

PRESS RELEASE

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PRELIMINARY VOTING MACHINE ALLOCATION REPORT RELEASED; IMPORTANCE OF ABSENTEE VOTING STRESSED

July 30, 2008 (Columbus, Ohio): The Franklin County Board of Elections today announced the release of a preliminary report containing voting machine allocation recommendations for the November 4, 2008 General Election. A public hearing is scheduled for Thursday, August 14 at 6:30 p.m. to accept public comment on the draft proposal.

"We're trying to reduce the possibility of long lines that could result this fall from record turnout and a long ballot that will take time for voters to complete," said Dennis L. White, Director of the Franklin County Board of Elections. "Voting machine allocation is just one part of our strategy for mitigating waiting times."

Ted Allen, associate professor of industrial and systems engineering at The Ohio State University and project manager for the Board's consultant, Sagata, Ltd., studied election data from 2004, 2006, and 2008 to produce preliminary recommendations to the Board. "We've documented the time it actually takes to vote a mock 2008 General Election ballot and the frequency with which voters have arrived at the polls in the past to determine voter servicing times and to predict possible waiting times."

Both Director White and Dr. Allen stressed, however, that while the projections are

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based upon simulations and defensible formulas, voting and waiting times could be longer or shorter than estimated. “More than anything, this report underscores the critical importance for Franklin County to vote early by mail using an absentee ballot,” said Director White. “The only way to guarantee you won’t have to wait in line is to vote early by mail.”

Deputy Director Matthew Damschroder noted that the Board has changed several of its Election Day procedures to streamline Election Day voting to reduce waiting times. “Voters now sign-in by the first letter of their last name instead of having to remember their precinct name or figuring out in which precinct’s line to stand.” The new procedure was implemented in March to positive reviews from voters and poll workers alike.

In addition to making the check-in process more efficient, Director White said that a voter will be able to use any machine in the voting location. Before this year, a voter had to wait to use a voting machine assigned to the voter’s precinct while machines assigned to another precinct in the same location may have sat idle. The Board is also seeking supplemental funding from the County Commissioners to rent additional voting machines, in the event that rental units are available.

The Columbus-based consulting team included the team from Sagata, Ltd, Dr. Ted Allen and Dr. Mikhail Bernshteyn, and Chris Rockwell of Lextant, a local research and user-experience firm.

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HELPING FRANKLIN COUNTY VOTE IN 2008: WAITING LINES

REPORT TO THE FRANKLIN COUNTY BOARD OF ELECTIONS

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INTRODUCTION

Many challenges are faced by our voting systems going into the November 2008 election. It is easy to sound alarmist. Challenges include: poll worker recruitment and training, voter suppression efforts, and substandard protections against computer security attacks cited by Balzarotti, Banks, Cova, Felmetsger, R. Kemmerer, Robertson, Valeur, and Vigna (2008).

Waiting lines on Election Day are a problem only some of the time. In 2004, at poll closing times lines were documented to last longer than five hours (Allen and Bernshteyn, 2006). In the lead up to the 2006 primary election day, lines longer than six hours were observed at the Board of Elections itself. Yet, in 2000 and 2006, lines were not considered to be important.

Moreover, even during elections with serious waiting issues, a recent report predicted that the vast majority of voters experienced waits of fewer than five minutes (Samuelson, Allen, and Bernshteyn, 2007). From examination of those simulations, we estimate that the total human hours wasted in the 2004 election in Franklin County were on the order of 40,000 person hours, which might be considered acceptable.

At the same time, Mebane and Herron (2005) estimated that African Americans who did vote in Franklin County in 2004 waited on average over thirty minutes longer than others. Allen and Bernshteyn (2006) further estimated that between 20,000 and 30,000 people were deterred from voting by lines costing the Democratic candidate John Kerry approximately 7,000 votes. Therefore, it seems likely that the primary harmful effects of waiting lines (if any) come through depriving voters the "equal access to voting" guaranteed by the Voting Rights act and the Help America Vote Act (HAVA).

Some have argued that unequal access to voting is inevitable given the way that machines are assigned by state law

(Samuelson, Allen, and Bernshteyn 2007). This occurs because the law generally (while vague) does not account for the variable ballot lengths across precincts in determining how machines are assigned. This could be a major issue in November of this year because Columbus (+6 issues) and, to a lesser extent, Gahanna (+1 issue) have longer ballots than other precincts. This issue provides much of the motivation for this report. One of its goals is to offer a simple way to correct for this and to permit outcomes in the spirit of HAVA.

Will there be lines in November? The answer relates to the balancing of positive and negative developments. The positive ones are obvious. Since 2004, the number of easily available direct recording equipment (DRE) machines has increased from approximately 2,800 to approximately 4,565. Also, the percentage of registered voters who voted prior to Election Day in 2006 was approximately 24%. If this trend continues, turnout on Election Day might represent only 63% of the votes cast.

On the other hand, the number of registered voters has increased. In 2004, Columbus voters faced ballots requiring choices on eleven issues in addition to the political races. Those voters used Danaher 1242 "open-faced" machines. In November 2008, the same voters will face fifteen issues and use screen-by-screen ES&S DREs. Here, we offer evidence that the average times needed to vote or be served by the new DREs will be more than twice the previous times.

How exactly do these balance? There is significant uncertainty mainly in the Election Day turnout. Yet, as we will explain, our unprecedented access to quality data and high fidelity statistical simulations offer cautions for policy makers. There is also unavoidable logic. If doing a task like voting requires double the time per DRE, then double the resources (DREs) are needed to accomplish this task in the same overall time.

EXECUTIVE SUMMARY

Long waiting lines in Franklin, Ohio in November 2008 are a serious likelihood. If the recommendations of this report are not followed, these waiting lines will likely cause a significantly higher loss of person hours waiting in line than in 2004. Moreover, these waiting lines will likely be selective, discriminating against African Americans and others who live in Columbus, Ohio precincts.

THEORY YOU SHOULD KNOW

In general, voting machines allocations across the country by lawmakers are made on a number of machines per registered voter basis. Yet, textbooks on queuing theory teach us that lines depend on both:

- Arrival rates (voters per hour) – In election systems this is proportional to the turnout fraction and, therefore, the number of registered voters assigned to the location times the turnout ratio.
- **Service rates** (voters per hour) – In election systems this relates to how much time voting requires while the voter is monopolizing the DRE depending on the length of the ballot (relatively long and variable in Ohio) and nature of the equipment (relatively slow in Franklin).

The dependence on service rates must be addressed to avoid lines and discrimination.

Another fact is the “explosive” nature of queuing. For example, adding a single issue to a ballot in a certain location can cause the system to go from having minimal waits to long lines. Therefore, it is only possible to guarantee the same wait by assuring that all locations should have minimal waits, which is likely with only 34% more DREs.

WHY LONG LINES ARE LIKELY

Long lines are likely in November simply because of the dramatic increase in the

service times and the corresponding reductions in the service rates. This is occurring because of the increases in the number of issues being voting on (compared with 2004) and the slower nature of the ES&S equipment required by navigation.

Average service times at Columbus precincts greater than 9.7 minutes are predicted both through extrapolations from actual 2006 voting time data and from our mock election, i.e., running 60 voters through ES&S machines and ballots with similar numbers of issues to those in November. Based on a 50% Election Day turnout, our simulations predict 37 locations will likely experience average waits longer than 3 hours.

PRETTY GOOD ALLOCATION

In performing this study, our team invented a simple rule for selecting how many machines are needed overall and how many should be used at specific locations (with minor adjustment). The rule is only marginally more complicated than the 175 per registered rule:

Number of machines =

$$\text{roundup} \left\{ \frac{(\text{avg. voting time mins.})(\#\text{registered})(\text{turnout})}{(0.85)(13 \text{ hr})(60 \text{ mins./hr.})} \right\}$$

where the factor 0.85 is a default value that should be adjusted based on requirements and simulation results for specific settings.

