Distribution of COVID-19 Personal Protective Equipment by California County Population

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Abstract

COVID-19 has been one of the most trying times of most of the population's lifetime. There was a sudden impact on everyone's day-to-day life and created a sense of unknown throughout the world. No one knew of the lasting impact that COVID-19 would have on every aspect of life, including logistics and supply chain distribution. One of the biggest issues that continues to plague companies is getting the necessary items to buyers and supplying areas with the critical equipment to help slow the spread of COVID-19. This critical equipment is called Personal Protective Equipment (PPE). PPE includes but is not limited to surgical masks, gloves, gowns, and face shields. From early on in the pandemic, health care workers have not had the proper amount of PPE to keep themself and those around them safe. This study will analyze data provided by the California Department of Emergency Services which gives PPE quantity filled for all 58 counties in the state. The findings show that from July 13, 2020 to January 17, 2021, the distribution of PPE was inconsistent to the population of each county or area. Improvements to the distribution are discussed and prove to be more effective than the original data.

Keywords
PPE, Personal Protective Equipment, Logistics, Quality Control, and COVID-19

1. Introduction
Historical books for every country since the beginning of recorded time are filled with hardships and triumphs. With the boom of technology in the past few decades, society has gotten very successful at predicting and preventing disasters. Though COVID-19 is not the first pandemic the world has faced, the Spanish flu claimed roughly 675,000 people globally from 1918 to 1919 according to Lambert (2021), it caused waves throughout supply chain and logistics that our newest and best technology could not have predicted. While there are many automated processes and the use of robots is becoming more popular, our society does not run without human power. The biggest problem to solve in the face of a pandemic was how to have people work as effectively as prior but six feet apart and with masks. Another issue that came along with people continuing to work together daily is spreading COVID-19. A lot of companies had to enter temporary shutdowns when one or more of their workers contracted the disease, slowing overall production and costing money that was not planned for. Prior to having vaccinations available, the only thing people had to protect themselves from others was personal protective equipment (PPE). With social media playing a significant part of today's society, it became known around the world that health care and other essential workers did not have the amount of PPE needed to protect themselves from COVID-19. This led to many hospitals either reusing old PPE or using non-FDA approved PPE. It was COVID-19 protocols which meant workers had to be out of work for two weeks if they contracted the disease, deaths of workers, workers quitting due to stress or unsafe working conditions, and numerous other reasons that initially led to the slow down of PPE distribution. Production was slowed down and logistics got hit hard but that did not stop the need for PPE. The whole world was and still is learning as they go to get things back

to normal, one part of that is figuring out how to distribute PPE best for those in need. This will not be a one size fits all solution but each proposed improvement gets the world one step forward.

1.1 Objective

The objective of this study is to utilize public data provided by the California Department of Emergency Services to improve COVID-19 PPE distribution to each California county based on population. Regression Analysis is used to verify that the data is useful for further analysis. A design of experiment (DOE) is used on the original data to explain and show any faults. A DOE is also used to show improvements, along with a fishbone diagram. This study will provide a sound analysis of current PPE distribution and provide improvements for the state of California.

2. Literature Review

Logistic and distribution studies are not new fields but COVID-19 specific data has only been studied since mid 2020. There have been a number of studies since then researching how people reacted, how business survived, and how to do better when the next pandemic or epidemic arises. This section will focus on three of those areas of study. In the pandemic, there was a wave of job losses and people coming up with creative ways to make a living and help others in their communities from their homes. This involves a lot of shipping services which have been taxing on global logistics. Lastly, we may not be entirely sure to what extent but we can be sure that COVID-19 has impacted everyone and will impact how people function and businesses run for the rest of time.

2.1 Alternative Supplies

With the shortages in PPE becoming unbearable early on in the pandemic and logistics and suppliers not able to catch up, researchers began looking into innovative ways to make up inventory. Subsequently, there has been a pressing need to provide safe and simple solutions to disinfect and reuse improvised or homemade (non-certified) cloth face coverings in order to prevent person-to-person transmission in the community and workplace (Rowan and Liffey 2021). One of the approaches was using Additive Manufacturing (AM), also known as 3D Printing. Efforts at universities and makerspaces operated independently, utilized different AM technologies and equipment, and involved individuals with varying backgrounds and expertise (Budinoff et al. 2021). Utilizing AM allows for suppliers to manufacture near identical PPE faster and with less waste. Although AM had advantages in addressing the supply and demand gap of PPE during COVID-19, the technology has limitations in terms of designs, materials, print quality, and productivity (Budinoff et al. 2021). AM is still fairly new, only gaining at-home traction in the mid 2010’s, and had a lot of questions surrounding it for the use of PPE. Material, cleanliness, and durability were the main concerns brought to attention when PPE began being printed. While AM is excellent for producing PPE like face shields, there was still a need for paper or cloth masks which cover the nose and mouth fully. CDC does not recommend use of face shields for normal everyday activities or as a substitute for cloth face coverings (Rowan and Liffey 2021). There had to be some sort of regulations put in place for the safety standards of AM or at-home made PPE. Disposable PPE are regulated by Regulation (EU) 2016/425 of the European Parliament and repealing Council Directive 89/686/EEC (European Parliament and the Council of the European Union, 2016, which obliges the manufacturer to apply the aforementioned CE marking and to follow the procedure for evaluating and complying with the requirements for that marking (Rowan and Liffey 2021). To create guidelines for future responses, we need to better understand to what extent these limitations impacted community efforts responding to the COVID-19 pandemic in 2020 (Budinoff et al. 2021). The reaction to COVID-19 was one of communal effort and individuals at home beginning to make non-official PPE to either donate or sell. Community-driven efforts at universities and makerspaces were decentralized and spearheaded by many individuals with different backgrounds, expertise, and equipment (Budinoff et al. 2021). The 145 identified efforts were led by different types of organizations including 105 universities (73%), 31 makerspaces (21%), and 9 local libraries (6%) (Budinoff et al. 2021). During the period of emergency medical supplies shortage, 81% of the identified efforts produced face shields, while 7% only produced masks, 10% produced both masks and shields, and 2% produced only other products such as ear savers, PAPR clips, ventilator moisture trap, and splitters for ventilators (Budinoff et al. 2021). This community effort was encouraging for those in need of PPE and gave a small amount of lead time for logistics and suppliers to play catch up. As such, novel alternatives should continue to be sought; however, it remains critically important they are subjected to objective industry standards in order to provide the most accurate safety data available (Lammers et al. 2021). We identified that the median production rate of community driven AM efforts was 77.5 units per day, a production rate that is much lower than potential production rates of traditional manufacturing processes (Budinoff et al. 2021).

