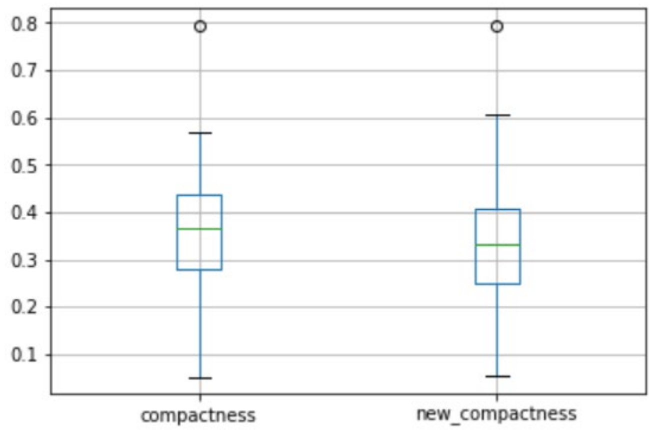
Table 4 highlights the current and Regional model summary statistics. Notably, the Southeast region has a 31% smaller CoV than the overall command signifying that the Regional model has less work to do to reduce variance than in other regions. The Regional model was not able to reduce the CoV as significantly is it was in the command or Northeast region, likely due the Florida peninsula effect.

Table 4. Southeast Region Army Enlistments per Company (Current Alignment vs. Regional Model)

Summary Stats	Command	Region	Regional Model	Change
Mean	283	404	404	0
St Dev	125	123	58	-65
Minimum	86	213	273	60
Maximum	889	889	543	-346
CoV	0.44	.30	.14	-0.16

3. Compactness

The Regional model did not significantly change the Southeast region's Schwartzberg compactness scores in Figure 34, with the average score only dropping from 0.36 to 0.34. The region's most compact 25% of companies also remained relatively the same with an average score of 0.5.



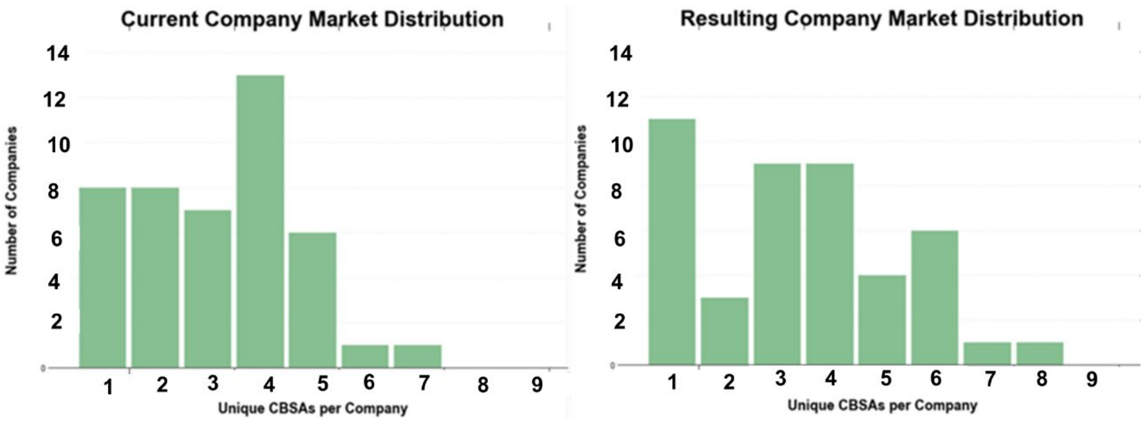
Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 34. Southeast Region Company Geo-Compactness (Current vs. Regional Model)

4. Market Integrity

Figure 35, the market integrity count shows an increase in single CBSA companies from eight to 11 and increase in six-plus CBSA companies from two to eight. The increase in single CBSA companies is positive if it caused by better market alignment to geographic boundaries, but since this was not part of the algorithm's objectives, its likely due to the reduction in company station counts in higher producing areas. For example, the Fayetteville, NC company originally had its six stations in three unique CBSAs (Fayetteville, Sanford, and Southern Pines, NC), but the resulting company only had two stations, both in Fayetteville reducing its count from three to one unique CBSA.

Conversely, the model resulted in a worse outcome by growing the six-plus CBSA companies to eight. This occurred primarily through the gerrymander effect by taking relatively market cohesive companies with 4 or fewer CBSAs and adding stations in outlying CBSAs in order to improve variance.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 35. Southeast Region Unique CBSAs per Company (Current Alignment vs. Regional Model)

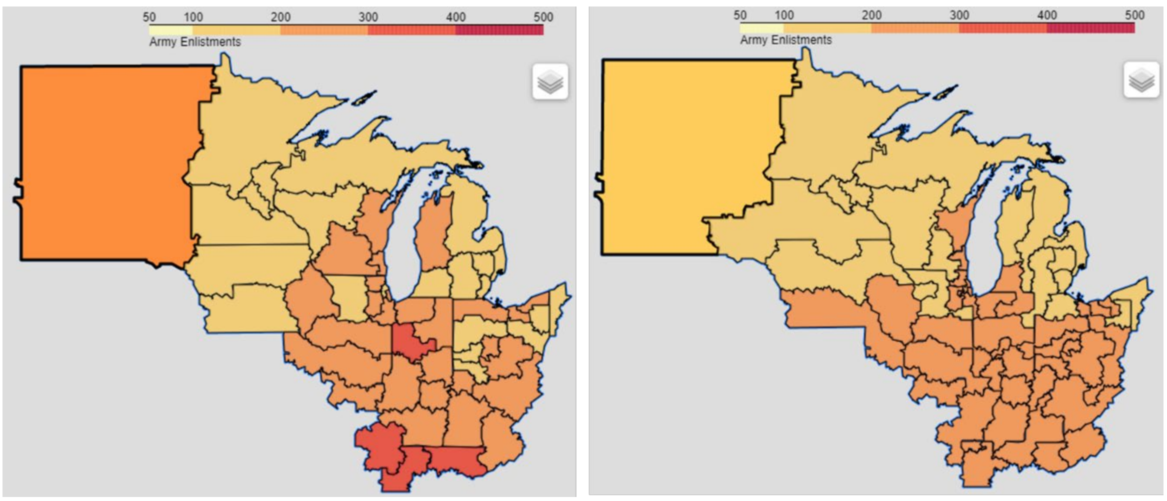
Overall, the Regional model performed as designed despite facing limited search options in the Florida peninsula. One way to correct this issue is to start with a different starting feasible solution with an additional company assigned to Florida (by taking a company away from a lower production region such as Louisiana or Mississippi), and checking to see if the model can further reduce enlistment variance like it did for the Northeast region.

D. MIDWEST

The Midwest region currently possesses the most companies (54), but also the lowest number of Army enlistments in the command, meaning that the region's companies are significantly lower contract producing than their peers. In the Command model, we saw that the region lost seven of its companies to other regions, but in the Regional model, the region maintained and redistributed its original 54 companies.

1. Mapped Results

In Figure 36a, we observe that most companies in the Midwest region are reasonably compact, regional companies with the exception of cluster of urban companies within the Chicago, IL CBSA. Overall, there appears to be less company enlistment variance in the Midwest region than other regions, with the most noticeable variance being the higher production companies located in the southern portions of the region in the state of Tennessee. In Figure 36b, the Regional model visually reduces enlistment variance by creating less geographically compact and regionally aligned company boundaries. Most noticeably, the Regional model reduces the variance in Tennessee by removing state boundary considerations and allowing some companies from the state of Kentucky to move south to include Tennessee stations. This resulted in an increase in the Kentucky company enlistments, and reduced the Tennessee company enlistments, overall reducing mission risk for the battalion commander that oversees both states.