LESSONS FOR THE NATION

Considering the lines in 2004 and the expected lines in 2008, one might reasonably suggest that Franklin County should not be making recommendations to the nation. Yet, if this report’s recommendations are followed, Franklin has the opportunity to lead the country by employing allocation based on service times. Also, operations researchers around the world will agree that significantly worse lines will have been avoided.

KEY FINDINGS

This report includes voting time data from the 2006 November election, the 2008 primary, a mock election involving 60 carefully selected citizens, and results from our simulation models and formulas. These results permit our team to make many findings relevant to the November election.

THE PROBLEM IS REAL

We considered what we feel is the best way to allocate the currently available 4,565 direct recording equipment (DRE) machines. We evaluated these scenarios using possibly the highest fidelity simulations of elections ever and various scenarios about uncertainty.

The largest uncertainty we face is the turnout on Election Day. Franklin County has approximately 798,500 registered voters. We consider ED turnout scenarios ranging from 41% to 55%. These could occur if the number of cast was the same as in 2004 (approximately 67% of those registered now) with between 24% and 37.5% of voters using absentee ballots. The 37.5% number might be reasonable given the experiences of other states offering no fault absentee voting and promises by Barack Obama to encourage it.

We also consider average service times (times each voter takes to monopolize the DRE and cast his or her ballot) to range between 6.6 minutes and 9.7 minutes.

With these assumptions, we predict numerous locations where the average voter waits longer than 60 minutes. The numbers of these locations (out of 543) range between 137 and 229. We also predicted last poll closing times. In our simulations, the expected last poll closing times range from 4.1 hours to 7.5 hours. In other words, the expected line lengths likely will be considerably longer than in 2004. Also, if Election Day turnout exceeds 50% and/or the number of state issues exceeds five, the

aforementioned calculations will be lower than the likely waits that will occur.

NEW MACHINES CAN HELP

We also studied what we feel is the best way to add 200 machines that might be rented for the election. In this scenario, the extra 200 machines reduced the number of locations with average times longer than 60 minutes from 81 to 40 and the expected last poll closing time from 4.1 hours to 3.4 hours.

INCREASING ABSENTEE VOTING IS KEY

We feel that Franklin County needs to make dramatic changes in order to avoid significant waiting times and negative voter experiences. Several actions are possible.

These include efforts to encourage voters to use their no fault absentee option, which could drive the ED turnout down significantly. Also, efforts to prepare voters by supplying them with information about issues in line or otherwise could drive down service times.

ONE-PAGE-PER-ITEM IS NOT JUSTIFIED

Our mock election provided highly trustworthy data as checked using 2006 actual voting times as a reference. The mock election data suggests that putting each issue and office on its own screen adds an average 1.24 minutes to the service times (times each voter needs to monopolize the DRE and cast his or her ballot).

The one-page-per-item approach does this while having no significant effect on the voter's comprehension score (one measure of voter quality). We suggest that implementing this change in our contest would likely take a problematic waiting line situation and make it significantly worse.

PRETTY GOOD ALLOCATION IS VIABLE

We invented a simple and computationally efficient way to apportion machines that accounts for variable ballot lengths across precincts. The proposed approach offers a reasonable and logical way to distribute voting machines based on the number of ballot issues. This can avoid discrimination against those who live in places with long ballots who might share demographic characteristics. The method needs to be tuned for each application with different numbers of locations, numbers of registered voters, and/or ballot lengths. It yields similar allocations and apportionment to much more computationally intensive allocations based on detailed simulations of each location with different numbers of machines.

Also, the resulting formula offers policy makers intuition. If one issue is added, one batch of new machines is needed. If two issues are added, two batches of new

machines are needed equal in size. The formula can also be implemented with minimal training using a standard spreadsheet to generate feasible allocations. These can then be evaluated using high fidelity simulation to check that expected waits fall into an acceptable range.

ONE HALF MINUTE PER ISSUE IS RULE

Our mock election also permitted detailed investigation of the times required by voters to process specific numbers of issues and ballot language. From this study of 60 carefully selected voters (balancing race, education level, and voter experience level) we developed the approximate rule that each issue typically requires 0.5 minutes. This approximate rule is specific to the ES&S DREs used in Franklin County but might help other political systems think about the waiting time implications of their initiatives.

TWO PROPERTIES OF WAITING LINES

How many voting machines are needed at specific locations? The answer is not as straightforward as one might hope. Note that allocation rules vary widely with Ohio mandating 1 machine per 175 registered voters and New York State, e.g., recommending only 1 machine per 550 or (historically) 825 registered. With such a divergence, one can wonder, is Ohio wasting a lot of money on machines? Similarly, is New York State experiencing or risking long lines?

While there are some justifications for these standards, their basic form (# registered per machine) shows a lack of understanding of waiting line theory. This theory has been applied successfully to determine how many cashiers are needed in fast food, in determining how many machines are needed in manufacturing jobs shops, and how many nurses are needed in hospitals.

TURNOUT AND BALLOTS MAKE LINES

Textbooks on queuing theory and simulation teach us that waiting times depend on (e.g., Banks, Carson, and Nelson, 2005):

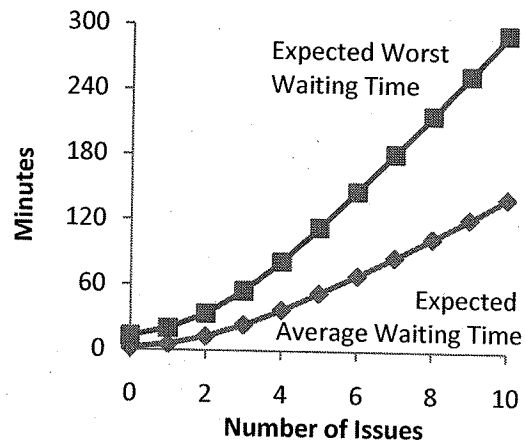
- **Arrival rates** (customers per hour) – In election systems this is proportional to the location turnout and, therefore, the number of registered voters assigned to the location times the turnout ratio.
- **Service rates** (customers per hour) – In election systems this relates to how much time voting requires once the user is monopolizing the DRE and depends on the length of the ballot (generally relatively long in Ohio) and nature of the equipment (relatively slow in Franklin).

To illustrate the dependence on service rates and ballot length, consider the following

example. Imagine a single precinct with 1,000 voters and turnout of 50% or 500 spread out across the 13 hour Election Day uniformly. Imagine that service times (times each voter takes to monopolize the DRE and cast his or her ballot) are exponentially distributed (randomly distributed).

Further imagine that the average voting time depends on the number of issues. The base time is 5.0 minutes with 0.5 minutes added for each issue.

The graph below shows the expected average voting times and expected worst waiting times for any voter as a function of the number of issues. The predictions are derived by averaging 1,000 simulated Election Days for each number of issues. The graph shows the degeneration of the polling location from minimal lines to long lines. The dependence on ballot length is clear as is the substantial difference between the average wait and the worst wait experienced by any voter.

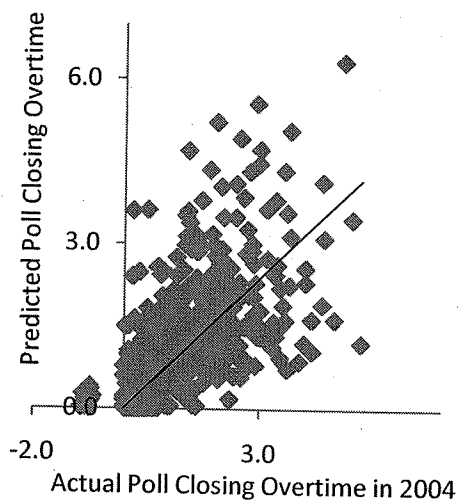


WORST LOCATIONS ARE MUCH WORSE

Historical analyses confirm that turnouts vary across locations (Allen and Bernshteyn, 2006). This variability combined with ballot variability and the natural properties of queuing systems can cause the wide range of voter waiting experiences.