2.2 Supply Chain Recovery

This overwhelming demand for the supply of medical supplies was unprecedented, since the last major pandemic is considered to be the Spanish flu in the early 1900s (Okeagu et al. 2021). Though the community effort was relentless and appreciated, manufacturers needed to solve their impediments, and do so quickly. Supply chain recovery is fundamental to supply chain disaster management and resilience (Paul et al. 2021). Companies had never experienced an impact like this, even though past epidemics and natural disasters. In order to stop the spread of the COVID-19 pandemic, many countries adopt a lot of embargo policies that cause a large-scale reduction in the supply of raw material in the global range (Chen et al 2021). To mitigate the COVID-19 impacts on supply chains, effective recovery management strategies are needed (Paul et al. 2021). When major crises and disruptions in supply chains are investigated, the deep upstream portions are often ignored (Paul et al. 2021). It is critical for the future of supply chain and logistics that the occurrences of COVID-19 are studied in depth and improvement plans are put in place. When a supply disruption occurs, if no action is taken, the company's capacity will drop, and out-of-stocks will occur for customer orders arriving at any given time (Chen et al 2021). PPE supply chains have suffered in the past. Statistics indicate that the frequency of such major supply chain outbreaks has increased in recent years (Paul et al. 2021). Even with these past outbreaks, no one was prepared for the intensity and longevity of COVID-19. As a result, many firms might go bankrupt from the impacts of COVID-19 (Choi 2020 as referenced in Paul et al. 2021), which will create difficulties in allocating funds and resources to implement recovery strategies (Paul et al. 2021). The economic impact from this will be long lasting, but unless supply chains can find a way to bounce back and produce the necessary PPE to sustain COVID-19 and all other critical diseases, the trust and money will be in question from the entire medical community. Although the outbreak's nature is unpredictable, efforts can still be made to ensure sufficient PPE and emergency response equipment supplies, which will be in high demand regardless of the types of the outbreak (Okeagu et al. 2021). In order to avoid further supply chain and logistic disasters, it is critical to identify where the recovery challenges lie in prominence. Table 1 lists the potential recovery challenges and Table 2 shows their rankings after determining the cause-effect relationships. The results show the following order for the 12 causal-oriented challenges: RC4 > RC1 > RC5 > RC17 > RC21 > RC16 > RC6 > RC23 > RC2 > RC19 > RC12 > RC22 (Paul et al. 2021). Overall, the shortage of physical and financial resources was and continues to be a critical issue for supply chains across the board, including PPE.

Table 1. Final list of RMG industry recovery challenges (with IDs) due to the COVID-19 pandemic (Paul et al. 2021)

Challenge ID	Name of the recovery challenges
RC1	Global economic recession in a longer term
RC2	Pressure from buyers on reducing delivery lead time
RC3	Increase of bankruptcy of supply chain partners
RC4	Shortage of physical and financial resources
RC5	Sharp fall of demand for a longer period
RC6	High level of layoff of highly paid workers
RC7	Long time to make a recovery decision
RC8	Closure of operations of supply chain partners
RC9	Changes in distribution networks
RC10	Shortage of skilled manpower
RC11	A slow rise in productivity to normal levels
RC12	Payment withholding from buyers
RC13	Low level of preparedness
RC14	Reduction in supply chain flexibility
RC15	Difficulties in supply chain collaboration
RC16	Long-lasting impact on the activities of end customers
RC17	Reduction in sourcing options
RC18	Long time to recover
RC19	Low level of financial flow in the market
RC20	Frequent order cancellation from buyers
RC21	Increase in price of raw materials
RC22	Pressure from buyers on using faster transportation mode
RC23	Dilemma of ‘survival vs. sustainability’ in making a decision

Table 2. The prominence and the net cause-effect for recovery challenges (Paul et al. 2021)

Recovery Challenges	r_i	c_j	$P_i = [r_i + c_j]$	Ranking Order	$E_i = [r_i - c_j]$	*Cause/ Effect*
RC1	4.200	3.792	7.992	2	0.409	Cause
RC2	3.450	3.385	6.835	10	0.065	Cause
RC3	3.130	3.357	6.487	21	−0.227	Effect
RC4	4.421	3.725	8.146	1	0.696	Cause
RC5	3.873	3.569	7.442	4	0.303	Cause
RC6	3.784	3.678	7.461	3	0.106	Cause
RC7	3.184	3.647	6.831	13	−0.463	Effect
RC8	3.366	3.422	6.788	15	−0.056	Effect
RC9	3.332	3.473	6.806	14	−0.141	Effect
RC10	3.417	3.425	6.841	9	−0.008	Effect
RC11	3.354	3.401	6.755	16	−0.047	Effect
RC12	3.472	3.450	6.922	8	0.022	Cause
RC13	3.175	3.516	6.691	17	−0.340	Effect
RC14	3.257	3.669	6.925	7	−0.412	Effect
RC15	3.256	3.575	6.832	12	−0.319	Effect
RC16	3.545	3.437	6.982	6	0.108	Cause
RC17	3.417	3.161	6.578	18	0.256	Cause
RC18	3.456	3.552	7.008	5	−0.096	Effect
RC19	3.441	3.393	6.834	11	0.049	Cause
RC20	3.209	3.364	6.573	19	−0.155	Effect
RC21	3.231	3.060	6.291	23	0.172	Cause
RC22	3.285	3.273	6.558	20	0.012	Cause
RC23	3.260	3.193	6.453	22	0.067	Cause

2.3 Lasting Impact

Prior to the COVID-19 pandemic, PPE were used by industries all over the board, but in a much lesser quantity. Once the pandemic hit, needs increased overnight, even for items outside of PPE. For example, the demand for necessary items such as personal protective equipment (PPE), ventilators, and dried and canned foods has increased (Chowdhury et al. 2021). Meanwhile, supply, transportation, and manufacturing face numerous challenges that reduce their capacities (Chowdhury et al. 2021). Though supply chain is a long-studied topic, the pandemic brought it to the foreground once again. Even before the COVID-19 pandemic, supply chains (SCs) were under pressure (Spieske and Birkel 2021). It was clear the supply chain industry got bullwhipped, there was a rise in demand with a reduction of production. As companies adapt, plan, and respond to the current pandemic situation, various stakeholders' and community needs and views should be incorporated in the analysis, strategy, and decision-making processes (Rajak et al. 2021). Researchers began taking a different look at supply chains and why they began to fail due to COVID-19 but not in previous outbreaks and how we could have done things differently during the initial reaction and how we can prepare in the future. With the surge of these studies, it has given insight into how plans should be made in the future. Moreover, future studies should investigate how supply chains can be safeguarded if the current demand mismatch causes the bullwhip effect mentioned previously (Chowdhury et al. 2021). Another area to investigate in regards to the PPE supply chain in a crisis is technology. The crucial difference between the COVID-19 pandemic and earlier disruptive events is twofold: First, the pandemic and its manifold and severe impacts were completely unforeseen (Spieske and Birkel 2021). Second, recent technological advancements have been made to counter SCD (supply chain disruptions) consequences (Spieske and Birkel 2021). Investigating the applicability and benefits of using emergent technology to manage the impacts of the COVID-19 pandemic is, we suggest, an important research topic (Chowdhury et al. 2021). Another area of study that researchers have been investigating is resilience. While most studies focused on probability estimation, a few studies have studied the recovery-based approach to supply chain resilience quantification (Fattahi et al. 2020 as referenced in Moosavi and Hosseini 2021). Measuring SC resiliency is a critical path to preparing a proactive plan for the next severe disruption (Moosavi and Hosseini 2021). Lastly, during the pandemic, a lot of rash decisions were made just to get supplies out but these plans are not set up for a long-term plan. Therefore, it gives motivation to sustainability researchers and practitioners that they should come up with solutions to address the SCD and try to bring sustainability to the supply chain during the pandemic outbreak (Rajak et al. 2021). We suggest the impacts on sustainable practices during the current COVID-19 pandemic should be explored rigorously to understand how disruptions impact sustainability (Chowdhury et al. 2021).