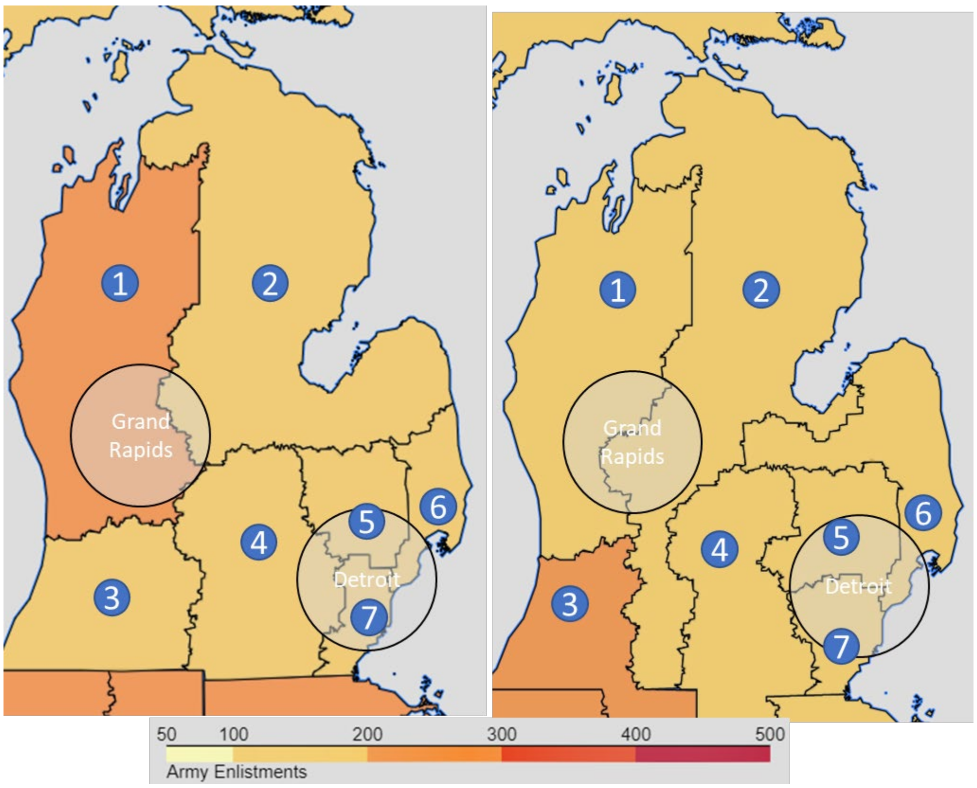


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 36. Midwest Region (Current Alignment vs. Regional Model Results)

In a local example, Figure 37a highlights the low enlistment variance within the state of Michigan. The seven companies held state border integrity and six of the seven produced less enlistments than the regional average of 211. Due to the state's companies' low enlistment production, it's reasonable to presume that the Regional model would reduce the number of companies in the state of Michigan to six, which would balance the company enlistment variance with the rest of the Midwest region. Interestingly, likely due to the peninsula effect, the Regional model was not able to reduce this variance and Michigan retained seven companies, albeit with two companies (#3 and #4) including stations in Ohio and Indiana as seen in Figure 37b.

Additionally, the Regional model reduces variance by splitting company #1, which encompasses the Grand Rapids CBSA, into two companies, breaking market integrity.

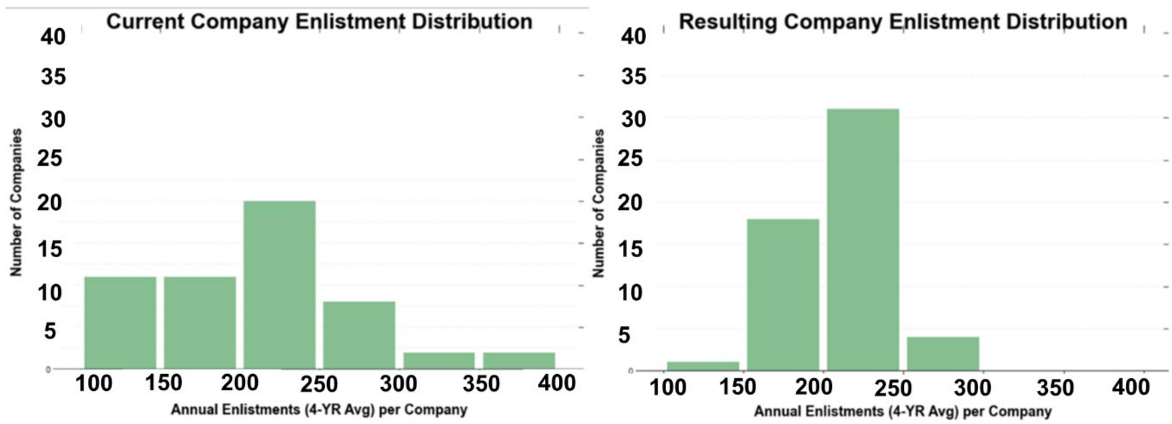


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 37. Michigan Local Example (Current vs. Regional Model Results)

2. Span of Control Metrics

Figure 38 highlights the reduction from eleven to one for companies with less than 150 enlistments and significant improvement in effectively spreading risks and span of control responsibilities.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 38. Midwest Region Army Enlistments per Company (Current Alignment vs. Regional Model)

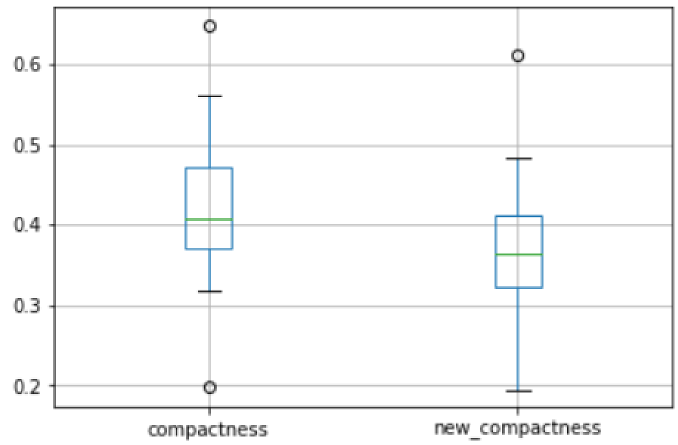
Table 5 highlights that the Midwest region currently has a lower coefficient of variance than the entire command and the other regions (0.44 vs. 0.28). The Regional model was able to reduce it by 50% to 0.14, a similar percentage drop to the Southeast region and command.

Table 5. Midwest Region Army Enlistments per Company (Current Alignment vs. Regional Model)

Summary Stats	Command Comparison	Region	Regional Model	Change
Mean	283	211	211	0
St Dev	125	61	31	-30
Minimum	86	111	142	31
Maximum	889	398	286	-107
CoV	0.44	0.28	0.14	-0.14

3. Compactness

As with all regions, Figure 39 highlights that the Regional model reduced Schwartzberg compactness from an average of 0.41 to 0.35. The Regional model also significantly worsened compactness of the 25% least compact companies from an average score of 0.35 down to 0.25.

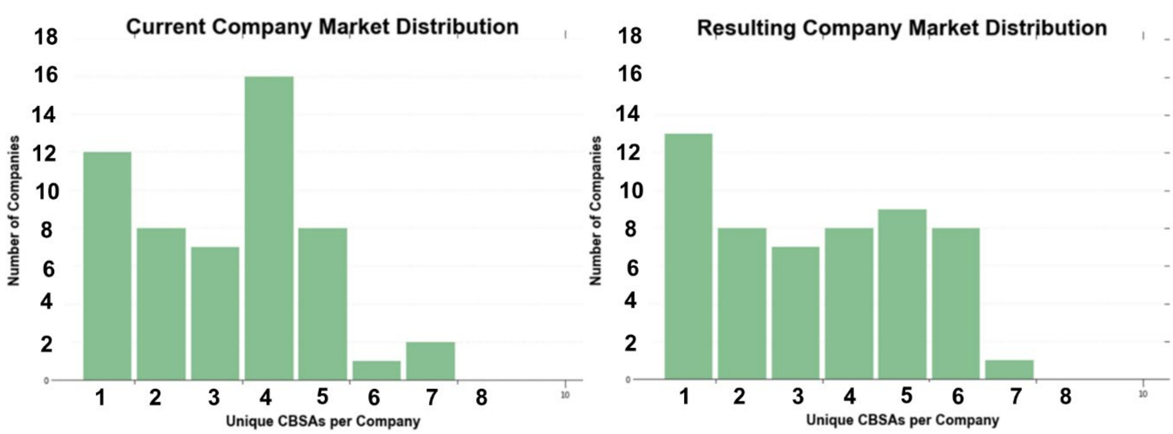


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 39. Midwest Region Company Geo-Compactness (Current Alignment vs. Regional Model

4. Market Integrity

Figure 40 again demonstrates that the Regional model results in the growth of six and seven CBSA companies (from three to nine) at the expense of companies that were previously generally capped at four and five CBSAs. This is most likely due to the gerrymander effect as companies split CBSAs in order to reduce enlistment variance as seen with the Grand Rapids CBSA.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 40. Midwest Region Unique CBSAs per Company (Current Alignment vs. Regional Model)

E. SOUTHWEST

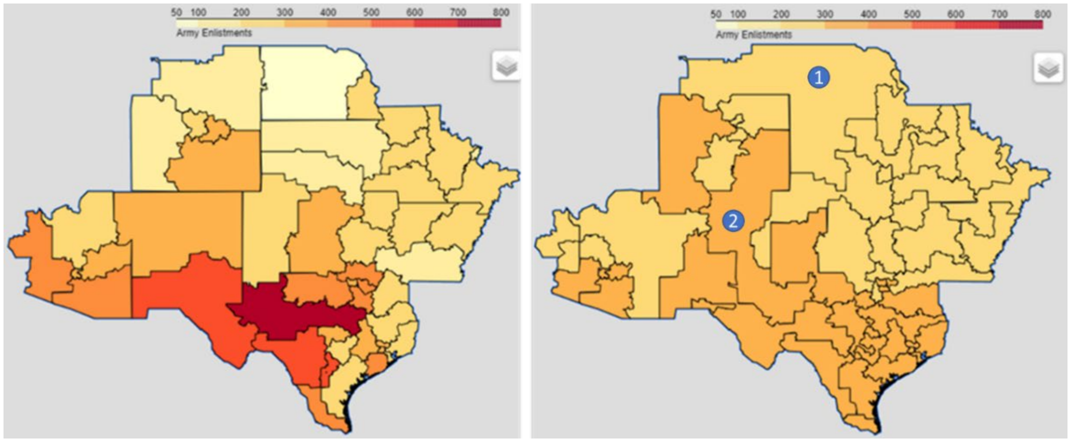
The Southwest region is the second highest enlistment production region in the command. Its 49 companies produce an average of 311 enlistments, slightly higher than the command average of 283. Its companies are primarily geographically large, regional companies with a several small, urban companies, clustered around the largest CBSAs such as Houston, San Antonio, and Dallas, TX, St. Louis, MO, Phoenix, AZ, and Denver, CO.