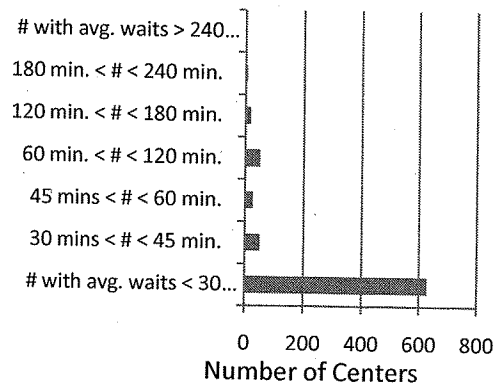
The simulation model used in this report is essentially similar to the one proposed in Hertzberg, Allen, and Bernshteyn (2006) with modifications related to the arrival pattern described in a later section. We applied this simulation to match the experience in 2004. We worked backwards to fill in data or “reverse simulate” data we did not have for that election. The Danaher machines did not record the service times. Therefore, we attempted to approximately match the poll closing times (which we did have). Our simulation also included random turnout ratios across precincts.

The plot below shows the actual poll closing times versus the predicted based on the following assumptions. The model is based on 2.0 minute base average time with increases up to 80% (up to 3.6 minutes on average) in the Columbus precincts because of longer ballots. The simulation model predictions explain approximately 69% of the observed variation (sample correlation).



Our simulation model together with other analyses in Allen and Bernshteyn (2006) provides strong evidence that variable ballot lengths caused much but not all of the variability in waiting times experienced in the November 2004 election in Franklin County.

The model predicts that the average voter waited approximately 20 minutes. At the same time, it predicts average voters in two locations waiting longer than 240 minutes or 4 hours. Further, these precincts were predicted to be the ones with the long ballots in Columbus. Lines formed early there and “exploded” because arrivals were not matched by service until the polls closed.



Even for some allocations designed to account for variable ballot lengths, it is likely that different vote centers will experience different waits. This follows in part because of the discrete nature of voting machines. Adding or removing a single machine in certain precincts can make it so that waiting time performance becomes excellent or poor.

Therefore, we suggest that the only way to effectively guarantee equal lines across locations is to allocate sufficient machines such that waiting lines are all minimal, e.g., expected to be less than 5 minutes. As we describe in our results, this is often possible with only a 34% increase in the number of machines, depending on ballot length. Alternatively, if there were few issues to vote on, minimal lines would be expected with the available numbers of machines.

WHY 2008 IS DIFFERENT

Franklin County, like many other counties, has run many elections in which waiting lines were not an important concern of voters. Examples have included the 2000 presidential and 2006 gubernatorial elections. Moreover, Franklin County has adopted at least two types of expensive measures designed in large part to reduce the likelihood of election lines: thousands of direct recording equipment (DRE) machines were purchased and no fault absentee voting was adopted. The question remains, why do we think that there will be long lines in November 2008?

POSITIVE DEVELOPMENTS

Partly to address equal access for handicap voter issues, the county purchased 4,565 ES&S DRE machines. This was a major increase from the 2,794 DRE machines in use in 2004.

Also, the State of Ohio recently adopted no fault absentee voting. In both the 2006 gubernatorial and 2008 primaries, approximately 100,000 citizens voted using absentee ballots. In both cases, this represented approximately 24% of the total ballots cast. In addition, other counties across the nation have observed over 33% of their voters using no fault absentee voting or early voting in presidential elections. The Obama campaign has further signaled its desire to strongly encourage voters to use absentee ballots for early voting. Combining these developments, we hypothesize that 200,000 citizens will vote with an absentee ballot in November. This would likely represent approximately 37.5% of votes cast.

TROUBLING DEVELOPMENTS

Our main concern for November is the increase in the long expected "service times"

because of the long ballots. We define service times as the time that each voter monopolizes the direct recording equipment (DRE) to cast his or her ballot. To understand our concern it is helpful to study service time data from two sources representing our unprecedented access to high quality data.

First, consider actual service times from the 2006 November election taken from ES&S machines in Columbus and Reynoldsburg precincts from actual voters. In the associated sample of 1,893 voters, the 719 Columbus voters voted on six issues including state and local and the Reynoldsburg voters faced six issues. The Gahanna average times (*) were estimated approximately based on adding $6 \times 0.5 = 3.0$ minutes to the Reynoldsburg times based on an approximate 0.5 minute per issue rule.

Precincts	2006 gubernatorial+	
	# issues	avg. time
Columbus	6	6.0
Gahanna	14	9.4*
Reynoldsburg	8	6.4

The data points to a dramatic increase in the service times compared with the times we estimate from reverse simulating the 2004 election. For example, we estimate that Reynoldsburg voters more than tripled their average service times.

Second, consider service times we estimated from our study of 60 registered voters in our mock election. The sample was selected to represent Franklin County demographics based on voting experience, race (African American, AA or other), and education levels. Other covariates were recorded together with the times required to cast their ballots (short, S, long, L, or one-issue-per screen, O). Retention scores based on six basic questions were also measured.