2.4 Summary

The COVID-19 pandemic had a large impact on all parts of society. When it came to the logistics and supply chain of PPE, it was a crisis around the world. Essential workers were unable to get the proper PPE to protect themselves against such an unknown disease. It is important to look into why these problems occurred, what the reaction of the public was, and how to plan and prepare in case something like this ever happens in the future. Communities came together for each other, figuring out ways to make up for the logistics and supply chain failures by hand making PPE to sell or donate. This came with its own problems, reliability and cleanliness coming into question. Essential workers need the most protective PPE available, but with the supply chain industry failing, a lot of research had to be done on the recovery of supply chains and logistics. It is important to cover all areas of research to get the best overall view of what went wrong. The pandemic has been a learning experience for all and will change how the supply chain will work in the future.

3. Methods

3.1 Participants

The data used for this study was collected by the California Department of Emergency Services (Emergency 2021). The data includes PPE logistic data for all 58 California, US counties, and nine other groupings. These groupings are county, Government Entity, Non-government Entity, Other, State Agency, State Agency or Other, Tribal, Unassigned, and blank. This study will not be using these groupings, the focus will be solely on the logistics of the counties.

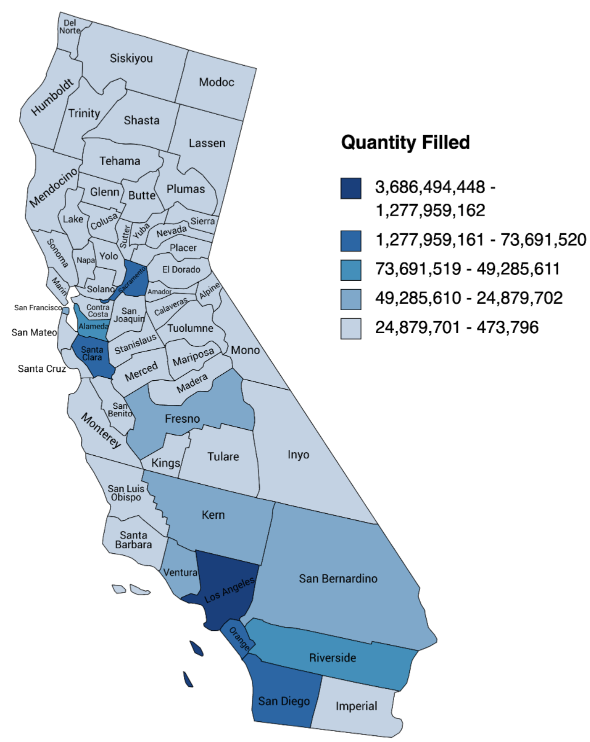

Figure 1. PPE Quantity Filled

3.2 Materials

The data collection is called “COVID-19 PPE Logistics - CKAN” (Emergency 2021). There are 100,000 data points total collected from all 58 California counties and the nine other categories. Each data point includes County, Product Family, Quantity Filled, Zip Code, and As of Date. The purpose of the data set is to show how much PPE quantity was filled in each zip code of each county from July 13, 2020 to January 17, 2021. Each quantity filled data is also grouped by product family to show a more in-depth detail of what PPE is being filled in each area.

3.3 Regression Analysis

The quantity filled data is represented in Figure 1 and the population data is represented in Figure 2. The mean of the quantity filled by month from June 2020 through January 2021, the total quantity filled in that time, and the quantity filled by month from June 2020 through January 2021, the total quantity filled in that time, and the population for each county were put through regression analysis. The resulting equation is as follows, Grand Total being the total PPE quantity filled per county and Population being the population per county:

$$Grand\ Total = 8175830 + 349.7\ Population$$

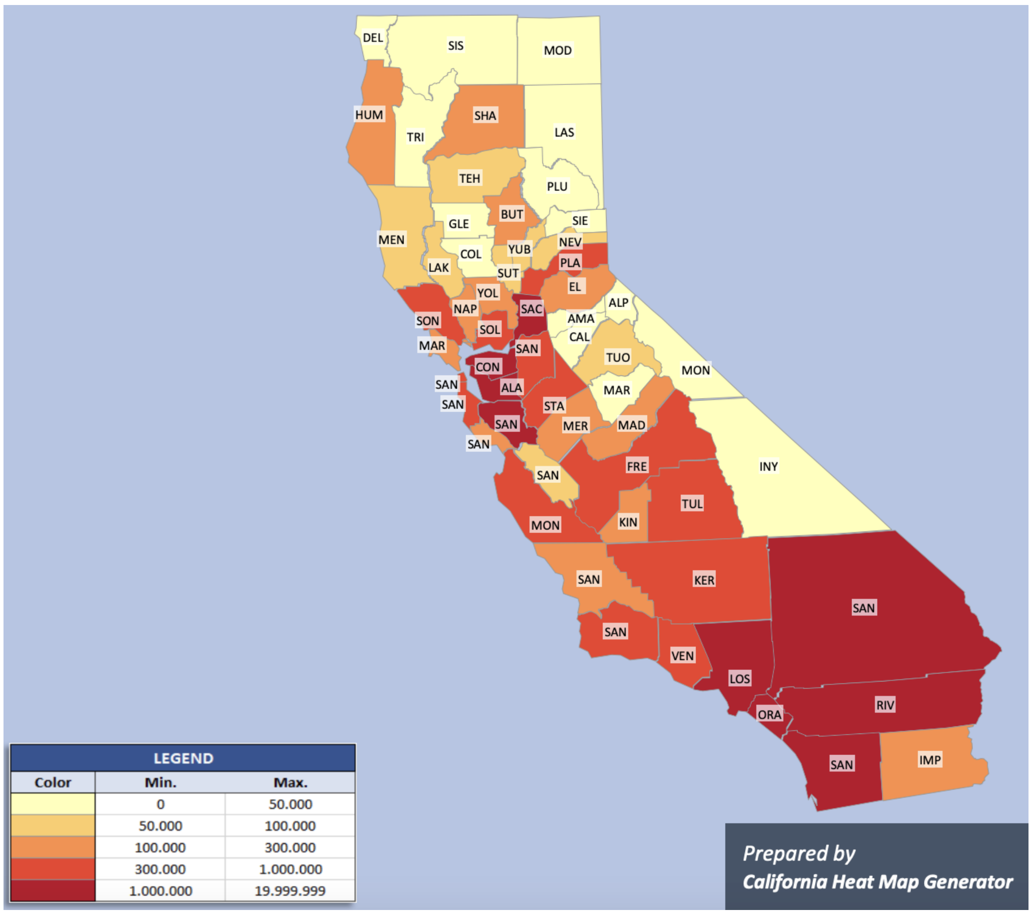

Figure 2. California Population Distribution (California 2020)