1. Mapped Results

In Figure 41a, we note that the Southwest region has internal geographic enlistment variance with the companies in the denser southern portions of the region such as Texas and Arizona having higher enlistments than the companies in the northern and more rural portions of the region such as Kansas and Nebraska. Note: In these very rural regions, in order to reduce the travel time requirements for company leadership to visit outlying stations, USAREC is willing to sacrifice some enlistment balance in order to have half-day drivable geographic regions.

In Figure 41b, we see the results of the Regional model and observe the extremely large geographic regions required to achieve enlistment balance. For example, companies #1 and #2, stretch across multiple states, with company #1 stretching 500 miles from eastern Nebraska to central Wyoming. Overall, the model was able to significantly reduce overall variance, but the intra-regional north and south variance remains visible.

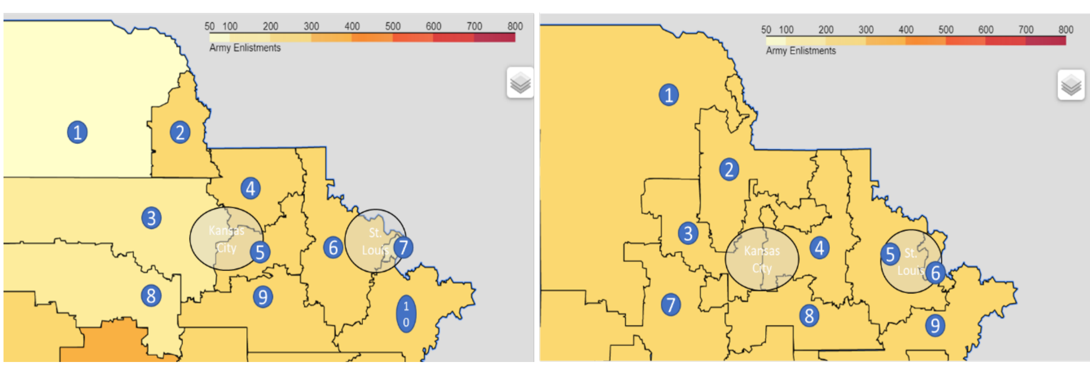
This is likely due to the increasingly rural and geographic spread of cities west of the Mississippi River. Unlike east of the Mississippi River, where medium to large CBSAs are typically no more than a two-hour drive apart from each other creating a dense network of interconnected CBSAs, western CBSAs are more spread out with drive-times between large CBSAs being more than three hours. For example, moving east to west along the Interstate-70/80 corridor the distances between large CBSAs increases, Columbus, OH to Indianapolis, IN (3 hours), Indianapolis to St. Louis (4 hours), St Louis to Kansas City (4 hours), Kansas City to Denver, CO (9 hours), Denver, CO to Salt Lake City (8 hours), Salt Lake City to Reno NV (8 hours).



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 41. Southwest Region (Current Alignment vs. Regional Model Results)

In Figure 42a, we see that the northeast portion of the region encompassing the states of Kansas, Missouri, and Nebraska, include nine regional companies and one urban company (#7 St. Louis, MO). The current companies are generally compact and expand along interstate highways. In Figure 42b, we see that due to lower enlistments in this portion of the region, the Regional model decreased the company count to nine total companies. Additionally, along with making Company #1 geographically very large, the remaining companies are visually less compact with companies and split CBSAs into multiple companies.

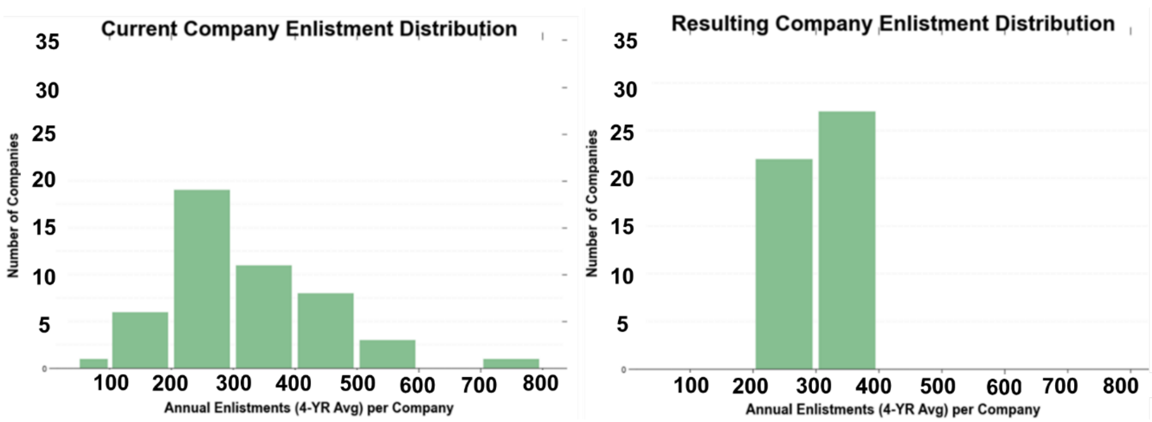


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 42. Nebraska, Kansas, Missouri Local Example (Current vs. Regional Model Results)

E.2. Span of Control Metrics

In Figure 43, we see the current and resulting distribution of company enlistments. With the exception of the outlier, surrounding the Fort Hood, TX military installation, the Southwest region started with the most normal distribution of the five regions. As a result of the model nearly all variation was eliminated as seen in Figure 43b where all companies' enlistments were between 200 and 400 enlistments.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 43. Southwest Region Army Enlistments per Company (Current Alignment vs. Regional Model)

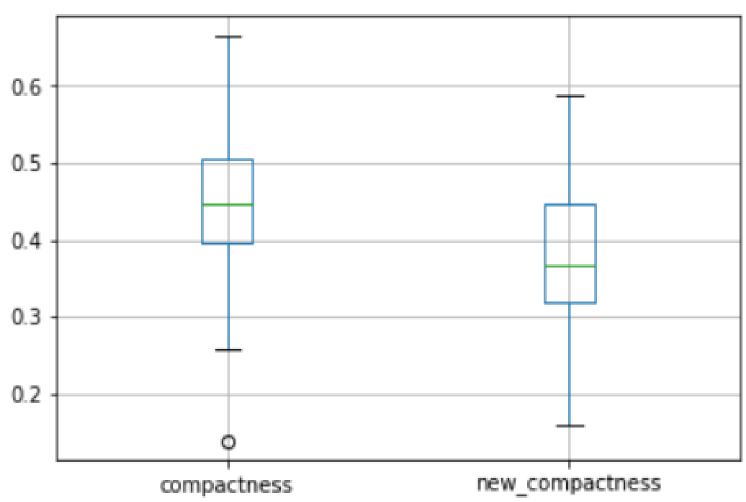
Table 6 highlights the current and Regional model summary statistics. With an initially high CoV, the Regional model reduced CoV by nearly 65%, slightly smaller than the Northeast region's percentage decrease. Of note, the Regional model reduced the Fort Hood, TX company from 700 to 393 enlistments by assigning some of its stations to adjacent companies, reducing mission risk for the Central Texas battalion commander.

Table 6. Southwest Region Army Enlistments per Company (Current Alignment vs. Regional Model)

Summary Stats	Command Comparison	Region	Regional Model	Change
Mean	283	311	311	0
St Dev	125	118	41	-77
Minimum	86	86	250	164
Maximum	889	700	393	-307
CoV	0.44	0.37	0.13	-0.24

2. Compactness

Figure 44 highlights the decrease in Schwartzberg compactness score from an average of 0.44 to 0.36, a slight drop in measured compactness. Similar to the Midwest region, the current companies that were least compact saw a more significant percentage drop in compactness, dropping from an average of 0.32 to 0.24. This decrease, as with other regions, is expected as the model attempts to reduce variance regardless of geographic compactness impacts.

