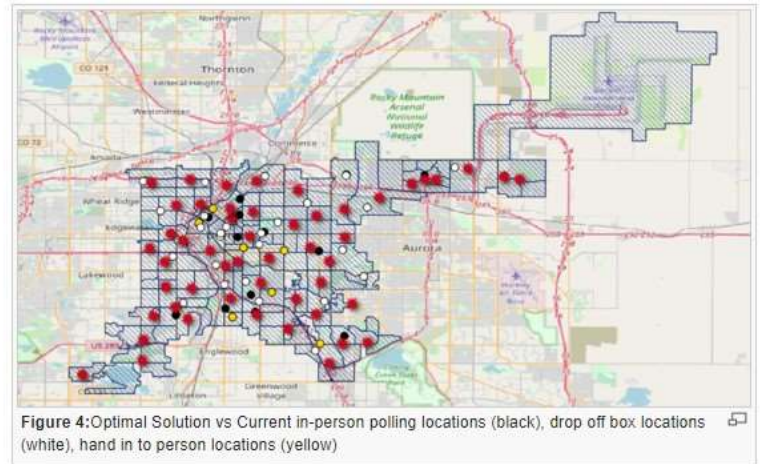


Figure 3 shows the optimal location of polling places in Denver County, presidential election.



Figure 4 shows the optimal polling locations compared with the current polling locations for the 20 presidential election.



```

ampl: reset; model project.mod; data tract.dat; solve;
MINOS 5.51: ignoring integrality of 74160 variables
MINOS 5.51: too many major iterations.
3801 iterations, objective 76.59404621
Nonlin evals: constrs = 2369, Jac = 2368.

```

Next Line will display the number of tracts assigned to each polling location

See excel file on github to match addresses with indices.

```

ampl: display {i in PPL} sum {j in CB} loc_used[i,j];
sum{j in CB} loc_used[i,j] [*] :=

```

1	2.82777	130 0	259 0	388 0
2	3.08649	131 0	260 0	389 0
3	3.18477	132 0	261 0	390 0
4	3.58771	133 0	262 0	391 0
5	4.2851	134 0	263 1	392 0
6	3.79509	135 0	264 0	393 0
7	4.7019	136 0	265 0	394 2
8	3.70349	137 0	266 0	395 0
9	4.33301	138 0	267 0	396 0
10	2	139 0	268 0	397 0
11	5.26155	140 0	269 0	398 0
12	1.97086	141 0	270 0.714899	399 0
13	2.82995	142 0	271 0	400 0
14	3.3768	143 0	272 0	401 0
15	2.86623	144 2.6232	273 0	402 0
16	3.34226	145 0	274 0	403 0
17	0	146 0	275 0	404 0
18	3.73396	147 0	276 0	405 0
19	0	148 0	277 0	406 0
20	2.49885	149 0	278 0	407 0
21	3.73191	150 0	279 0	408 0
22	2.18289	151 0	280 0	409 0
23	2.91636	152 1.96396	281 0	410 0
24	5.03604	153 2.41229	282 0	411 0
25	3.12371	154 0	283 0	412 0
26	3.56685	155 0	284 0	413 0
27	0	156 0	285 0	414 0
28	0	157 0	286 0	415 0
29	0	158 0	287 0	416 0
30	3.47265	159 8.47636e-17	288 0	417 2.96728
31	4	160 0	289 0	418 0
32	1.06918	161 0	290 0	419 0
33	3.48409	162 0	291 0	420 0
34	4.38013	163 0	292 0	421 0
35	0	164 0	293 0	422 0