MOCK ELECTION RESULTS

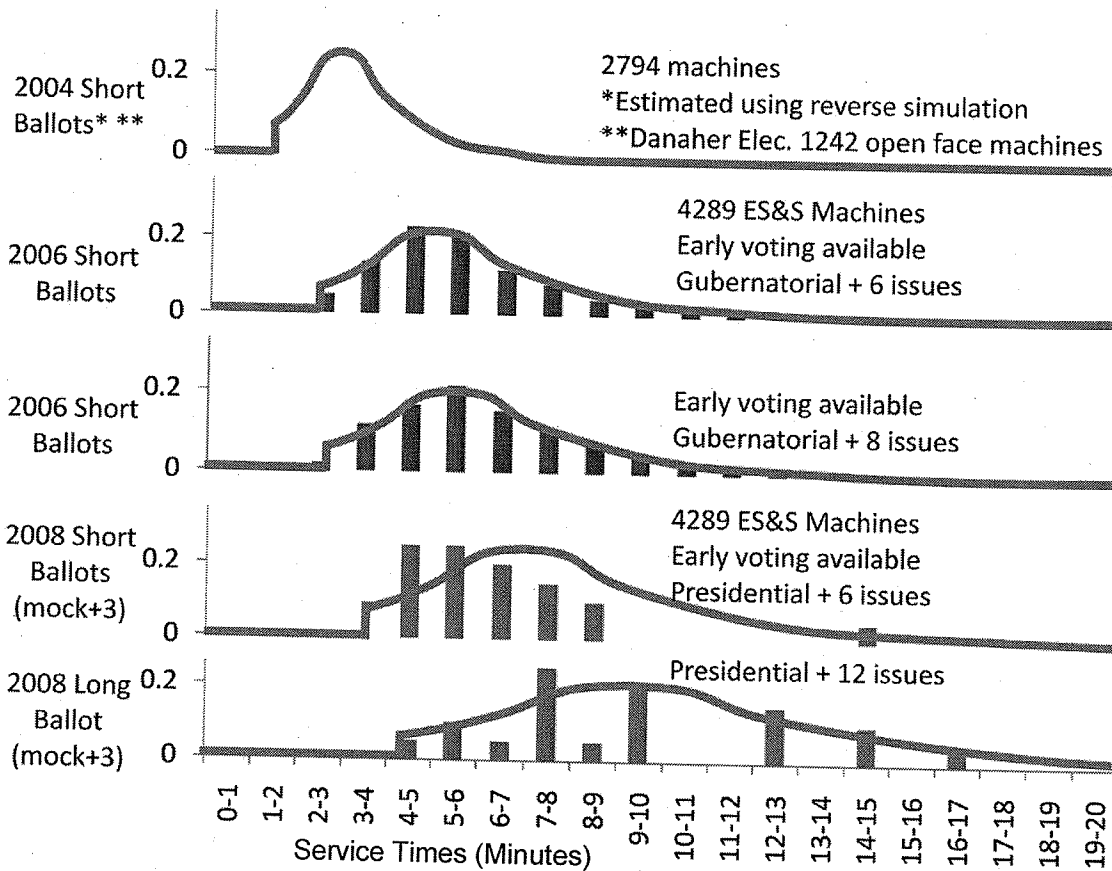
#	ID#	Experience	Race	Education	Sex	Age	Income	Q1	Q2	Q3	Q4	Q5	Q6	Score	Ballot	Time
1	4	Voted 1-4 T	AA	High School	Female	20	25	c	c	d	a	c	c	67%	S	6.9
2	5	4+ Pres. Elect.	Other	College+	Female	65	250	c	b	d	a	d	b	67%	S	4.5
3	6	Voted 1-4 T	AA	College+	Female	34	35	c	a	d	a	c	c	67%	L	9.7
4	7	Voted 1-4 T	Other	High School	Female	38	75	c	b	d	a	c	c	83%	S	4.9
5	8	4+ Pres. Elect.	Other	High School	Male	69	75	a	a	a	a	cd	a	17%	S	5.5
6	9	4+ Pres. Elect.	Other	College+	Female	61	35	c	b	d	a	c	b	100%	L	4.6
7	10	4+ Pres. Elect.	Other	High School	Male	40	50	c	b	d	a	c	c	83%	O	6.9
8	11	Voted 1-4 T	AA	High School	Female	24	50	c	b	d	a	c	c	83%	O	8.9
9	12	Voted 1-4 T	Other	High School	Female	20	150	c	a	d	a	c	e	83%	S	5.0
10	14	Voted 1-4 T	AA	College+	Female	30	35	c	b	d	a	c	c	83%	S	4.5
11	15	Voted 1-4 T	AA	High School	Female	21	35	c	a	d	a	c	b	83%	O	6.3
12	16	4+ Pres. Elect.	Other	High School	Female	65	25	c	b	d	a	cd	b	83%	O	7.7
13	17	4+ Pres. Elect.	Other	College+	Female	67	250	c	b	d	a	d	c	67%	S	5.2
14	18	Voted 1-4 T	AA	High School	Male	41	150	c	b	d	a	c	c	83%	S	3.8
15	20	Voted 1-4 T	Other	College+	Male	30	75	c	b	d	a	c	b	100%	O	4.2
16	21	Voted 1-4 T	Other	College+	Male	26	100	c	b	d	a	c	c	83%	S	3.7
17	22	Voted 1-4 T	Other	High School	Male	42	250	c	b	d	a	c	bcd	83%	O	8.6
18	23	Voted 1-4 T	Other	High School	Male	43	35	a	d	c	a	c	c	33%	S	6.5
19	24	4+ Pres. Elect.	Other	College+	Female	67	25	c	b	d	a	c	b	100%	L	6.9
20	25	Voted 1-4 T	AA	High School	Male	45	100	c	b	d	d	c	b	83%	L	12.1
21	26	Voted 1-4 T	AA	High School	Male	26	25	c	c	d	a	c	d	67%	L	7.7
22	27	Voted 1-4 T	Other	High School	Male	50	75	c	c	a	a	cd	b	50%	O	5.0
23	29	Voted 1-4 T	Other	High School	Female	44	75	c	b	d	a	c	b	100%	L	14.9
24	30	Voted 1-4 T	Other	College+	Female	31	35	c	a	d	a	c	b	83%	L	7.3
25	31	Voted 1-4 T	Other	College+	Female	27	25	c	b	d	a	c	b	100%	L	12.7
26	32	Voted 1-4 T	Other	High School	Female	21	25	c	a	d	a	c	d	67%	L	9.3
27	33	Voted 1-4 T	Other	High School	Female	46	50	c	b	d	a	cd	c	67%	S	6.5
28	34	Voted 1-4 T	Other	College+	Female	27	50	c	b	c	a	c	b	83%	O	6.2
29	35	Never Voted	Other	College+	Male	32	150	n/a	n/a	n/a	n/a	n/a	n/a	NA	L	7.4
30	37	Voted 1-4 T	Other	College+	Male	39	n/a	c	b	d	a	c	e	100%	S	4.2
31	38	Voted 1-4 T	AA	High School	Male	24	25	b	b	d	a	c	d	67%	O	8.4
32	39	Never Voted	AA	College+	Male	32	75	c	b	d	a	c	c	83%	S	13.7
33	40	Never Voted	Other	High School	Female	20	75	c	b	d	a	c	e	83%	L	5.5
34	41	Voted 1-4 T	AA	High School	Male	27	25	c	b	d	a	c	b	100%	L	9.6
35	43	4+ Pres. Elect.	AA	College+	Male	39	100	c	b	d	a	c	b	100%	O	6.8
36	44	Voted 1-4 T	AA	High School	Male	63	75	d	b	d	a	d	c	50%	S	6.5
37	45	4+ Pres. Elect.	Other	High School	Female	62	25	c	c	d	a	c	b	83%	O	20.1
38	46	Voted 1-4 T	AA	College+	Female	56	35	c	d	d	a	c	b	83%	O	15.9
39	47	Voted 1-4 T	AA	High School	Male	25	25	c	b	d	a	c	c	83%	L	9.8
40	48	4+ Pres. Elect.	Other	College+	Male	59	35	c	b	d	a	c	c	83%	S	8.0
41	49	Voted 1-4 T	Other	High School	Female	46	25	n/a	n/a	n/a	n/a	n/a	n/a	0%	L	7.1
42	52	Voted 1-4 T	Other	College+	Female	31	50	c	b	c	a	c	c	67%	S	4.1
43	53	Voted 1-4 T	Other	College+	Male	59	150	c	b	d	a	d	bcd	67%	O	10.9
44	54	Never Voted	Other	High School	Female	24	35	c	b	d	a	c	b	100%	O	12.5
45	56	Voted 1-4 T	AA	High School	Male	32	25	c	b	d	a	c	c	83%	O	19.0
46	58	Never Voted	Other	High School	Male	43	35	c	a	b	a	c	e	50%	O	18.7
47	59	Never Voted	Other	High School	Male		35	b	d	b	c	c	c	17%	S	7.3
48	60	4+ Pres. Elect.	Other	College+	Male	36	75	c	c	d	a	c	bcd	67%	L	7.9
49	61	Never Voted	Other	High School	Male	21	25	c	b	d	a	c	b	100%	L	8.5
50	62	Voted 1-4 T	AA	High School	Female	43	50	c	b	d	c	c	d	67%	L	5.6
51	63	Voted 1-4 T	AA	High School	Female	53	25	c	b	c	a	c	e	67%	O	12.9
52	65	4+ Pres. Elect.	Other	College+	Male	60	75	c	b	d	a	c	b	100%	L	14.8
53	66	Never Voted	Other	College+	Male	30	100	c	d	d	a	c	b	83%	O	8.4
54	67	Never Voted	AA	High School	Male	21	100	c	b	d	a	c	c	83%	L	12.0
55	68	Never Voted	Other	High School	Male	20	50	c	b	d	a	c	b	100%	O	12.8
56	69	Never Voted	Other	High School	Male	20	25	c	b	d	a	n/a	e	83%	S	5.8
57	70	n/a	Other	High School	Male	25	35	c	c	d	a	c	c	67%	S	7.9
58	71	Voted 1-4 T	AA	High School	Male	23	n/a	c	b	c	d	c	c	50%	S	6.5
59	72	Voted 1-4 T	Other	College+	Female	24	n/a	b	b	d	a	c	c	67%	O	12.8
60	73	Voted 1-4 T	Other	College+	Male	24	n/a	c	n/a	d	a	c	bcd	67%	L	16.4

The mock election results provide interesting information on several issues. Here, we focus on the implication for service and waiting times. Implications related to retention issues are discussed later. (The correct answers were c, b, d, a, c, and b or e.)