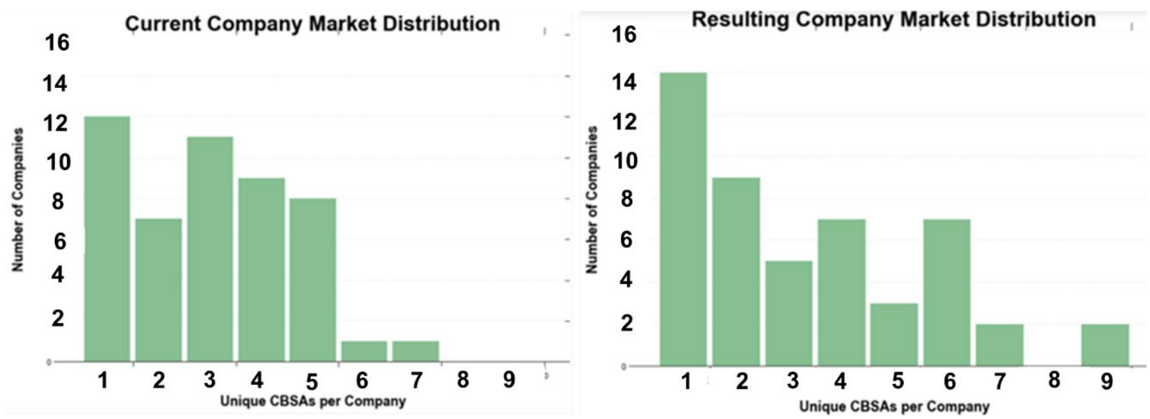


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 44. Southwest Region Company Geo-Compactness (Current Alignment vs. Regional Model)

3. Market Integrity

In Figure 45 we observe the same significant growth in companies with six or more unique CBSAs, increasing from two to eleven. This is a result of a mixture of the gerrymandering effect and the station growth effect specifically in the rural regions, where some companies increased their station counts from the previous maximum of eight, increasing up to eleven stations in order to better balance company enlistments across the rural, low enlistment regions.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 45. Southwest Region Unique CBSAs per Company (Current Alignment vs. Regional Model)

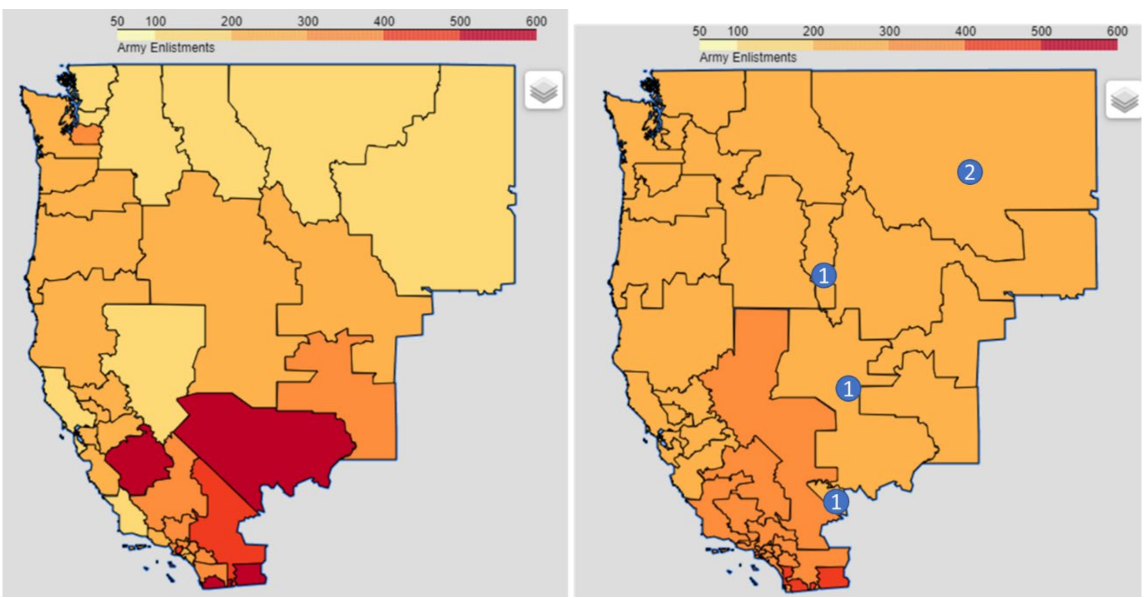
F. WEST

Finally, we analyze the Regional model's results on the West region. The region, much like the Southwest region, is a mixture of dense, urban companies stretching along the West Coast from San Diego, California to Seattle, Washington and geographically large, regional companies anchored by smaller CBSAs like Reno, Nevada, Salt Lake City, Utah, Boise, Idaho, and Billings, Montana.

1. Mapped Results

In Figure 46a, we observe that the current alignment has a noticeable enlistment variance based on geographic factors similar to the Southwest region. Companies located along the coast are geographically smaller and generally produce more contracts than the large, interior companies. These interior companies are limited by geographic distances and as a result have fewer stations and consequentially lower enlistments, than would normally occur in a more densely populated region.

In Figure 46b, we observe that the Regional model results in the consolidation of rural companies into fewer companies, most clearly demonstrated in company #2 where the state of Montana's two lower producing companies were merged into one. Similarly, company #1 is a clear example of the gerrymandering effect, by stretching from the Boise, ID CBSA south through the Salt Lake City, UT CBSA, and ultimately to the Las Vegas, NV CBSA. Overall, the Regional model reduces variance, but like the Southwest region it's not able to eliminate all of the enlistment variance between the urban and rural companies. The companies in the southwest portion of the region have higher enlistments than the rest of the region.

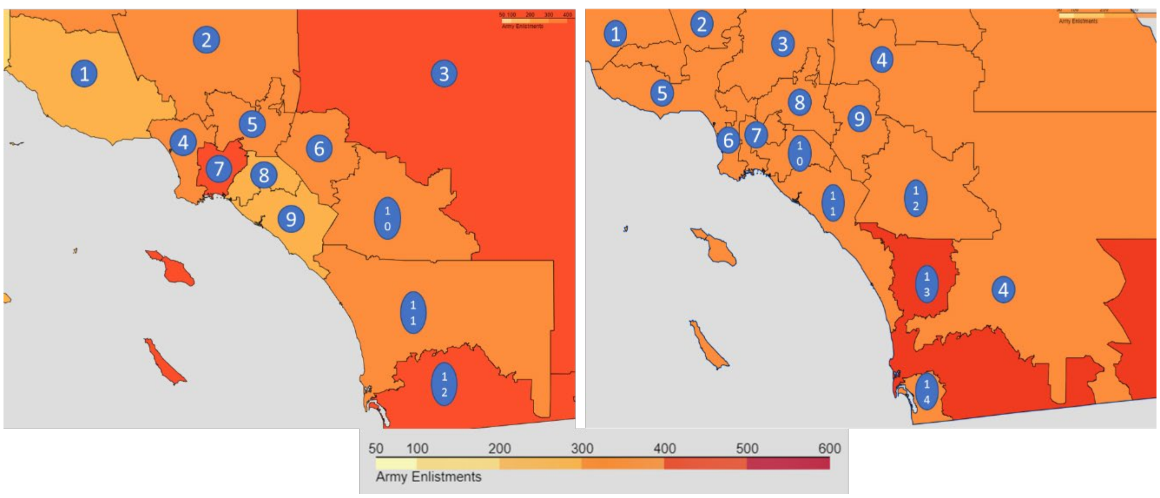


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 46. West Region (Current Alignment vs. Regional Model Results)

In Figure 47a we zoom in to look closer at Southern California's twelve current companies. They are generally compact and follow county boundaries, resulting in some enlistment variance between adjacent companies. The most noticeable example is companies #7 and #8 which border along the Los Angeles and Orange County lines. Company #7 produces roughly double the enlistments of #8 which leaves open the opportunity for station—company realignments which would result in improved balance in company leadership responsibilities and reduced mission risk for the Southern California battalion commanders.

In Figure 47b, we observe that the Regional model resulted in the growth of two companies into Southern California from elsewhere in the region. We also note that all but one company in this area are producing roughly 300 enlistments per year, a noticeable improvement in mission risk reduction. As with the other regions and examples, there is noticeable decline in compactness.