36	3.79857	165	0	294	3.69546	423	0
37	0	166	0	295	0	424	0
38	3.52735	167	0	296	0	425	0
39	0	168	0	297	0	426	0
40	8.47636e-17	169	0	298	0	427	8.47636e-17
41	0.050989	170	0	299	0	428	0
42	0	171	0	300	0	429	0
43	0	172	0	301	3	430	0
44	0	173	0	302	0	431	0
45	0	174	0	303	0	432	0
46	0	175	0	304	0	433	0
47	0	176	0	305	0	434	0
48	0	177	0	306	0	435	0
49	0	178	0	307	0	436	0
50	0	179	0	308	0	437	0
51	0	180	0	309	0	438	0
52	0	181	0	310	0	439	0
53	0	182	0	311	0	440	1
54	0	183	0	312	0	441	0
55	0	184	0	313	0	442	0
56	0	185	0	314	0	443	0
57	0	186	0	315	3.08278	444	0
58	0	187	0	316	0	445	0
59	0	188	0	317	0	446	0
60	0	189	0	318	0	447	0
61	0	190	0	319	0	448	0
62	0	191	0	320	0	449	0
63	0	192	0	321	8.47636e-17	450	0
64	0	193	0	322	0	451	0
65	0	194	0	323	0	452	0
66	0	195	0	324	0	453	0
67	0	196	0	325	0	454	0
68	0	197	0	326	0	455	0
69	0	198	1	327	0	456	0
70	0	199	1.6334	328	0	457	0
71	0	200	0	329	0	458	0
72	0	201	0	330	0	459	0
73	0	202	0	331	0	460	0
74	8.47636e-17	203	0	332	0	461	0
75	0	204	0	333	0	462	0
76	0	205	0	334	8.47636e-17	463	0
77	0	206	0	335	0	464	0
78	0	207	0	336	0	465	0
79	0	208	0	337	0	466	0
80	0.255791	209	0	338	0	467	0
81	0	210	0	339	0	468	0
82	0	211	0	340	0	469	0
83	0	212	0	341	0	470	1
84	0	213	0	342	0	471	0
85	0	214	0	343	0	472	0
86	0	215	0	344	0	473	0
87	0	216	0	345	0	474	0
88	0	217	0	346	0	475	0
89	0	218	0	347	0	476	0
90	2.89528	219	0	348	0	477	0

```

91 0          220 0          349 0          478 0
92 0          221 0          350 0          479 0
93 0          222 0          351 0          480 0
94 0          223 0          352 0          481 0
95 8.47636e-17 224 0          353 0          482 0
96 0          225 0          354 0          483 0
97 0          226 0          355 0          484 0
98 0          227 0          356 0          485 0
99 0          228 0          357 0          486 0
100 0         229 0          358 0          487 0
101 0         230 0          359 0          488 0
102 0         231 0          360 0          489 0
103 0         232 0          361 0          490 0
104 0         233 0          362 0          491 0
105 0         234 0          363 0          492 0
106 4         235 0          364 0          493 0
107 0         236 0          365 0          494 0
108 0         237 0          366 0          495 0
109 0         238 0          367 0          496 0
110 0         239 0          368 0          497 0
111 0         240 0          369 0          498 0
112 0         241 0          370 0          499 0
113 0         242 0          371 4.85723e-17 500 8.47636e-17
114 0         243 0          372 0          501 8.47636e-17
115 0         244 0          373 0          502 1.02914
116 0         245 0          374 0          503 0
117 0         246 0          375 0          504 1
118 0         247 0          376 0          505 0
119 0         248 0          377 0          506 0
120 0         249 0          378 0          507 1
121 0         250 0          379 0          508 0
122 0         251 0          380 0          509 0
123 0         252 0          381 0          510 0
124 0         253 0          382 0          511 0
125 0         254 0          383 0          512 0
126 0         255 0          384 0          513 0
127 0         256 0          385 0          514 0
128 0         257 0          386 0          515 0
129 0         258 0          387 0
;

```

Next Line will display the number of people assigned to each polling location

```

ampl: display {i in PPL} sum {j in CB} loc_used[i,j]*pop[j];
sum{j in CB} loc_used[i,j]*pop[j] [*] :=
1 2153      173      0      345      0
2 15000     174      0      346      0
3 15000     175      0      347      0
4 15000     176      0      348      0
5 15000     177      0      349      0
6 15000     178      0      350      0