Related to service times (times each voter takes to monopolize the DRE and cast his or her ballot), our initial observation is that the times agree with the actual times in the 2006 election. The minimal difference between the 2006 election with six issues and the mock election with five issues is explainable by the slightly longer presidential slate of candidates. Therefore, we feel that the mock analysis results provide highly trustworthy information.

Ballot	mock presidential +	
	# issues	avg. time
Short (S)	5	6.1
Long (L)	11	9.2
One-Page-Per (O)	11	10.5

The mock election and 2006 results permit us to fill in the picture in the histograms below. The plots also show our freehand depiction of our best fit truncated normal distributions. The data shows a continuous progression to substantially longer service times. The question addressed by our simulation investigation is: Do these longer service times more than balance the positive developments?



Relative frequency histograms showing the trend to substantial service time increases.

THE ELEMENTS OF HIGH FIDELITY SIMULATION

The structure of our simulation is essentially the same as the one described in Hertzberg, Allen, and Bernshteyn (2006). Voters arrive and queue (with registration issues ignored). Partly because waits caused by registration are ignored, we suggest that our results are optimistic. If we predict a major problem, then one is likely. However, waiting problems might happen even if we fail to predict them. Also, breakdowns inevitably occur and these machines will be removed from use for periods of time. Details about the assumptions that govern our simulations follow.

TURNOUT OR "ARRIVAL" AT QUEUE

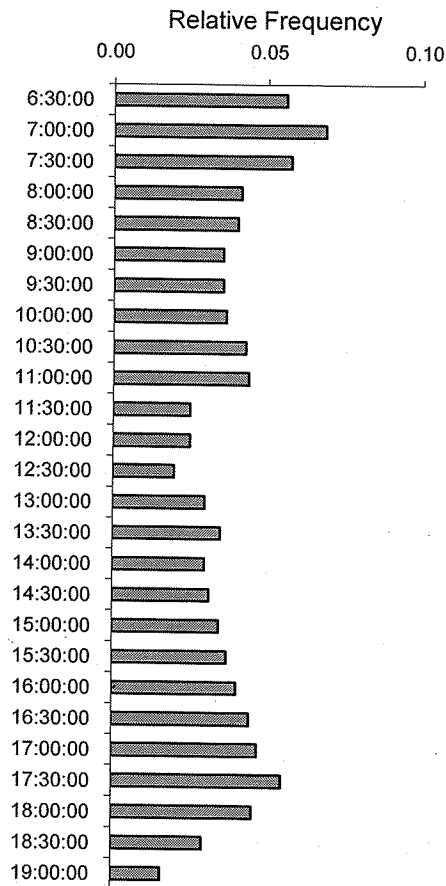
Voter arrival at the polling location is uncoordinated, leading to a random pattern. The arrival process is constrained in that it is not possible to have many more arrivals than there are possible voters living in the area. Therefore, our approach is two step, i.e., first the number of voters is generated and then the arrival times are selected.

Strictly speaking, the number of possible voters is greater than the number of registered voters because provisional ballots are possible. Yet, our approach constrains the turnout using a randomly generated fraction of the number of registered voters. Define an overall Election Day (ED) turnout parameter, T , roughly corresponding to the overall turnout fraction, e.g., 0.5 for 50% turnout. Then, the simulation generates the turnout, $T(i)$ for each polling location i is given by:

- $(T) \times (\# \text{ Registered}) \times 0.6$ with probability 0.25
- $(T) \times (\# \text{ Registered}) \times 0.8$ with probability 0.25
- $(T) \times (\# \text{ Registered}) \times 1.2$ with probability 0.25
- $(T) \times (\# \text{ Registered}) \times 1.4$ with probability 0.25

We feel that these assumptions are a source of conservatism in our studies because the range 0.6 to 1.4 is larger than in Allen and Bernshteyn (2004). We considered four ED turnout scenarios, $T = 0.41, 0.45, 0.50,$ and 0.55 .

When voters arrive is also of critical importance to the formation of lines. We analyzed 1,893 voters from 2006. Since lines were generally minimal, voters arrived at the queuing area at approximately the same time they arrived at the machines. Therefore, in our simulations, we assumed arrival at queue followed the distribution from the following relative frequency histogram. The histogram shows increased arrivals right after polls opened and before they closed.



Arrivals based on the above empirical distribution are considered to be relatively high fidelity compared with uniform or Poisson arrival or following rush periods as described in Magleby and Christensen (1994).

BALLOT LENGTH OR "SERVICE RATES"

Voters spend an uneven amount of time monopolizing DRE machines when they are casting their ballot. Differences stem in part from interest and ability to synthesize the ballot and the amount of material presented. An obvious other factor is how much they need to read or synthesize, i.e., the ballot length which includes candidates and variable numbers of issues.

In our simulations, we use truncated normal distributions with the standard deviation equal to one quarter of the parameter μ and the cutoff equal to 0.333 of parameter μ . Therefore, the true mean is generally negligibly different than the μ parameter. The distributions used are indicated together with the data from the 2006 and mock elections as shown in the mock elections section.

Therefore, the rule used was 0.5 minutes per issue, inflating the average times for each of the three groups of polling places. Columbus precincts are predicted to have five state issues (the other three likely will not pass) plus one school issue and six city issues.

Precincts	Main scenario		Alternative	
	#issues	av. time	#issues	av. time
Columbus	12	9.7	15	11.2
Gahanna	7	7.1	10	8.6
Other	6	6.6	9	8.1

Gahanna precincts will have the five state issues, a school issue, and a single Gahanna specific issue. Other locations are assumed to have only five issues. This assumption is another source of optimism in the analysis.

MACHINE BREAKDOWNS

Out-of-service conditions refer here to situations in which the DRE machines become unavailable to voters. This could occur for any of the reasons listed below which summarizes 289 service calls during the 2006 November election.



Other reasons are also possible. Our analysis of the time data from the 2006 election suggests that there were many instances of breakdown that did not trigger a service call. Presumably, the poll workers repair machines in these instances. In our simulations, we assume that breakdowns arrive at machines at a rate of 0.1 per hour and last a time that is exponentially distributed with mean equal to 1 hour.

VOTE CENTERS OR "MULTIPLICITY"

Headlines generally focus on the experiences in the worst precinct or polling location. The worst experiences depend on the details of the queues (arrival and service rates) and the number of queues. Each queue is an opportunity for a problematic event.

In addition to offering fewer locations where problems can occur, grouping precincts together generally causes improved waiting line performance because the system is better able to get ahead during the slow periods (Banks, Carson, and Nelson, 2005). We used the 534 locations rather than the 780+ precincts as the basis for assignment.

PRETTY GOOD FORMULA AND ALLOCATION

Simulating 534 unique queues and testing alternative numbers of machines is a computational challenge even with modern computing power. This problem is made even more difficult because financial constraints on the total number of machines creates the necessity for performance tradeoffs between precincts.

The simulation allocation generation (SAG) method in Hertzberg, Allen, and Bernshteyn (2006) involves simulating each queue individually and adding machines until user-specified service requirements are met. After assigning all locations, the overall number of machines is summed. If the overall number is too high (low), individual location performance requirements are loosened (tightened). For example, one might start with precinct specific requirement that no voter should expect, in that precinct, to wait longer than five minutes. (Note that, because of multiplicity, this requirement could be met and a few voters might wait longer than one half hour.) After putting enough machines in each location to meet the requirements, the total required might exceed the number of available machines and iteration would be needed. For acceptable numbers of replicates or simulated Election Days (over 100), this process is prohibitively slow.