Table 3. Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	8175830	20023748	0.41	0.685	
Population	349.7	12.5	28.06	0.000	1.00

The coefficient values can be seen in Table 3. The P-value of Population, 0.000, is less than the significance level which means that the relationship between quantity field and population is statistically significant. The model summary in Table 4 shows that the R-Squared (R-sq) and Adjusted R-Squared (R-sq(adj)) results are close in value, 93.36% and 93.24% respectively. This means that the data can be used for future aspects of this study. The fitted line plot is shown in Figure 3. Minitab was utilized to perform this regression analysis.

Table 4. Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
138111612	93.36%	93.24%	90.71%

4. Data Collection

The data collection was reported from the State of California's Department of Emergency service. All 58 counties' total PPE quantity filled and percent PPE filled by Population data can be seen in Table 13 at the end of this paper. The top five counties can be seen in Table 5. This study collected this data from *catalog.Data.Gov* and utilized it to run analysis and report improvements on how to distribute PPE based on population needs. The analysis that will be run are a design of experiment (DOE) and fishbone diagram. These will be completed via Minitab and excel.

Table 5. Pivot Table Sorted by % PPE by Population, Top 5 Counties

County	PPE Filled Grand Total	Population	% PPE by Population	PPE Filled Ranking	Population Ranking	Ranking Diff
Colusa	73,691,520	21,547	342,003.62%	31	50	-19
Del Norte	71,709,914	27,812	257,838.03%	33	49	-16
Inyo	36,412,097	18,039	201,852.08%	41	52	-11
Tuolumne	76,187,468	54,478	139,849.97%	30	43	-13
Modoc	9,959,406	8,841	112,650.22%	52	56	-4

5. Analysis

5.1 DOE

A Design of Experiment was conducted on a subset of the data, the top 16 values from Table 13. The purpose of the design was to see the effects of the county population and the PPE quantity filled on the ranking difference. The ranking difference is calculated by ranking each county from highest to lowest in both total quantity filled and population, then taking the difference. The coefficients can be seen in Table 6 and the equation is as follows:

*Ranking Difference = -11.53 + 0.000000 PPE Filled - 0.000000 Population + 0.000000 PPE Filled*Population*

The model summary is shown in Table 7, R-Squared (R-sq) is low at 35.63% and has a 16.09% difference from Adjusted R-Squared (R-sq(adj)), which is 19.54%. This shows a low variance for the data used. Though this is low, Figure 4 shows a statically significant predictor in term A - PPE quantity filled. Figure 5 shows a left skewed histogram for the design, the mean is less than the median. This means that PPE is not being distributed properly, more counties have access per population.

Table 6. DOE Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		-8.44	1.20	-7.03	0.000	
PPE Filled	6.12	3.06	1.20	2.55	0.025	1.00
Population	0.63	0.31	1.20	0.26	0.799	1.00
PPE Filled*Population	0.62	0.31	1.20	0.26	0.799	1.00

Table 7. DOE Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
4.80234	35.63%	19.54%	0.00%

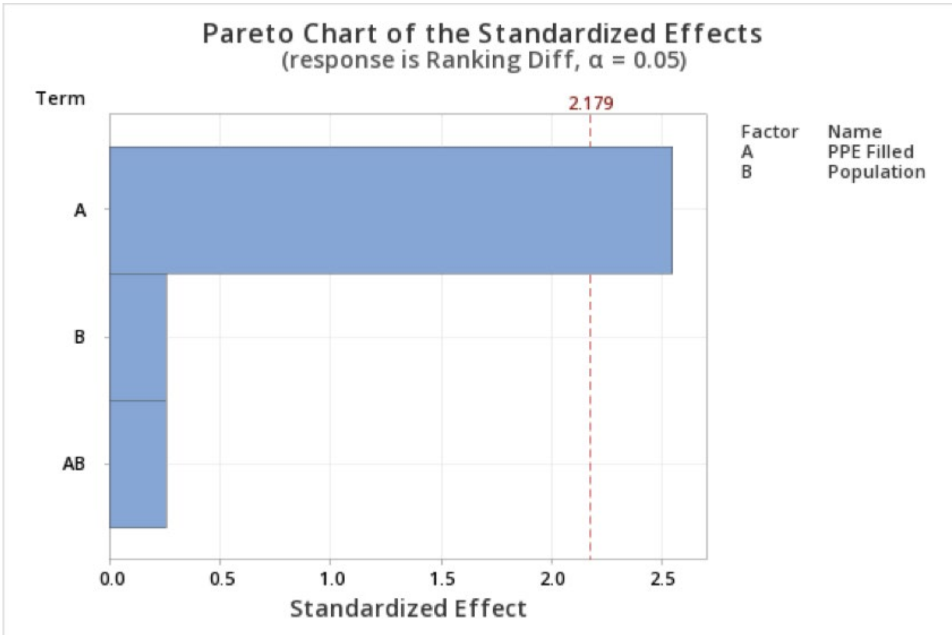

Figure 4. DOE Pareto Chart

5.2 Fishbone

The fishbone or cause-and-effect diagram can be seen in Figure 6. The six cause factors are People, Politics, Equipment, Protective Measures, Environment, and Location. People are broken up into two categories, Social Media and Celebrities. Highly populated areas are going to bring in more social media presence, especially when those areas are populated highly with celebrities or other powerful people. When those people either get COVID-19 or see their cities struggling, it is easier for that to get out to the general public and cause outrage and change online. Los Angeles and San Fransisco being two notably heavily celebrity populated cities. Los Angeles comes in at number 1 for population and PPE total quantity filled, and San Francisco comes in at number 12 for population and 9 for PPE quantity filled in Table 13. Politics is broken up into two categories, Republican and Democrat. According to Snibbe 2021, every county in dark blue in Figure 1 votes democratic and the light blue counties vote mostly republican. Though COVID-19 is not inherently a political issue, it quickly turned into one in the United States. Only 14% of Americans say they will definitely not get vaccinated. But this group is 69% white, compared with 7% Black and 12% Hispanic. Republicans make up 58% of this group, while Democrat's account for 18% (Baragona, 2021). Equipment is broken up into two categories, Prior PPE Quantity and Hospital Capacity. The higher the