```

7	15000	179	0	351	0
8	15000	180	0	352	0
9	15000	181	0	353	0
10	8657	182	0	354	0
11	15000	183	0	355	0
12	15000	184	0	356	0
13	15000	185	0	357	0
14	15000	186	0	358	0
15	15000	187	0	359	0
16	15000	188	0	360	0
17	0	189	0	361	0
18	15000	190	0	362	0
19	0	191	0	363	0
20	15000	192	0	364	0
21	15000	193	0	365	0
22	8075	194	0	366	0
23	15000	195	0	367	0
24	15000	196	0	368	0
25	15000	197	0	369	0
26	15000	198	3687	370	0
27	0	199	8121.55	371	1.92492e-13
28	0	200	0	372	0
29	0	201	0	373	0
30	15000	202	0	374	0
31	13527	203	0	375	0
32	4101.45	204	0	376	0
33	15000	205	0	377	0
34	15000	206	0	378	0
35	0	207	0	379	0
36	15000	208	0	380	0
37	0	209	0	381	0
38	13782	210	0	382	0
39	0	211	0	383	0
40	3.79826e-13	212	0	384	0
41	348	213	0	385	0
42	0	214	0	386	0
43	0	215	0	387	0
44	0	216	0	388	0
45	0	217	0	389	0
46	0	218	0	390	0
47	0	219	0	391	0
48	0	220	0	392	0
49	0	221	0	393	0
50	0	222	0	394	7821
51	0	223	0	395	0
52	0	224	0	396	0
53	0	225	0	397	0
54	0	226	0	398	0
55	0	227	0	399	0
56	0	228	0	400	0
57	0	229	0	401	0
58	0	230	0	402	0
59	0	231	0	403	0
60	0	232	0	404	0
61	0	233	0	405	0

62	0	234	0	406	0
63	0	235	0	407	0
64	0	236	0	408	0
65	0	237	0	409	0
66	0	238	0	410	0
67	0	239	0	411	0
68	0	240	0	412	0
69	0	241	0	413	0
70	0	242	0	414	0
71	0	243	0	415	0
72	0	244	0	416	0
73	0	245	0	417	10894
74	3.78385e-13	246	0	418	0
75	0	247	0	419	0
76	0	248	0	420	0
77	0	249	0	421	0
78	0	250	0	422	0
79	0	251	0	423	0
80	543	252	0	424	0
81	0	253	0	425	0
82	0	254	0	426	0
83	0	255	0	427	5.67492e-13
84	0	256	0	428	0
85	0	257	0	429	0
86	0	258	0	430	0
87	0	259	0	431	0
88	0	260	0	432	0
89	0	261	0	433	0
90	14106	262	0	434	0
91	0	263	4289	435	0
92	0	264	0	436	0
93	0	265	0	437	0
94	0	266	0	438	0
95	4.73744e-13	267	0	439	0
96	0	268	0	440	10138
97	0	269	0	441	0
98	0	270	5494	442	0
99	0	271	0	443	0
100	0	272	0	444	0
101	0	273	0	445	0
102	0	274	0	446	0
103	0	275	0	447	0
104	0	276	0	448	0
105	0	277	0	449	0
106	12989	278	0	450	0
107	0	279	0	451	0
108	0	280	0	452	0
109	0	281	0	453	0
110	0	282	0	454	0
111	0	283	0	455	0
112	0	284	0	456	0
113	0	285	0	457	0
114	0	286	0	458	0
115	0	287	0	459	0
116	0	288	0	460	0

117	0	289	0	461	0
118	0	290	0	462	0
119	0	291	0	463	0
120	0	292	0	464	0
121	0	293	0	465	0
122	0	294	15000	466	0
123	0	295	0	467	0
124	0	296	0	468	0
125	0	297	0	469	0
126	0	298	0	470	6137
127	0	299	0	471	0
128	0	300	0	472	0
129	0	301	10066	473	0
130	0	302	0	474	0
131	0	303	0	475	0
132	0	304	0	476	0
133	0	305	0	477	0
134	0	306	0	478	0
135	0	307	0	479	0
136	0	308	0	480	0
137	0	309	0	481	0
138	0	310	0	482	0
139	0	311	0	483	0
140	0	312	0	484	0
141	0	313	0	485	0
142	0	314	0	486	0
143	0	315	15000	487	0
144	12218	316	0	488	0
145	0	317	0	489	0
146	0	318	0	490	0
147	0	319	0	491	0
148	0	320	0	492	0
149	0	321	3.49311e-13	493	0
150	0	322	0	494	0
151	0	323	0	495	0
152	8750	324	0	496	0
153	13895	325	0	497	0
154	0	326	0	498	0
155	0	327	0	499	0
156	0	328	0	500	3.3346e-13
157	0	329	0	501	4.62046e-13
158	0	330	0	502	7239
159	4.09493e-13	331	0	503	0
160	0	332	0	504	6962
161	0	333	0	505	0
162	0	334	6.2013e-13	506	0
163	0	335	0	507	1165
164	0	336	0	508	0
165	0	337	0	509	0
166	0	338	0	510	0
167	0	339	0	511	0
168	0	340	0	512	0
169	0	341	0	513	0
170	0	342	0	514	0
171	0	343	0	515	0