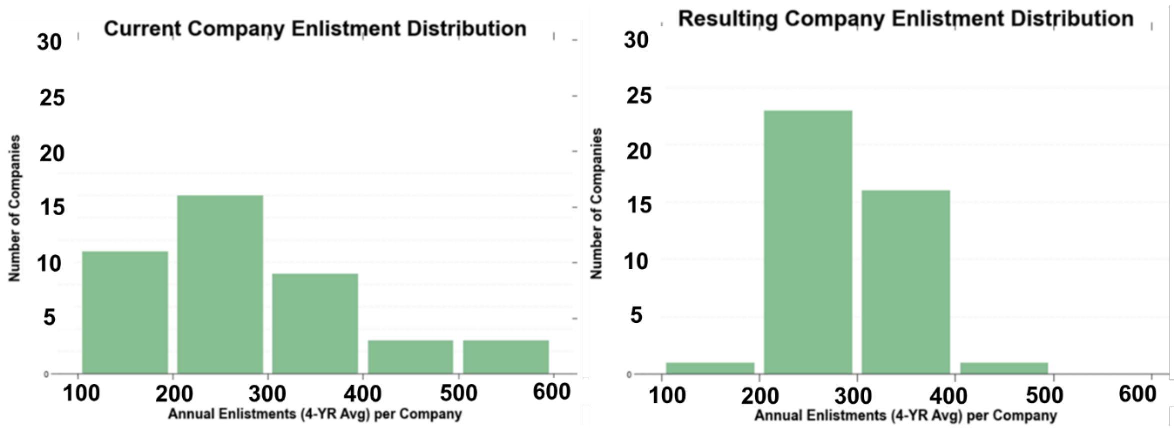


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 47. Southern California Local Example (Current vs. Regional Model Results)

2. Span of Control Metrics

Figure 48 highlights the reduction in companies producing less than 200 and more than 400 enlistments per year from 17 to 2.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 48. West Region Army Enlistments per Company (Current Alignment vs. Regional Model)

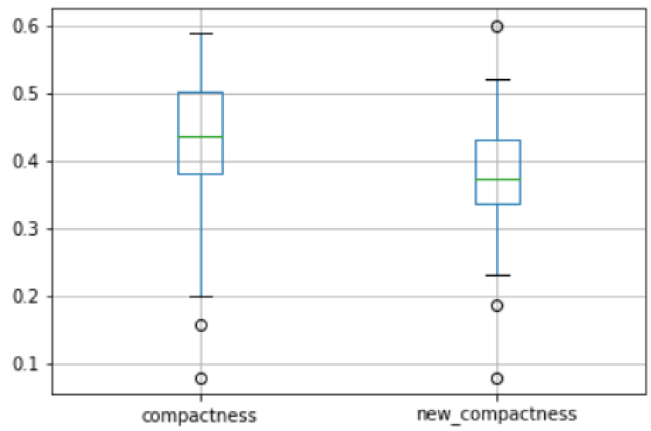
Table 7 highlights that similar to most other regions, the current CoV in the West region was slightly less than the command CoV. It was reduced by 50% by the Regional model with was similar to other regions.

Table 7. West Region Army Enlistments per Company (Current Alignment vs. Regional Model)

Summary Stats	Command Comparison	Region	Regional Model	Change
Mean	283	281	281	0
St Dev	125	113	59	-54
Minimum	86	123	154	31
Maximum	889	534	400	-134
CoV	0.44	0.40	0.20	-0.20

3. Compactness

Figure 49 highlights a slight reduction in the West region's Schwartzberg score compactness, dropping from 0.44 to 0.37 in the model. Interestingly, we observe that the model resulted in less variance, where we observed the variance stayed the same or increased in the other regions. More analysis of individual company regions would need to be done to further explore this result.

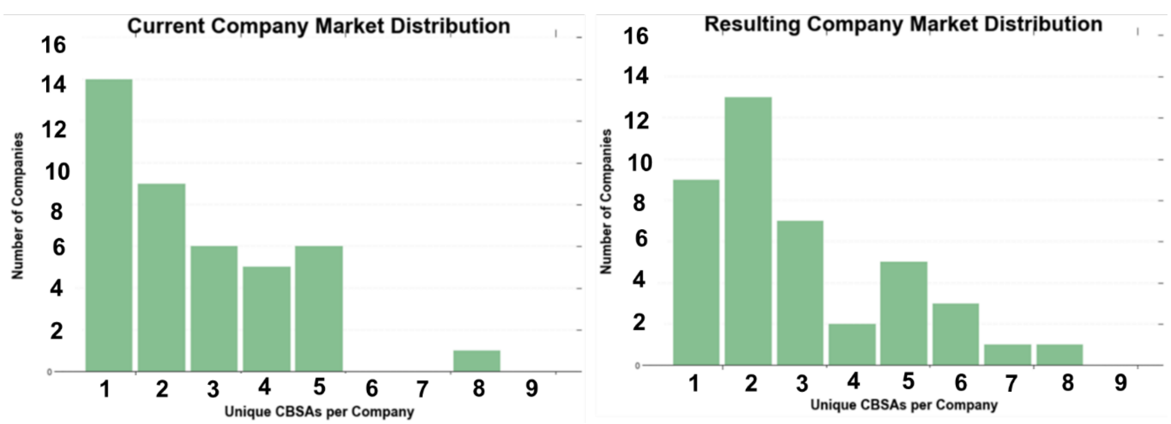


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 49. West Region Company Geo-Compactness (Current Alignment vs. Regional Model)

F.4. Market Integrity

In Figure 50, we observe that the West region was the only region that saw a significant decrease in companies with only one unique CBSA, decreasing from 14 to 9 companies. These five companies added stations from at least one adjacent CBSA, decreasing the market integrity of the current company alignment. Companies with six or more CBSAs increased from 1 to 5 in the Regional model, likely a result of station growth in rural, lower producing regions that require additional stations in order to minimize internal enlistment variance.



Generated using USAREC provided data (Stokan 2021) and model generated results.

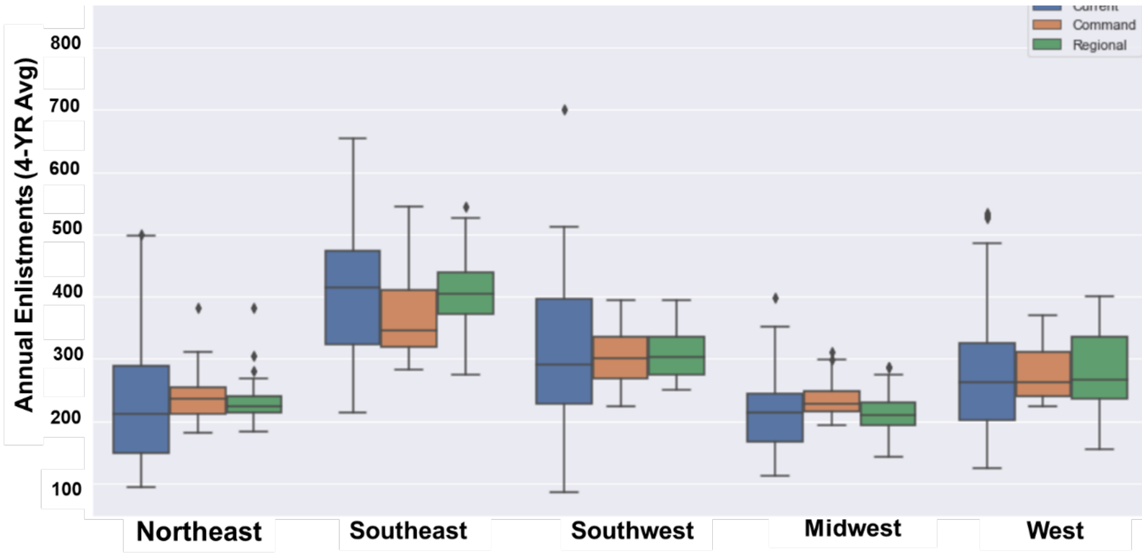
Figure 50. West Region Unique CBSAs per Company (Current Alignment vs. Regional Model)

G. COMMAND VS. REGIONAL MODEL COMPARISON

Finally, we highlight some of the results where the Command and Regional models produce significantly different results in some regions of the command. As referenced in Table 2, the Command model changed the numbers of companies managing the stations in each region in order to reduce the current inter-regional enlistment variance. As discussed in Section A.3 and specifically Figure 21, the Command model changed the regional boundaries due to its ability to group stations in different brigade regions into the same company. Since the regional boundaries and subsequently enlistments are slightly modified in the Command model, it is impossible to do a perfect regional comparison between each model's results. Additionally, since neither model considered market integrity or compactness, we do not discuss the differences in the model's results in these factors.

G1. Overall

Figure 51 highlights the Command and Regional model results, compared to the current station—company alignment. First, we note that the Regional model does not change the enlistment mean for each region, but it always reduces the variance. In the Northeast, Southeast, and Southwest regions, the Regional model reduced variance more than the Command model, whereas the Midwest and West regions achieved lower variance in the Command model. The reason for this result is unclear. Initially, we hypothesized that the Regional model would always reduce intra-regional variance more than the Command model, due to less initial variance.