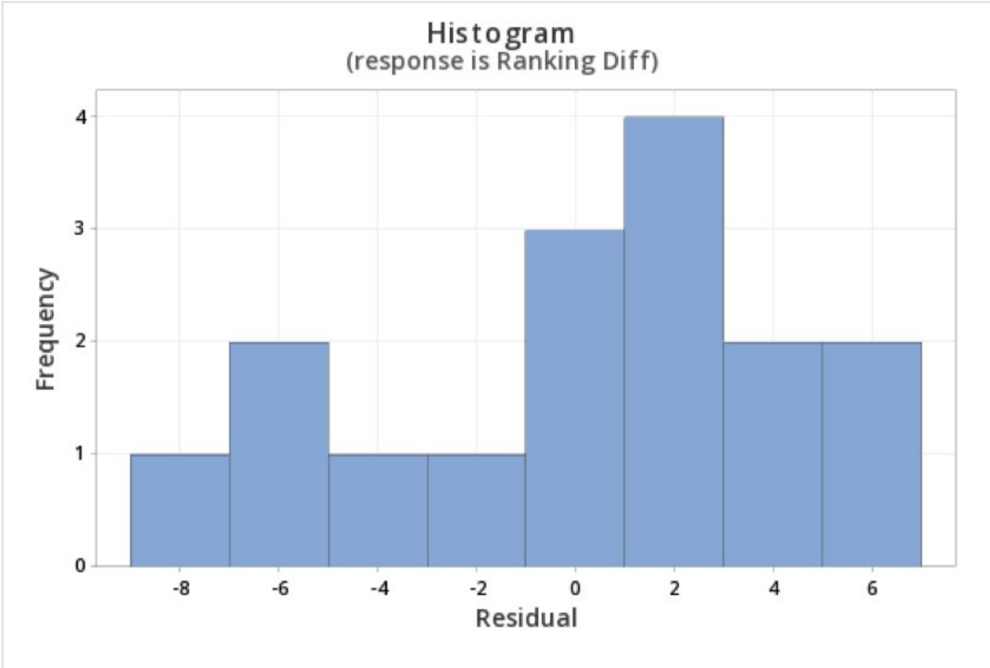

Figure 5. DOE Histogram

population, the more likely there will be better access to higher capacity and better hospitals. Though no hospital was prepared for COVID-19 hospital capacities, more sophisticated hospitals in the populous areas had a better chance of having PPE reserves. Protective Measures is broken up into Mask Mandate and Vaccine status. Past studies have shown that having mask mandates in place, along with a high vaccinated population percentage, lowers the number of serious COVID-19 cases and brings death down to nearly 0%. When counties put mask mandates in place, it allows for PPE to be distributed easier to areas in need. States, such as New York, are even mandating proof of vaccines to eat at restaurants or attend indoor events.

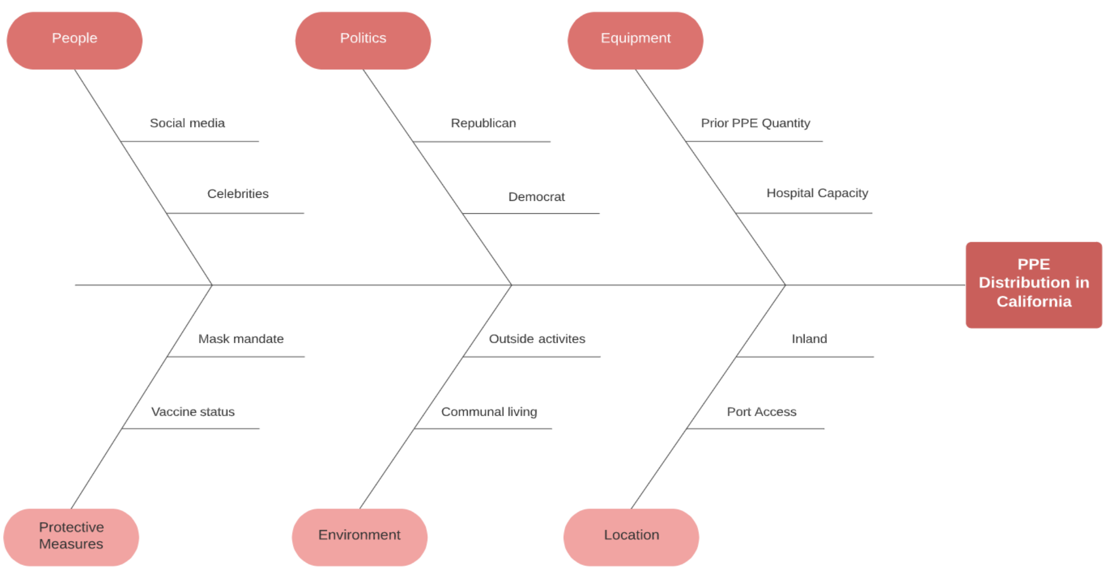

Figure 6. Fishbone

Environment is broken up into Outside Activities and Communal Living. When living in warmer climates, it is easier to see normal activities like concerts resume because open air venues are more common. Outside activities are important to slowing the spread of COVID-19. It is also important to look at high communal living areas, counties with high apartment or rental living. It is much harder to dictate who you come into contact with when living in apartment buildings because you do not know everyone. Large amounts of communal living can increase the need for more PPE. Location is broken up into Inland and Port Access. When it comes to getting PPE delivered efficiently, location of the county can play a big part. There are only 15 out of 58 counties that have water side port access, allowing them easier access via water transit logistic plans. There is also one inland county bordering Mexico and without port access or bordering any other state. These inland counties have lower fulfilled PPE than counties bordering over states or that have port access.

6. Improvement

6.1 Population Coverage

In order to better cover PPE by population, one improvement would be to get all % PPE by Population to be between 25,101.03% and 51,422.71% which would make the Ranking Difference 0. There are currently 8 of the 58 counties at 0, which is only a 14% success rate. Running a DOE on these factors gave the following results. The coefficients are in Table 8, and the equation is:

*Ranking Difference = -9.79 + 0.01030 % PPE by Population - 0.000009 Population + 0.000000 % PPE by Population*Population*

Table 8. Improvement 6.1 DOE Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		-7.813	0.904	-8.65	0.000	
% PPE by Population	6.125	3.063	0.904	3.39	0.005	1.00
Population	-3.875	-1.937	0.904	-2.14	0.053	1.00
% PPE by Population*Population	3.375	1.687	0.904	1.87	0.086	1.00

Table 9. Improvement 6.1 Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
3.61421	61.99%	52.49%	32.43%

The Model Summary in Table 9 shows a much-improved R-squared (R-sq) at 61.99% which is a 26.36% improvement from the original DOE. There is only a 9.5% difference between Adjusted R-Squared (R-sq(adj)) and R-squared. Figure 6 also shows that Factor A - % PPE by Population is statistically significant. Figure 7 shows a normally distributed histogram, this shows that the mean and median are equal and PPE is distributed correctly.