A key parameter in queuing theory is the dimensionless number, ρ , given by:

$$\rho = \frac{\lambda}{c\mu} = \frac{\text{arrival rate}}{(\# \text{ machines})(\text{service rate})}$$

which might be called the "utilization" of machines and which often provides much of the information needed to evaluate the queue quality. In terms of the quantities that are readily available quantities, ρ can be estimated using:

$$\approx \frac{(\text{avg. voting time minutes})(\# \text{ registered})(\text{turnout})}{(\# \text{ machines})(60 \text{ minutes/hr})(13 \text{ hr})}$$

where the average times are in minutes.

We propose the following heuristic method for determining the numbers of machines needed at each location. It is based on finding iteratively a target utilization ρ_0 that either meets performance goals which can relate to the available budget for machines (i.e., the goal is to hit the target available) or waiting time performance goals.

Pretty good allocation (PGA)

Initialize: $\rho_0 = 0.85$;

Repeat{

Repeat for all locations {
number of machines =

$$\text{roundup} \left\{ \frac{(\text{avg. voting time mins.})(\# \text{ registered})(\text{turnout})}{(\rho_0)(13 \text{ hr})(60 \text{ mins./hr.})} \right\}$$

If{ performance is too poor} increase ρ_0 ;

If{ performance is too good} decrease ρ_0 ;

Until{performance is acceptable}

For budget related goals, the above method can be implemented quickly using a spreadsheet. For waiting time performance related goals, the above must be implemented in conjunction with a simulation model. The allocations are generated via spreadsheet and evaluated using simulation.

As an example, consider the following scenarios focusing initially on scenario 1. For this first scenario and the 543 locations, one first assigns the times to each vote center. Then, one iterates until as close as possible to the 4,565 machines are included. This results in the first allocation given in the results section generated using a utilization parameter ρ_0 equal to 0.8335. The procedure requires only a few minutes and excel.

	Scenario		
	1	2	3
ED Turnout	41%	45%	50%
Columbus (avg. min.)	9.7	9.7	9.7
Gahanna (avg. min.)	7.1	7.1	7.1
Other (avg. min.)	6.6	6.6	6.6

RESULTS AND ENDNOTES

In this section, the recommended allocations are described together with the simulation evaluations of their performance. The general conclusion is that action is critical for avoiding waiting lines longer than in November 2004.

We begin with an evaluation of the allocation used by Franklin County in the primary. This allocation only used 4,289 machines so that no one is really suggesting that this allocation should be used. Yet, in some sense this allocation is representative of allocations that do not use allocations design to address ballot differences, i.e., variable service times. It is hypothetically possible that this allocation might have been used without a vigilant management team.

The table shows the allocation used in the primary under three scenarios and evaluated using our high fidelity simulation method. Under ever scenario considered, the results are substantially worse compared with the experience in 2004. Part of this is likely the conservatism of our turnout assumptions. Yet, this answers the question such that the negative developments overwhelm the positive developments since 2004.

Next, we consider our proposed allocations made with performance measured by the number of machines. It should be noted that every allocation generated designed to be feasible for constraints on the number of machines can be viewed as having been generated from performance requirements. For example, the first allocation could have been generated to yield expected waits for randomly selected voters equal to approximately 20 minutes.

As an initial observation, consider that the pretty good allocation with 4,655 machines is substantial improvement over the allocation used in the primary. Essentially, it transforms an experience much worse than November 2004 into an

experience of approximately the same level of waiting and frustration. Further, the results show that increases in the numbers of machines result in improvements in waiting lines that might be considered important.

Scenario #	1	2	3
ED Turnout	41%	45%	50%
Columbus (avg. min.)	9.7	9.7	9.7
Gahanna	7.1	7.1	7.1
Other	6.6	6.6	6.6
Allocation #	Used in the 2008 primary		
Number machines	4289	4289	4289
Max of Avg (min.)	559.4	622.0	776.1
Avg of Avg (min.)	44.1	61.8	88.5
Avg of Max (min.)	94.4	129.8	183.0
Max Overtime (min.)	1133.7	1250.4	1565.3
Avg Overtime (min.)	95.1	130.6	183.9
# Centers w/ avg. wait >...			
30 minutes	175.0	195.3	236.9
45 minutes	161.8	184.4	218.2
60 minutes	146.7	175.9	204.3
120 minutes	82.9	127.8	169.8
180 minutes	31.7	74.0	123.9
240 minutes	11.7	28.4	75.3

For example, consider that under scenario #1, the number of centers with average waits longer than 60 minutes drops from 80.8 to 6.1 as the number of available machines increases from 4,565 to 5,000. Note that because of the careful allocation it is generally difficult to predict in advance which centers will wait longest. Also, the average wait for all voters decreases from 20.3 to 9.1 minutes.

In addition to the allocations presented below, we generated and evaluated one with 6,115 machines (a 34% increase). The allocation yielded overall average waits of 8.3 minutes even in the 50% turnout scenario. In even that scenario, no location has average waits longer than 74.5 minutes.

Three allocations and three scenarios are below together with information from simulation evaluations. We subjectively interpret the numbers to conclude that only the 4,999 machine (essentially 5,000) allocation is able to well handle the 41% turnout scenario. The performance of this allocation is "good" because the overall average voter waits less than 10 minutes.

We rate the overall performance of all three allocations as "poor" under the 50% turnout scenario as well as the first allocation's performance under scenario 2 (45% turnout). This follows because in all cases some polls are expected to close over five hours after the poll closing time. Also, the average voter waits longer than thirty minutes.

For the other cases, we assign a subjective rating of "fair" indicating that

performance better than in 2004 is expected. However, lines are expected to affect voter perception of the election and significant numbers of voters will likely be deterred by lines.

In addition, we evaluated each precinct using the 45% turnout scenario (scenario 2) and put the average waiting time in with the allocations. Note that this can be viewed as the long run average times because on any given day one or more locations will have unusually long waits. This explains why our simulated worst locations in previous tables are associated with significantly worse performance than indicated in this table. Also, the locations with the worst performance expected long run might not be exactly the same as the ones with the actual worst performance on Election Day.

RESULTS SUMMARY

Number of machines	4,565			4,765			4,999		
Scenario #	1	2	3	1	2	3	1	2	3
ED Turnout	41%	45%	60%	41%	45%	60%	41%	45%	50%
Columbus (avg. min.)	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7
Gahanna	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Other	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Allocation #	1	1	1	2	2	2	3	3	3
Max of Avg (min.)	127.3	170.3	228.8	108.8	148.3	202.8	82.6	122.4	175.3
Avg of Avg (min.)	20.3	26.3	30.3	14.6	28.1	50.3	9.1	19.7	38.3
Avg of Max (min.)	46.4	78.2	125.4	35.4	61.6	100.2	24.5	45.0	87.8
Max Overtime (min.)	246.7	337.6	452.6	205.9	286.6	407.2	158.4	238.2	341.1
Avg Overtime (min.)	46.3	79.9	128.6	34.8	62.8	108.7	24.0	45.6	85.2
# Centers with avg. wait longer than...									
30 minutes	136.8	220.9	253.2	108.2	179.9	253.5	66.0	130.8	230.4
45 minutes	107.5	183.0	250.2	76.7	138.2	230.6	27.4	106.4	197.0
60 minutes	80.8	144.9	236.1	39.5	113.4	209.0	6.1	80.4	154.2
120 minutes	1.1	61.8	124.4	0.2	10.0	63.7	0.0	0.7	58.4
180 minutes	0.0	0.2	37.3	0.0	0.0	6.1	0.0	0.0	39.0
240 minutes	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.4
Subjective assessment	Fair	Poor	Poor	Fair	Fair	Poor	Good	Fair	Poor