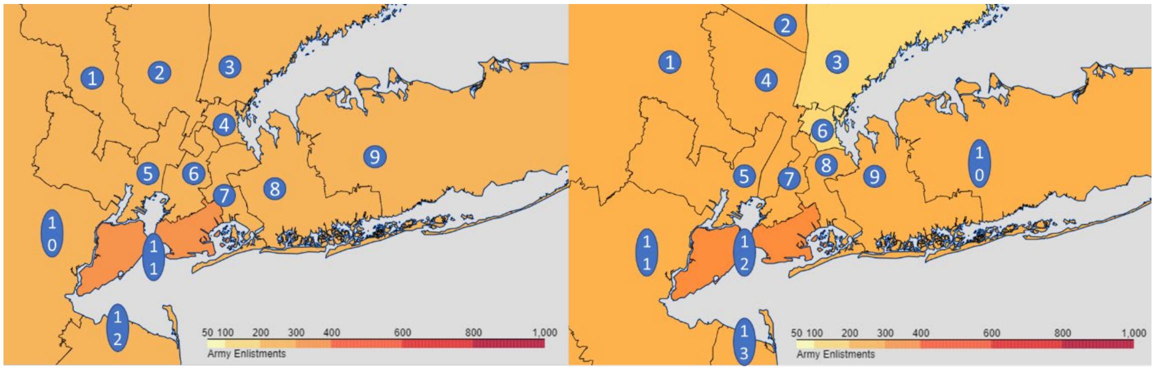


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 51. Army Enlistments per Company by Region (Current Alignment vs. Command Model vs. Regional Model)

G2. Local Examples

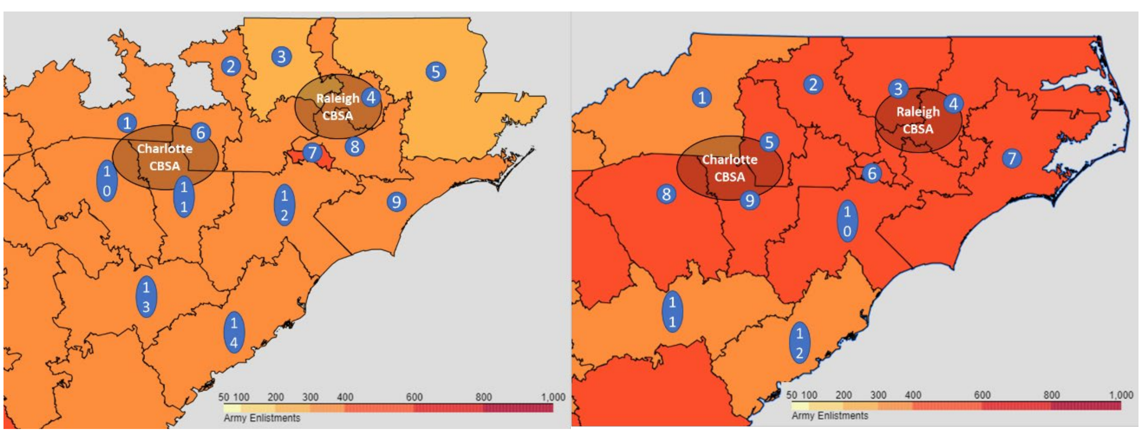
In order to highlight the geographic differences, we compare the Command model and the Regional model directly using the cities and states highlighted in the previous sections. First, in Figure 52 we highlight the models' results in the New York City CBSA with its current 11 companies. Despite looking similar the Command model added a 12th company, while the Regional model added a 12th and 13th company to the CBSA. This is a result of the Regional model not being able to shift companies to other regions, so it assigned more companies into the same area to reduce variance. As a result, the region retains the company and specifically the New York City CBSA uses the 13th company to reduce company enlistment variance.



Generated using USAREC provided data (Stokan 2021) and model generated results

Figure 52. New York City CBSA Local Example—Command (left) vs. Regional Model (right)

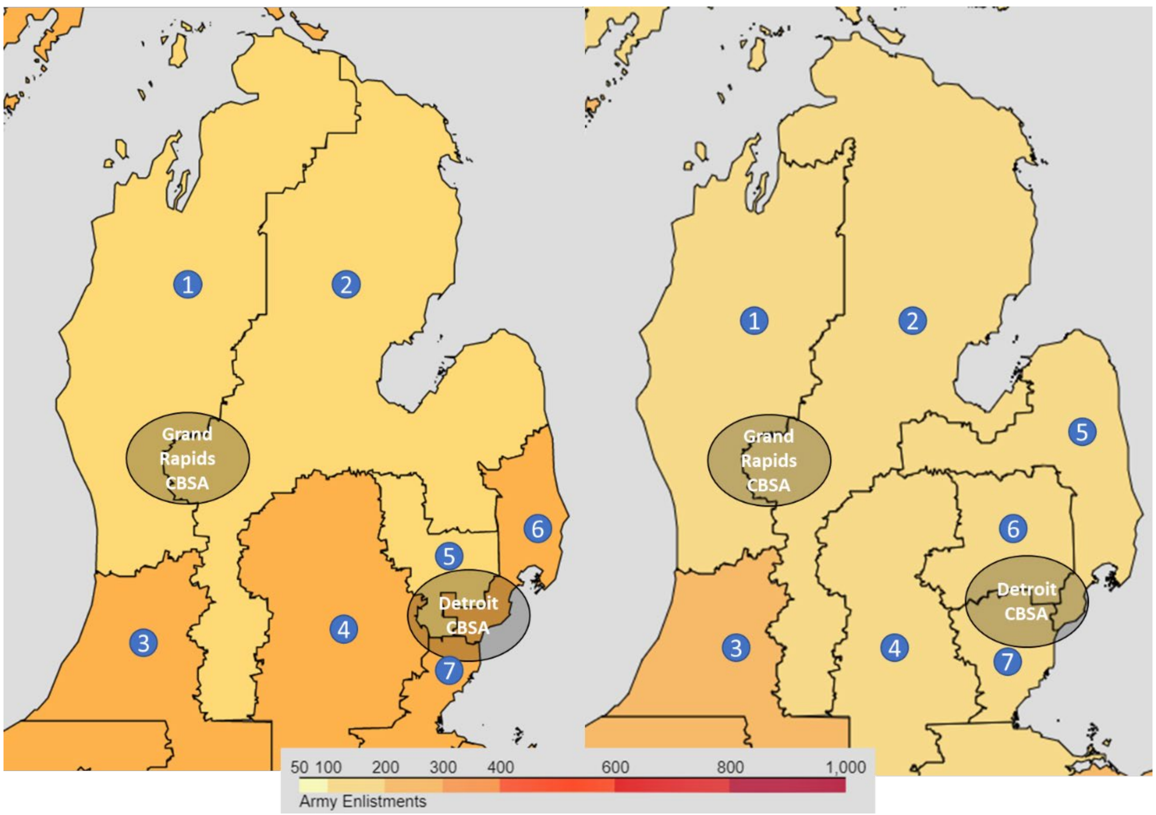
In the Southeast region, Figure 53 shows how the Command model impacted regional boundaries in the states of North Carolina and South Carolina. Stations in northwest and northeast North Carolina were lost to the Midwest and Northeast region companies, respectively. Second, the Command model moves two additional companies into the area, increasing the company count from the current alignment and Regional model from 12 to 14 companies. Overall, the Command model reduces the company enlistment average from over 400 in the Regional model to over 300 by adding the additional companies.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 53. North and South Carolina Local Example—Command (left) vs. Regional Model (right)

In the Midwest region, the local example of the state of Michigan, Figure 54, demonstrates that both models recommended seven companies to manage the state's stations. The primary difference is that the Command model resulted in four of the seven companies producing over 200 enlistments, whereas the Regional model only had one of seven companies over that threshold. This is a result of the Command model shifting companies out of the Midwest region, thus resulting in higher enlisments per company in the Command model.

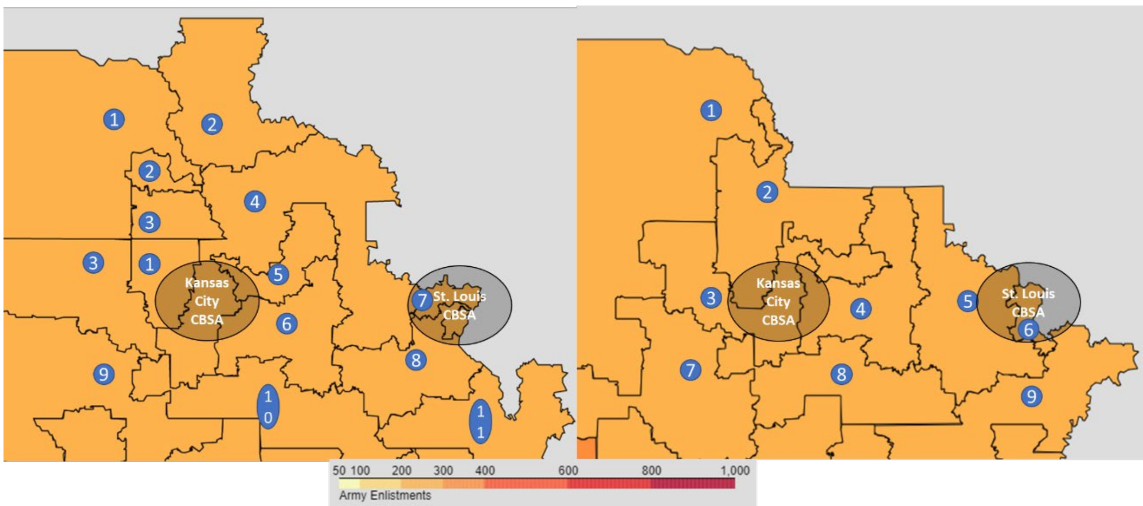


Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 54. Michigan Local Example—Command (left) vs. Regional Model (right)