6.2 Distribution Centralized Areas

Another way to improve is utilizing centralized areas for PPE distribution. To test this improvement, the counties were broken up into four quadrants: North, Central, LA, and South. These quadrants are depicted in Figure 8. The data for each county is in Table 10, each county has roughly 9 million population. A DOE was run to analyze this set of data. The design was set up to get the % PPE by Population Sum between 13,106.88% and 64,648.4% which comes from the minimum and maximum of the % PPE by Population of all the values where Ranking Difference is 11, 4, -1, and 0, match the Ranking Difference Sum in Table 10, in Table 13. Since there is no Ranking Difference of value 4, the highest % PPE by Population value of 3 and the lowest of 5 were used. The Coefficients can be seen in Table 11 and the equation is as follows:

*Ranking Difference = -15.9 - 0.00384 % PPE by Population + 0.000001 Population + 0.000000 % PPE by Population*Population*

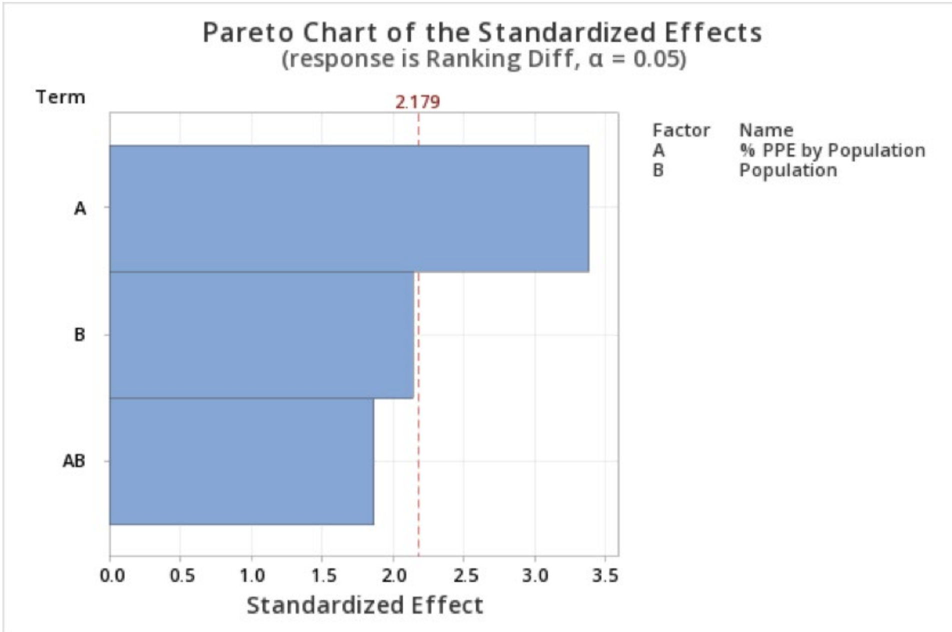

Figure 6. Improvement 6.1 DOE Pareto Chart

The Model Summary in Table 12 shows an improved R-squared (R-sq) at 44.99% which is a 9.36% improvement from the original DOE. There is only a 7.5% difference between Adjusted R-Squared (R-sq(adj)) and R-squared. Figure 9 also shows that Factor B - Population is statistically significant. This is a variant on the original data and Improvement 6.1. Population is far more important with this improvement structure than with the other two. This means that it is important to keep the population in the centralized areas as even as possible to keep PPE distributed correctly. Figure 10 shows a mostly normally distributed histogram with a slight left skew; this shows that the mean and median are almost equal but PPE is distributed correctly.

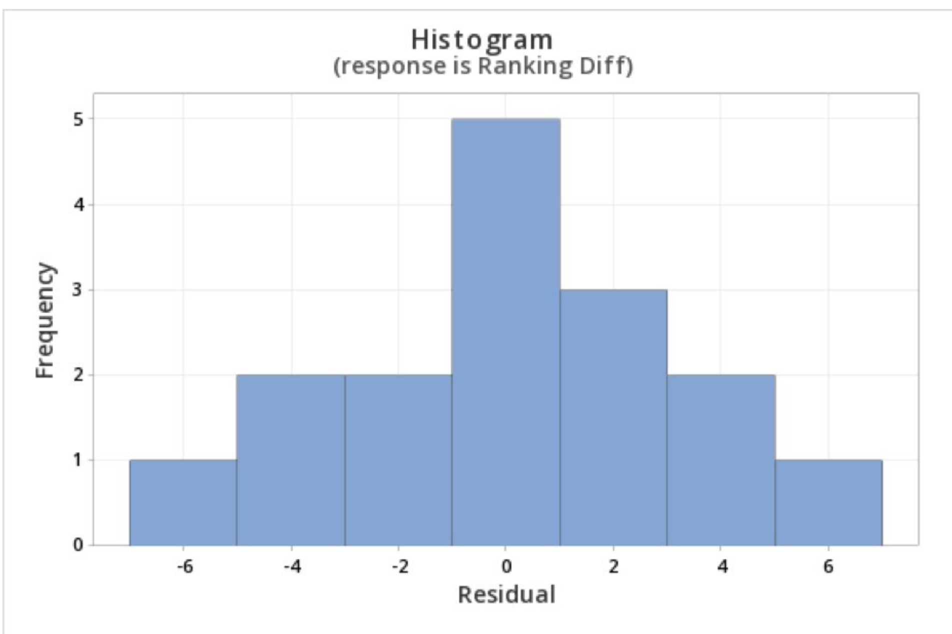

Figure 7. Improvement 6.1 DOE Histogram

Table 10. Quadrant Data

Quadrant	PPE Filled Grand Total Sum	Population Sum	% PPE by Population Sum	PPE Filled Ranking Sum	Population Ranking Sum	Ranking Difference Sum	Number of Counties
North	4,064,527,363	8,927,326	1,931,887.31%	1107	1096	11	30
Central	1,888,367,040	9,199,922	389,725.09%	219	215	4	20
South	7,363,681,517	9,165,783	1,566,638.44%	781	782	-1	5
LA	3,686,494,448	10,039,107	36,721.34%	1	1	0	1