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ALLOCATIONS

Vote Center (meeting place)	# Reg.	From Primary 4289	4565	Avg. Wait	4765	Avg. Wait	4999	Avg. Wait
1ST PRESBYTERIAN CHURCH	2015	9	9	38.7	9	34.0	10	16.8
ALADDIN SHRINE CENTER	6296	34	39	49.4	41	49.8	43	25.9
ALEXANDER GRAHAM BELL SCHOOL	1433	6	9	57.9	10	30.2	10	22.3
ALKIRE ROAD CHURCH OF CHRIST	1761	10	8	24.0	8	33.9	9	16.0
ALL SAINTS ACADEMY	1797	10	12	35.4	12	17.8	13	13.5
ALL SAINTS EPISCOPAL CHURCH	806	4	4	19.8	4	20.4	4	19.7
ALL SAINTS LUTHERAN CHURCH	629	4	3	37.1	3	19.3	3	12.1
ALPINE ELEMENTARY SCHOOL	757	4	5	23.0	5	39.6	6	10.8
ALTON HALL ELEMENTARY SCHOOL	1564	9	7	31.5	7	18.5	8	11.3
ALUM CREEK BAPTIST CHURCH	1474	8	10	38.9	10	31.8	10	23.3
AMERICAN LEGION POST #239	872	5	4	33.8	4	40.8	4	23.9
AMERICAN LEGION YOUNG-BUDD #171	1917	11	8	50.4	9	34.5	9	17.8
AMERICAN LUNG ASSOCIATION	1599	9	10	42.6	11	37.1	11	20.8
ANNEHURST ELEMENTARY SCHOOL	2503	14	11	44.2	11	27.7	12	26.7
ANTRIM PARK SHELTER HOUSE	910	5	6	43.8	6	36.3	7	15.3
ARC INDUSTRIES	920	5	6	40.2	6	32.4	7	9.4
ARLINGTON PARK ELEMENTARY SCHOOL	832	5	6	17.7	6	16.8	6	15.3
ASBURY UNITED METHODIST CHURCH SOUTH	2297	15	15	44.4	15	25.9	16	21.0
ASCENSION LUTHERAN CHURCH	929	5	6	35.7	6	41.9	7	16.9
ATONEMENT LUTHERAN CHURCH	2089	11	13	57.2	14	29.0	15	10.5
AVALON ELEMENTARY SCHOOL	852	5	6	30.0	6	21.2	6	32.3
AVERY ELEMENTARY SCHOOL	1409	8	6	39.6	7	20.3	7	20.4
BAILEY ELEMENTARY SCHOOL	625	4	3	21.1	3	29.4	3	29.8
BARACK RECREATION CENTER	1298	6	8	60.8	9	22.8	9	18.0
BARNETT RECREATION CENTER	1101	6	7	50.0	8	20.4	8	20.9
BARRINGTON ELEMENTARY SCHOOL	1597	9	10	25.0	11	28.5	11	28.3
BEACON ELEMENTARY SCHOOL	1034	6	5	21.4	5	27.3	5	18.7
BECK STREET ELEMENTARY SCHOOL	1068	6	7	52.5	7	37.1	8	20.7
BEECHCROFT HIGH SCHOOL	1119	6	7	43.0	8	16.4	8	20.8
BEECHWOOD ELEMENTARY SCHOOL	923	5	6	16.9	6	32.8	7	10.1
BERWICK ALTERNATIVE SCHOOL	2229	13	14	35.5	15	32.7	16	27.4
BERWICK MANOR PARTY HOUSE	1070	6	7	50.6	7	36.8	8	12.2
BETH MESSIAH CONGREGATION	2078	11	13	47.2	14	32.2	14	39.9
BETHEL UNITED METHODIST CHURCH	1224	6	8	37.6	8	33.2	9	16.8
BEXLEY HIGH SCHOOL	2702	15	17	56.6	18	25.9	19	21.9
BEXLEY UNITED METHODIST CHURCH	1271	8	8	34.9	9	14.9	9	16.1
BIG WALNUT AERIE F.O.E. #3261	728	4	4	5.8	4	9.1	4	6.3
BIG WALNUT PARK SHELTER HOUSE	560	3	4	38.5	4	28.7	4	31.5
BISHOP READY HIGH SCHOOL	1846	10	12	46.1	12	36.1	13	20.8
BLACKBURN RECREATION CENTER	2396	12	15	58.3	16	42.4	17	15.0
BLENDON TOWNSHIP SENIOR CENTER	845	5	4	26.7	4	23.6	4	24.8

BOB DANIELS BUICK	794	4	5	51.2	6	18.7	6	12.5
BOLLINGER TOWER	1047	6	7	35.3	7	30.4	8	11.5
BOULEVARD PRESBYTERIAN CHURCH	841	5	6	20.7	6	22.6	6	18.8
BOYS AND GIRLS CLUB	1291	6	8	38.2	9	21.9	9	23.4
BRENTNELL ELEMENTARY SCHOOL	1127	6	7	56.8	8	17.0	8	24.8
BRICE UNITED METHODIST CHURCH	2314	13	10	39.7	11	29.7	11	16.9
BRIGGS HIGH SCHOOL	1263	n/a	8	49.2	9	25.2	9	28.6
BRITTON ELEMENTARY SCHOOL	1569	9	7	39.6	7	27.9	8	11.1
BROAD STREET PRESBYTERIAN CHURCH	959	n/a	6	33.4	7	19.4	7	19.3
BROAD STREET UNITED METHODIST CHURCH	2057	6	13	45.3	14	15.0	14	21.2
BROADLEIGH ELEMENTARY SCHOOL	1456	10	9	50.6	10	27.8	10	15.2
BROADVIEW HEALTH CARE CENTER	1092	6	5	42.0	6	10.4	6	16.4
BROOKHAVEN HIGH SCHOOL	816	5	5	55.4	6	16.1	6	13.3
BROOKPARK MIDDLE SCHOOL	2362	13	10	49.2	11	19.4	11	27.3
BROOKSIDE ELEMENTARY SCHOOL	929	5	6	41.0	6	39.4	7	13.5
BROWN TOWNSHIP HOUSE	1726	10	8	25.5	8	30.3	8	19.4
BRYCE ECK ACTIVITIES CENTER	2372	13	15	41.1	16	24.6	16	35.7
BUCKEYE CHRISTIAN CHURCH	1465	8	7	24.4	7	25.4	7	31.4
BUCKEYE MIDDLE SCHOOL	927	5	6	36.5	6	47.7	7	13.0
BUCKEYE VILLAGE RECREATION HALL	1495	6	10	47.6	10	44.8	11	14.8
BUCKEYE WOODS ELEMENTARY SCHOOL	2384	12	10	60.2	11	29.3	11	31.9
BURBANK ELEMENTARY SCHOOL	1690	10	11	39.0	11	49.5	12	22.8
CALVARY CHAPEL OF COLUMBUS	915	5	6	30.0	6	45.5	7	10.1
CAMPUS CENTER SCHNEIDER ROOM	1955	10	12	55.3	13	28.5	14	14.5
CANAL WINCHESTER COMMUNITY CENTER	331	3	2	5.5	2	6.3	2	7.8
CANAL WINCHESTER HIGH SCHOOL	658	4	3	39.2	3	31.9	4	3.5
CARRIAGE PLACE RECREATION CENTER	745	4	5	26.5	5	25.8	6	8.0
CEDARWOOD ELEMENTARY SCHOOL	1086	6	7	39.8	7	45.4	8	19.4
CENTENARY UNITED METHODIST CHURCH	1321	6	9	28.4	9	24.0	9	46.3
CENTENNIAL HIGH SCHOOL	989	5	7	17.6	7	31.6	7	19.3
CENTRAL COLLEGE ELEMENTARY SCHOOL	1226	8	6	22.4	6	13.1	6	18.6
CHAPMAN ELEMENTARY SCHOOL	2056	12	9	32.0	9	46.1	10	16.6
CHERRINGTON ELEMENTARY SCHOOL	918	5	4	51.2	4	43.8	5	6.7
CHERRY BLOSSOM APARTMENTS	2036	12	13	51.5	13	42.4	14	36.5
CHRIST FELLOWSHIP CHURCH	2587	12	11	38.6	12	25.0	12	16.0
CHRIST PRESBYTERIAN CHURCH	949	5	6	38.3	7	20.3	7	9.8
CHRIST UNITED METHODIST CHURCH	1772	11	11	54.1	12	28.6	12	16.8
CHRISTIAN ASSEMBLY	1796	10	12	44.2	12	41.1	13	13.5
CHRISTIAN FELLOWSHIP CHURCH	1023	5	7	19.5	7	46.2	7	35.0
CHRISTIAN LIFE CENTER	2163	11	10	34.8	10	27.7	10	31.0
CHURCH OF GOD OF PROPHECY	2198	12	14	55.5	15	29.0	15	27.7
CHURCH OF GOOD SHEPHERD U M CHURCH	702	4	5	27.3	5	25.1	5	27.3
CHURCH OF THE LIVING WORD CHAPEL	977	5	6	51.7	7	17.1	7	21.1
CHURCH OF THE MESSIAH UNITED METHODIST	876	5	4	22.9	4	32.4	5	3.1
CHURCH OF THE REDEEMER UNITED METHODIST	2372	11	15	54.0	16	25.6	16	34.9
CHURCH OF THE RESURRECTION	2402	12	11	36.0	11	20.4	12	17.0
CITY LIFE CENTER	960	5	6	58.5	7	20.4	7	17.4
CLAREMONT RETIREMENT VILLAGE	1512	6	10	36.4	10	25.8	11	16.7
CLINTON HEIGHTS LUTHERAN CHURCH	1878	11	12	42.7	12	31.9	13	17.5
CLINTON TOWNSHIP FIREHOUSE	607	4	4	25.4	4	40.2	5	8.2
CLINTON TWP TOWN HALL	1312	6	9	22.3	9	21.2	9	30.8
CLUBHOUSE II AT THE QUARRY	1337	6	9	37.1	9	27.3	10	8.4
COLEETA DAY CARE	1376	6	9	28.8	9	26.6	10	12.5
COLERAIN ELEMENTARY SCHOOL	823	5	6	20.9	6	14.9	6	24.7
COLUMBIA HEIGHTS U M CHURCH	2765	15	12	26.4	13	20.0	13	11.2