In the Southwest region, Figure 55 highlights the changes in the states of Nebraska, Kansas and Missouri, and anchored by the largest CBSAs of Kansas City and St. Louis. First, we note the changed regional boundaries as a result of some Midwest stations getting reassigned to the Soutwest region, for example as seen in companies #2 and #11 in the

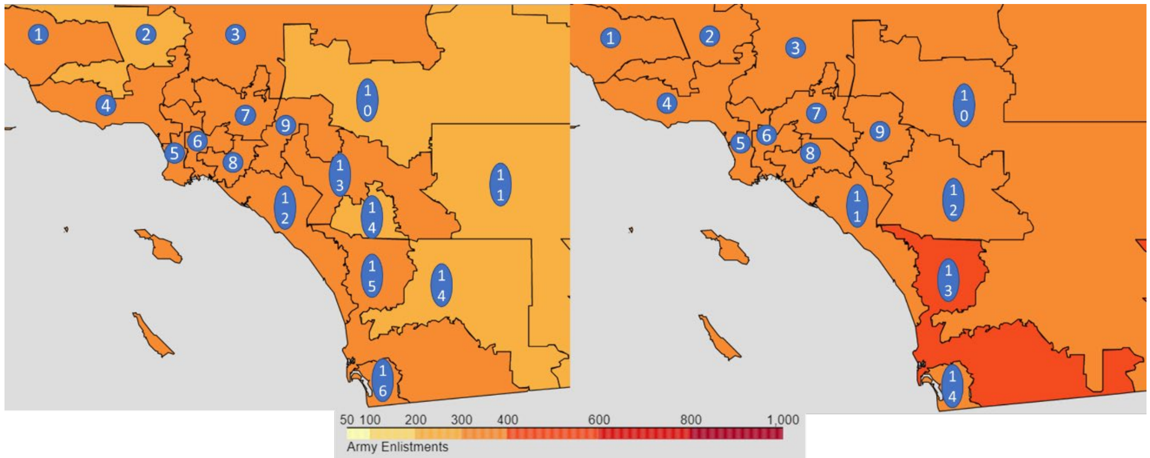
Command model. We note that the Command model resulted in an increase in companies from 9 to 11, while maintainig a similar company enlisment count. By adding the additional stations (and their enlistments) from the Midwest region, the companies in both models maintained low enlisment variance as noted by the same region color in both maps.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 55. Nebraska, Kansas, Missouri Local Example—Command (left) vs. Regional Model (right)

Finally, Figure 56 highlights the modelled differences in the West region's Southern California markets. The Command model increases the company count from 12 to 16, while the Regional model only increased the company count to 14. Since the Command model increased the number of companies in the area, the company enlistment average as lower.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 56. Southern California Local Example—Command (left) vs. Regional Model (right)

H. RECOMMENDATIONS

The current version of the USAREC station-company redistricting model is the first step toward developing a local search optimization algorithm that reduces enlistment variance across the companies. In general, both Command and Regional models are able to reduce enlistment variance across companies when compared to the current command structure. Still, reduction in variance using local search produces negative impacts on other span of control metrics, specifically compactness and market integrity. This is not surprising as local search does not incorporate these metrics in station—company assignments. Future steps that will be discussed more in depth in Chapter V should include objectives or constraints that also consider compactness and market integrity. Still, the reduction in compactness and market integrity may be outweighed by corresponding reduction in enlistment variance. Hence, we recommend utilizing our initial results in a specific regions and sub-regional areas to test whether realignment actually reduces mission risk and if these benefits outweigh costs associated with the difficulty of managing non-compact regions that incorporate more CBSAs.

In order to test the effectiveness of enlistment balance on reducing battalion mission risk, we recommend utilizing the model's recommendations on the companies in two battalions in the Northeast, Southeast, and Midwest region. We do not recommend using the Southwest or West regions due their geographic size, which results in enlistment balanced companies that are geographically too large for reasonable travel. This threshold would select six of the 38 battalions, approximately 36 companies to be reorganized with the objective of minimizing enlistment variance. The model would be run by isolating each selected recruiting battalion (similar to the Regional model method) and minimizing internal battalion enlistment variance between its 6–7 companies.

Ultimately, after a few years, USAREC would be able to analyze and determine if enlistment balanced battalions performed better than their non-balanced battalion peers. If the balanced battalions did perform significantly better, USAREC should work to improve the USAREC station-company realignment model by adding compactness and market integrity constraints in order to implement the model command wide.

V. CONCLUSION

A. USAREC STATION-COMPANY REALIGNMENT MODEL

1. Problem Summary

USAREC is tasked to enlist over 60,000 young people each year into the U.S. Army utilizing more than 7,000 recruiters spread across the United States in over 1,300 recruiting stations. Accomplishing this unique mission poses challenges to its leaders on how best to manage its resources and minimize its mission risk. USAREC's commanders must determine how best to geographically organize its recruiting forces in a way that maximizes organizational efficiencies such as balancing leadership span of control responsibilities and geographically aligning units to natural markets, but also minimizes the probability of mission failure. Historically, USAREC has primarily focused on improving organizational efficiencies at the expense of allowing its companies to become imbalanced over time. Our key assumption is that enlistment imbalance poses mission risk to ensure when a company fails their assigned mission it is easier for the remaining regions to make up the shortfall. Therefore, the goal of this thesis was to create an algorithm that reduces mission risk by balancing company enlistment production.

This problem is ultimately an operations research districting problem where USAREC is trying to determine the best station-company alignment possible using its current leadership resources and recruiting station distribution. The objective for districting problems is to maximize and/or balance three different and often competing factors: balance, continuity, and compactness. First, balanced districts are relatively equal in a specified metric or set of metrics. Balance is a common goal in different districting problems, such as in politics where creating equal democratic voting regions is constitutional and in business where creating balanced sales territories is more profitable. Second, most districting problems require all of a district's sub-units to be geographically contiguous or connected. Third, districting problems also consider compactness which is the relationship between geographic area and perimeter. In political districting, non-compact districts are considered gerrymandered and potentially illegal. In business and recruiting, non-compact districts are also organizationally inefficient often due to transportation requirements increasing travel time and costs. Importantly, the most balanced districting solution is not necessarily contiguous nor most compact, and vice versa.

2. Modeling Approach

USAREC currently lacks a programmatic method for re-districting its companies based on a specified optimization objective. Districting a large number of stations into companies using a traditional integer linear program and finding a global optimum is considered NP-hard, so our thesis relied on other research to develop a local search algorithm to find a local optimal solution. Our USAREC station-company redistricting model's objective is to iterate through different station-company alignments in order to find station-company alignments that reduce company enlistment variance.

Our model allows USAREC to begin with any initial feasible (contiguous) station-company assignment and the model exhaustively iterates through all possible station-company exchanges in order to find station-company alignments with less enlistment variance than the iteration's starting solution. After each iteration, the model selects the station-company exchange that reduces variance the most and uses it as the starting point for the next iteration. This method allows for the model to conduct an efficient search for improved station-company alignments that maximize balance (i.e., minimize enlistment variance) while maintaining continuity. Our model did not consider compactness in the local search.

We find our USAREC station-company redistricting model useful for its potential for immediate application and practical use. USAREC is able to use this model on their current alignment or any other starting condition (change total number of companies, add/ remove companies from specific region, etc.). With slight modifications and enhancements, the model framework allows USAREC to add additional balance metrics, such as the number of recruiters, or add constraints, such as limiting the total number of stations assigned to a company.

3. Model Results

We ran the model on the entire command and for each USAREC region to compare new company alignment with current COAs. First, the Command model highlighted that USAREC regions had significant inter-regional enlistment variance. Local search shifted companies across regions to balance company enlistments, with additional companies being moved to the Southeast, Southwest, and West regions. Second, despite initial inter-regional variance, the Command model performed very well reducing the company enlistment coefficient of variance (CoV) by nearly 50% (a similar reduction to how the model performed on the individual regions). Despite these benefits, the Command model did not consider market integrity, compactness, or station counts in local search. As a result, company-station assignment produced geographically large and gerrymandered companies, including a handful of large 9+ station companies that would be difficult to manage from an operational perspective.

We further studied each USAREC region individually. Regional models allow brigade commanders to visualize how to improve enlistment balance within their own regions without disrupting other regions. Local search performed the best on the Northeast region, reducing CoV by nearly 75% and reducing compactness relatively less. In contrast, the other Regional models performed roughly the same as the Command model, with the exception of some improved balance and a smaller relative drop in compactness.

We found some common results across all command and regional results when using local search. Both the Command and Regional models generally shifted more companies into the urban, higher enlistment CBSAs of the command and away from the less dense and lower producing areas. This resulted in both geographically larger, less compact regional companies and smaller, but also less market aligned companies within large CBSAs due to the station growth and gerrymandering effects, respectively. When comparing the Command and Regional models directly, we noted examples where the Command model typically changed the number of companies managing stations at state and city level, whereas the Regional model did not have as drastic of a change in the number of companies in those same regions.