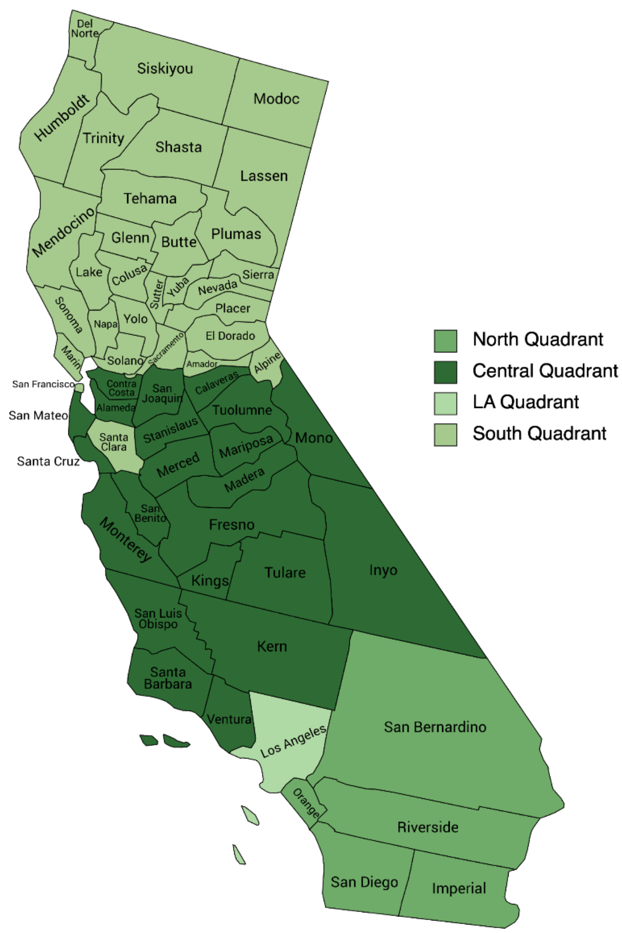

Figure 8. Quadrant Map

Table 11. Improvement 6.2 DOE Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		-7.81	1.04	-7.54	0.000	
% PPE by Population	-2.38	-1.19	1.04	-1.15	0.274	1.00
Population	5.37	2.69	1.04	2.59	0.024	1.00
% PPE by Population*Population	4.12	2.06	1.04	1.99	0.070	1.00

Table 12. Improvement 6.2 Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
4.14578	49.99%	37.49%	11.10%

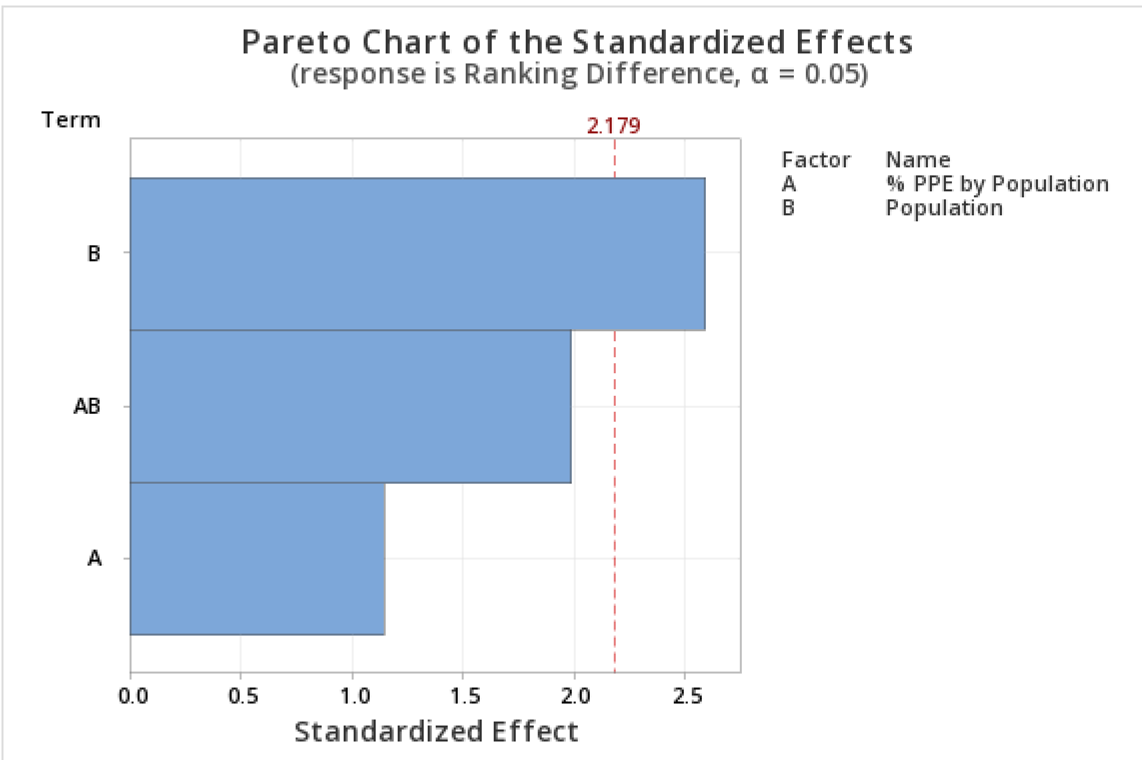

Figure 9. Improvement 6.2 DOE Pareto Chart

6.3 Hypothesis Testing

Initial data comparison for the improvements in 6.1 and 6.2 shows overall improvement to the original distribution data. To further prove improvement, a hypothesis test was performed on the data collected. The p-value used for each test is for the statistically significant value and is gathered from the Table 8 for 6.1 and Table 11 for 6.2.

H0 = 35.63%
H1 > 35.63%
alpha = 0.05
6.1 Improvement
p = 0.005 > 0.05
H0 is rejected

6.2 Improvement
p = 0.024 > 0.05
H0 is rejected

In both cases, H0 is rejected. This proves that all R-Squared values are greater than 35.63%. This means that both improvement models explain more than 35.63% of the variation, 6.1 Improvement has an R-Squared of 61.99% and 6.2 Improvement has an R-Squared of 49.99%. This also shows that both improvement models are more likely to replicate outcomes of PPE distribution than the original design.