COLUMBUS ALTERNATIVE HIGH SCHOOL	1064	6	7	34.4	7	36.2	8	15.0
COLUMBUS COLONY	633	4	3	23.4	3	27.9	3	32.2
COLUMBUS COMMUNITY OF CHRIST	1356	6	9	30.7	9	39.4	10	22.8
COLUMBUS FIREHOUSE #18	1014	6	7	15.9	7	37.1	7	18.5
COLUMBUS FIREHOUSE #19	1079	6	7	53.1	7	47.0	8	11.8
COLUMBUS FIREHOUSE #21	893	5	6	24.5	6	29.4	7	10.7
COLUMBUS FIREHOUSE #26	758	4	5	46.9	5	34.0	6	6.6
COLUMBUS FIREHOUSE #27	1308	7	9	35.6	9	31.4	9	24.2
COLUMBUS FIREHOUSE #29	2277	12	10	25.1	10	40.4	11	20.4
COLUMBUS FIREHOUSE #30	1228	6	6	24.3	6	19.4	6	33.1
COLUMBUS FIREHOUSE #31	946	11	6	55.4	7	18.1	7	14.7
COLUMBUS FIREHOUSE #33	903	5	6	32.1	6	42.6	7	8.1
COLUMBUS FIREHOUSE #6	1172	6	8	30.9	8	33.5	8	26.6
COLUMBUS MENNONITE CHURCH	1468	8	9	38.0	10	27.3	10	22.3
COLUMBUS SPANISH IMMERSION ACADEMY COMMUNITY CENTER	855	5	6	37.1	6	28.2	6	26.2
1734	9	8	21.0	8	28.2	8	27.9	
COMO AVENUE ELEMENTARY SCHOOL	1745	10	11	44.3	12	16.3	12	29.5
CONGREGATION BETH TIKVAH	909	5	4	39.5	4	35.7	5	4.8
COUNTRY RIDGE	1057	6	5	20.9	5	16.4	5	20.2
COVENANT BAPTIST CHURCH	1407	8	9	17.6	9	45.8	10	30.2
COVENANT PRESBYTERIAN CHURCH	1836	10	12	31.3	12	40.0	13	17.9
CRANBROOK ELEMENTARY SCHOOL	866	5	6	31.7	6	23.7	6	28.2
CROSSROADS UNITED METHODIST CHURCH	2899	15	18	40.0	19	23.0	20	19.2
CROSSWINDS VILLAGE LEASING OFFICE	1145	6	8	23.7	8	13.2	8	19.1
CYPRESS MINISTRIES CENTER	1776	10	8	23.3	8	35.7	9	11.9
DANA ELEMENTARY SCHOOL	1157	6	8	24.8	8	30.2	8	20.9
DARBY CREEK ELEMENTARY SCHOOL	2077	11	9	39.8	10	17.2	10	22.8
DARBY WOODS ELEMENTARY SCHOOL	721	4	4	9.3	4	13.7	4	6.0
DARBYDALE ELEMENTARY SCHOOL	1618	9	7	26.2	8	18.0	8	13.6
DAVID LUTHERAN CHURCH	1647	9	7	39.6	8	25.1	8	25.0
DAVIS MIDDLE SCHOOL	2623	14	11	36.9	12	40.2	13	15.2
DAYSRING COMMUNITY CHURCH	2373	11	10	57.7	11	26.6	11	21.7
DESHLER ELEMENTARY SCHOOL	2354	12	15	38.4	16	24.9	16	21.3
DEVONSHIRE ELEMENTARY SCHOOL	1112	6	7	49.6	8	19.6	8	16.9
DISCOVER CHRISTIAN CHURCH	797	4	4	17.0	4	23.0	4	22.8
DODGE PARK RECREATION CENTER	1476	6	10	42.8	10	36.1	10	28.2
DOMINION MIDDLE SCHOOL	1023	6	7	20.2	7	25.3	7	26.9
DRIVING PARK RECREATION CENTER	5343	28	33	46.9	35	27.9	36	42.2
DUBLIN CITY HALL	748	5	4	15.0	4	13.3	4	7.2
DUBLIN COMMUNITY CHURCH	1464	4	7	16.6	7	28.1	7	22.0
DUBLIN COMMUNITY RECREATION CENTER	1081	5	5	32.4	5	39.1	5	18.1
DUBLIN SCIOTO HIGH SCHOOL	1573	6	7	28.0	7	40.6	8	12.2
DUNLOE ELEMENTARY SCHOOL	863	5	6	29.8	6	11.9	6	29.3
DUXBERRY PARK ALTERNATIVE SCHOOL	1223	6	8	43.1	8	49.7	9	10.3
EAST COLUMBUS COMMUNITY CHURCH	2286	12	10	36.2	10	42.4	11	17.6
EAST FRANKLIN ELEMENTARY SCHOOL	2002	11	13	49.7	13	50.3	14	24.1
EAST LINDEN SCHOOL	967	5	6	42.9	7	19.2	7	19.0
EAST SIDE GRACE BRETHREN CHURCH	2974	14	13	41.4	13	46.1	14	23.2
EASTGATE ASSEMBLY OF GOD	881	5	4	30.5	4	38.2	5	4.2
EASTGATE ELEMENTARY SCHOOL	624	4	4	32.9	4	46.7	5	10.0
EASTHAVEN ELEMENTARY SCHOOL	1988	11	13	37.0	13	32.8	14	16.7
EASTLAND CAREER CENTER	2395	12	10	55.4	11	32.1	11	36.7
EASTLAND LANES	650	4	4	75.2	5	12.0	5	11.3
EASTLAND MANOR	1134	6	7	28.0	8	20.5	8	27.2
EASTMINSTER PRESBYTERIAN CHURCH	1858	11	12	45.8	12	45.1	13	17.0