Overall, local search with our USAREC station-company redistricting model performed well and produced similar results across the command and regions. With its sole objective of reducing enlistment variance, results highlighted its limitations in dealing with compactness and market integrity as well with as its sensitivity to geographic conditions in the current alignment's network structure.

B. LIMITATIONS

Our local search model was limited in providing immediately usable results because it did not include compactness, market integrity, and span of control objectives or constraints. Results produced numerous examples of gerrymandering – where companies stretched from CBSA to CBSA – to reduce variance. We also highlighted several companies in rural regions that while, relatively balanced, were too large and likely difficult to effectively manage. We think that if our model was enhanced to include these additional input factors, the local search approach would produce immediately usable results.

We also recognize that even the perfect local search algorithm would still have its limitations based on factors both internal and external to USAREC's control. Internally, the model is sensitive to three primary factors: station locations and boundaries, the model's initial USAREC station – company alignment, and command policies that would govern an enhanced model's decisions. Externally, the United States' physical geography impacts the results of the model.

First, USAREC determines its station locations and boundaries based on market analysis and funding. Changing the number of stations and/or boundaries changes the underlying network's nodes and edges. Adding stations splits total enlistments into smaller groups; this would generally allow the model to consider a significantly larger number of station exchanges and would likely lead to even less variance. Conversely, fewer stations would result in a network with fewer edges, and therefore fewer station-company exchanges and likely result in a higher variance. Additionally, small changes in current station boundaries can change the network relationships, allowing new exchanges to be considered.

Second, the initial station-company alignment determines which exchanges are considered in the early iterations of the algorithm. Even a small number of changes to the starting alignment would likely produce different results on the final alignment, albeit both with reduced variance. This is important for both Command and Regional models. For example, manually redistricting and moving additional companies to the Southeast and Southwest regions to reduce the initial inter-regional variance, and then running local search, we expect to see even more reductions in inter-regional variance due to the improved starting alignment.

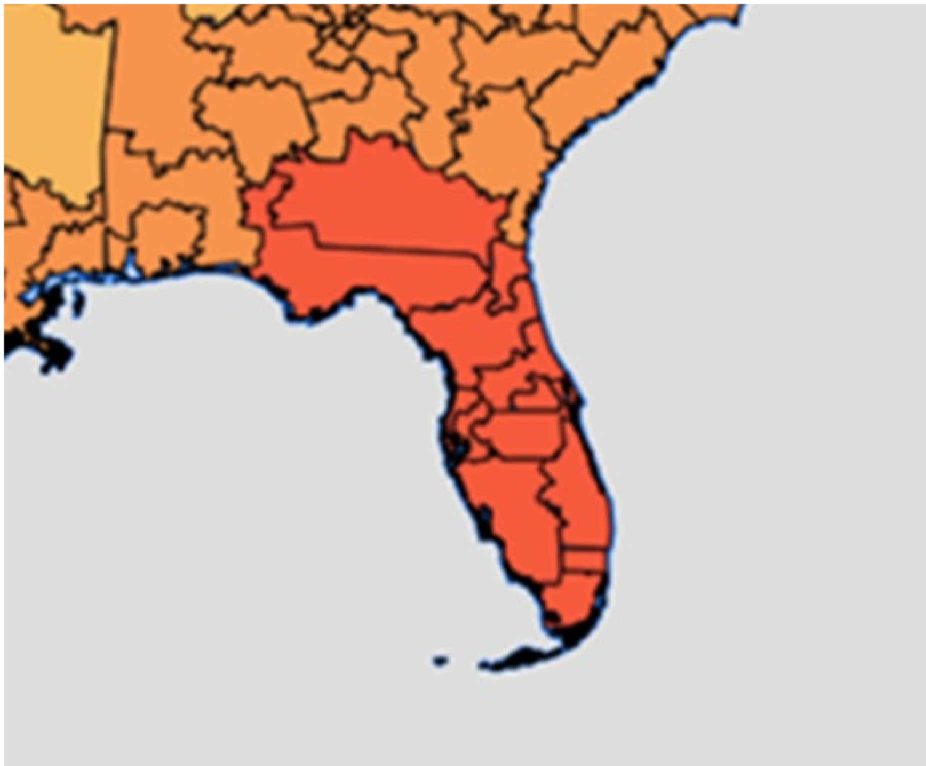
Third, USAREC policy on span of control and market integrity would significantly impact the results of an enhanced model. By limiting the number of recruiting stations or number of companies per market the model would produce significantly different results. For example, if urban companies required a minimum of three stations and rural companies were limited to eight stations, then we expect the final variance would be higher than current results. However, the resulting company-station alignment would likely be easier to manage and implement in practice. Similarly, imposing market integrity requirements on companies will cause excess variance, but make final results more actionable.

Finally, local search approach is also sensitive to the United States' geography regardless of USARECs station boundaries and the initial station-company alignment. There is limited network connectivity specifically in peninsular regions such as Florida, Great Lakes, and New England and along coast lines. Hence, the model has fewer station-company exchange options to consider and check for reduced variance when only considering neighboring companies. We suspect that local search may produce sub-optimal solutions in these regions since there were no additional station-company exchanges to consider. In contrast, in central locations without coastlines, the model is able to explore more variance reduction options. We refer to this issue as the "peninsula effect."

C. FUTURE WORK

1. Different Starting Alignments

The first step towards exploring additional improvements in station-company alignment is to use our model after changing both the station boundaries and initial station-company alignment. Changing either initial condition may improve identified limitations, such as the reducing the impact of peninsulas and/or inter-regional variance. For example, it is likely that in the Command model, as seen in Figure 57, Florida's companies retained higher average enlistments than the rest of the command due to the peninsula effect which limited the network geography and ultimately the model's explorable options. Northern Florida is relatively rural compared to the rest of the state and there are only a handful of stations that stretch east-to-west across northern Florida. These stations essentially 'cut-off' the rest of the state's stations from connecting with Georgia and Alabama. If our model found a station-company alignment using only the northern Florida stations (as it appears in Figure 57 to have done), the rest of the state's companies would not have a chance to explore exchanges with Georgia and Alabama stations. This network geography limitation could possibly be fixed by increasing the number of stations in northern Florida, effectively expanding the network's searchable solutions.



Generated using USAREC provided data (Stokan 2021) and model generated results.

Figure 57. Command Model – Florida

Another option to consider to reduce peninsula effect and other inter-regional variance concerns is to manually redistrict the command in a way that increases companies in higher enlistment regions, including Florida. The addition of new companies into Florida would immediately lower the state's average company enlistments, and better balance company enlistments even if these companies were effectively blocked by the limited exchange possibilities.

2. Local Search Model Enhancement

The second priority for improving USAREC company enlistment balance would be to enhance this local search model by including market integrity and span of control limits. Gerrymandering effects could be reduced by penalizing the station-company exchanges that added stations outside of a company's primary CBSAs. This could be done as either a constraint or secondary objective function. Station growth issues could be improved by adding simple constraints in the algorithm to control for a maximum or minimum number of stations, recruiters, miles between stations, etc.

An effective way of reducing the gerrymandering effect is to include market integrity into the objective function, offsetting the exclusive search for enlistment variance reduction. Since each station is one CBSA and the number of unique CBSAs is being measured, the enhanced objective function would penalize the station-company exchange if the variance reduction was insufficient to offset the addition of a new unique CBSA. For example, if the considered station-company exchange reduced a company's enlistments from 320 to 310 (objective: 283), but increased the unique CBSA account from 6 to 7 (objective: 1), the model would reject the exchange because the market integrity decreased more than enlistment variance improved.

3. Different Algorithms

Finally, there are additional algorithms to consider when trying to improve balance and compactness beyond the methods presented in this work. In general, these methods employ heuristic techniques to manage combinatorial issues with districting problems. Applying techniques such as a genetic algorithm, simulated annealing, particle swarm optimization, or other simulation-optimization methods are less sensitive to the starting network alignment and would likely provide valuable results to address USAREC's enlistment imbalance. For example, these heuristic methods are able to explore balance improvements from additional starting station-company alignments generated during model solve, whereas our local search algorithm is limited to human generated starting alignments. Additionally, some of these methods, such as the simulated annealing are able to start with a non-contiguous station-company alignment, find a local optimum, and then iterate until the contiguous constraint is established.

D. FUTURE WORK

Overall, the USAREC station-company redistricting model seeks to reduce enlistment variance utilizing a local search approach; it iterates through all feasible station-company exchanges until variance is no longer reduced. While computationally intensive and sensitive to the initial station-company alignment, the model ultimately reduces enlistment variance through exhaustive exploration. Future researchers are provided a ready-to-use template for a local search variance reduction algorithm, which can be improved to balance additional metrics and including span of control responsibilities and market alignment. Our initial results highlight a limited number of station-company redistricting actions USAREC can take to improve balance and reduce mission risk. Our recommended model enhancements will significantly increase the number of immediate actions USAREC can take, proving this thesis to be valuable for USAREC's future success in a demographically changing country.

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