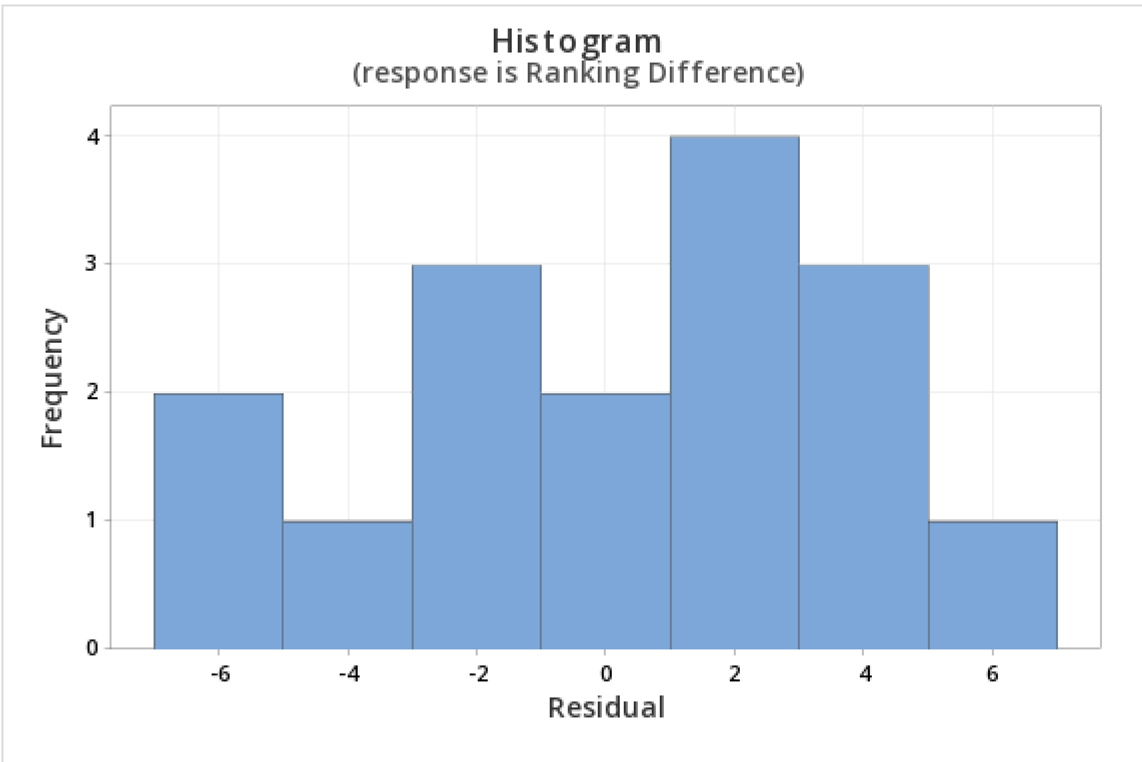

Figure 10. Improvement 6.2 DOE Histogram

7. Results and Discussion

The results from both improvement plans show a better distribution plan of PPE for the 58 California counties. Population coverage is the better plan of the two based on the R-Squared and p-value in the collected data. This plan consists of distributing PPE based on population such that the ranking of population and the ranking of PPE fulfilled are the same. The DOE conducted suggests that the % of PPE by Population should be between 25,101.03% and 51,422.71% to achieve this goal. The % of PPE by Population was significantly significant for this plan so that variable should stay within the bounds to achieve continuous success. Distribution centralized areas plan is not as effective but still shows an improvement from the original data. For this plan, the 58 counties were separated into four quadrants based on summed population. In this case they each totaled out to around 9 million population each. The population was statistically significant for this plan, this explains that the population needs to stay around 9 million for continued success.

8. Conclusion

COVID-19 has been a hardship for all people and normal ways of life. Distribution and logistics have been faced with many challenges and are still working to resolve and better their practices. Utilizing public data supplied by the California Department of Emergency Services, this study analyzed the data via regression testing and DOE. Two improvements were then analyzed, population coverage and distribution centralized areas. Overall, population coverage showed a significant improvement of the original data and should be considered in the future for PPE distribution.

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Biography

Kayla Akey is a master's student in the Mechanical, Robotics, and Industrial Engineering Department at Lawrence Technological University. Her experience and expert area is software engineering, specifically in the Public Sector. She has a BS in Computer Engineering from Michigan State University (2018), and is pursuing her Master's in Engineering Management from Lawrence Technological University.

Table 13 Pivot Table Sorted by %r PPE by Population

County	PPE Filled Grand Total	Population	% PPE by Population	PPE Filled Ranking	Population Ranking	Ranking Diff
Colusa	73,691,520	21,547	342,003.62%	31	50	-19
Del Norte	71,709,914	27,812	257,838.03%	33	49	-16
Inyo	36,412,097	18,039	201,852.08%	41	52	-11
Tuolumne	76,187,468	54,478	139,849.97%	30	43	-13
Modoc	9,959,406	8,841	112,650.22%	52	56	-4
Imperial	193,412,902	181,215	106,731.18%	18	30	-12
Napa	130,980,121	137,744	95,089.53%	24	34	-10

Lassen	27,499,704	30,573	89,947.68%	42	47	-5
Mono	12,401,388	14,444	85,858.4%	49	54	-5
Sacramento	1,261,785,223	1,552,058	81,297.56%	2	8	-6
Humboldt	105,697,308	135,558	77,972.02%	26	35	-9
Yuba	58,542,563	78,668	74,417.25%	35	39	-4
Lake	45,855,698	64,386	71,219.98%	36	41	-5
Trinity	7,942,056	12,285	64,648.4%	54	55	-1
Siskiyou	27,120,900	43,539	62,291.05%	43	45	-2
Santa Cruz	143,465,662	273,213	52,510.55%	22	25	-3
Mariposa	8,846,248	17,203	51,422.71%	53	53	0
Glenn	14,129,340	28,393	49,763.46%	48	48	0
Monterey	214,344,673	434,061	49,381.23%	15	21	-6
Placer	192,638,663	398,329	48,361.7%	19	22	-3
Ventura	407,996,518	846,006	48,226.2%	8	13	-5
San Francisco	405,802,664	881,549	46,032.91%	9	12	-3
Mendocino	37,907,945	86,749	43,698.42%	40	38	2
Amador	17,123,124	39,752	43,074.87%	46	46	0
Merced	117,230,815	277,680	42,217.95%	25	24	1
Santa Barbara	188,015,579	446,499	42,108.85%	20	20	0
Alpine	473,796	1,129	41,965.99%	58	58	0
Santa Clara	793,224,917	1,927,852	41,145.53%	5	6	-1
Alameda	674,166,490	1,671,329	40,337.15%	6	7	-1
San Benito	25,204,146	62,808	40,128.88%	45	42	3
Kings	59,777,889	152,940	39,085.84%	34	33	1
Fresno	383,375,522	999,101	38,372.05%	10	10	0
Stanislaus	204,022,924	550,660	37,050.62%	17	16	1
Los Angeles	3,686,494,448	10,039,107	36,721.34%	1	1	0
Tulare	154,838,252	466,195	33,213.19%	21	18	3
Yolo	72,418,949	220,500	32,843.06%	32	27	5
Marin	84,299,234	258,826	32,569.85%	28	26	2
San Joaquin	248,067,874	762,148	32,548.52%	13	15	-2
San Diego	1,042,362,136	3,338,330	31,224.06%	3	2	1
Kern	257,090,357	900,202	28,559.19%	12	11	1
San Luis Obispo	80,493,289	283,111	28,431.71%	29	23	6
Madera	43,771,244	157,327	27,821.83%	39	32	7
Sonoma	136,247,400	494,336	27,561.7%	23	17	6
San Mateo	208,027,069	766,573	27,137.28%	16	14	2
Riverside	659,900,570	2,470,546	26,710.72%	7	4	3
Orange	822,760,281	3,175,692	25,908.06%	4	3	1
Plumas	4,814,632	18,807	25,600.21%	56	51	5
Sierra	754,286	3,005	25,101.03%	57	57	0
El Dorado	45,324,668	192,843	23,503.4%	38	29	9
Solano	100,311,719	447,643	22,408.87%	27	19	8
Butte	45,447,960	219,186	20,734.88%	37	28	9
Contra Costa	229,527,473	1,153,526	19,897.9%	14	9	5
Tehama	11,397,782	65,084	17,512.42%	50	40	10
Nevada	14,560,437	99,755	14,596.2%	47	36	11
Shasta	25,980,203	180,080	14,427.03%	44	31	13
Calaveras	6,016,714	45,905	13,106.88%	55	44	11
San Bernardino	272,826,396	2,180,085	12,514.48%	11	5	6
Sutter	11,357,758	96,971	11,712.53%	51	37	14