172 0 344 0
;

ampl:

project.mod

```
set PPL; # set of possible polling locations.
param latp {j in PPL}; # indices refer to addresses in data document
param lonp {j in PPL}; # latitude and longitude included

set CB; #set of all census tracts
param latc {j in CB}; # indices refer to lat/lon coordinates of centroids of tracts
param lonc {j in CB};
param pop {j in CB}; # includes population in each tract

param poll_max >= 0; # max number of people that can vote at a single poll
param poll_num >= 0; # max number of polls to which the program will assign tracts

var loc_used {PPL cross CB} binary;
    # 1 if CB is assigned to a PPL, 0 otherwise

minimize Total_Distance: sum {i in PPL} (sum {j in CB} (pop[j]*loc_used[i,j]*
    ((latp[i] - latc[j])^2 + (lonp[i] - lonc[j])^2)));
    # minimizes total distance traveled by all voters to the polls. This is
    weighted by population

subject to Assignment {j in CB}: sum {i in PPL} loc_used[i,j] = 1;
    # ensures each tract is assigned to exactly one poll

subject to Max_People {i in PPL}: sum {j in CB} loc_used[i,j]*pop[j] <= poll_max;
    # Ensures no poll will serve over a maximum amount of voters
    # Denver has 600,000 voters. If we have 50 polling locations, that is an
    average of 12,000 people/CB
    # As a result, we picked 15,000 for our max in this program

subject to Maximum_Number_of_Places_Used: sum {i in PPL}
    (prod {j in CB} (1-loc_used[i,j])) >= 515 - poll_num;
    # We chose 50 to reflect the approximate number of actual voting places in
    Denver

# Copy what is below this in the command line. It will run the program and display the
515 polling
# locations as well as how many tracts and how many people will be voting there

# reset; model project.mod; data tract.dat; solve;
# display {i in PPL} sum {j in CB} loc_used[i,j]; display {i in PPL} sum {j in CB}
loc_used[i,j]*pop[j];
```

```
param poll_max = 15000;
```

```
param poll_num = 50;
```

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set PPL := 1
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515; # Possible Polling Locations
param: lonp latp :=
1      -105.020394  39.734841
2      -105.013285  39.697129
3      -105.034555  39.717906
4      -105.051467  39.656551
5      -104.981475  39.752499
6      -104.986615  39.714975
7      -104.998739  39.726918
8      -104.952355  39.721037
9      -104.982983  39.689277
10     -104.958905  39.70175
11     -104.964872  39.757288
12     -104.767213  39.784856
13     -105.025893  39.682542
14     -104.87468   39.654643
15     -104.839991  39.779611
16     -104.932768  39.747552
17     -104.922699  39.76403
18     -105.029721  39.740129
19     -104.900686  39.758846
20     -104.904956  39.718677
21     -105.045106  39.780391
22     -104.937327  39.665204
23     -104.962255  39.781817
24     -104.9311    39.688861
25     -105.033682  39.698518
26     -105.025392  39.76279
27     -104.903438  39.712804
28     -104.941058  39.712394
29     -105.023861  39.793053
30     -104.911434  39.702037
```

31	-105.052257	39.640341
32	-104.893043	39.7595
33	-104.962315	39.676626
34	-104.977074	39.718332
35	-104.909672	39.626013
36	-104.919609	39.729668
37	-104.868608	39.671218
38	-104.886785	39.68493
39	-104.892866	39.697362
40	-104.930957	39.745737
41	-104.829289	39.782505
42	-105.060433	39.676145
43	-104.915805	39.654851
44	-104.997895	39.730298
45	-104.996553	39.760189
46	-104.912647	39.62564
47	-104.983444	39.738597
48	-105.041066	39.769863
49	-105.013413	39.758604
50	-105.027739	39.763933
51	-105.054599	39.640327
52	-104.975277	39.668327
53	-104.892866	39.697362
54	-105.036323	39.659699
55	-104.935954	39.671614
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66	-104.9543657	39.73652315	4357
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78	-104.9128483	39.75651452	4289
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125	-104.9047035	39.64445843	6979
126	-105.0750195	39.66507445	2194
127	-105.0627244	39.64378005	2032
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129	-105.0969344	39.63107134	6137
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132	-104.935714	39.69309409	3313
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138	-104.8147712	39.79193784	4511
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