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ANALYSIS OF LAYOUT IMPACTS ON RESOURCE ALLOCATION FOR VOTING: A LOS ANGELES VOTE CENTER

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ABSTRACT

The overlap of facilities layout planning and resource allocation models are relatively new and untested in election administration. Depending on the jurisdiction, Election Day(s) in-person voting location layouts are either planned, suggested with rough drawings, or arranged election officials at the time of set up. This study aims to build better analytical options for election administrators prior to Election Day. A vote center in Los Angeles County, California, during their 2020 Presidential Primary was investigated with discrete-event simulation to determine differences in performance based on layout and operational changes. The results indicate that by separating the processing of provisional voters at check-in, a significant reduction in the amount of time that voters spend in the vote center can be realized. This finding indicates the potential benefit of additional innovation and research investigating the relationship between facility layout and resource allocation for improved voter routing methods and polling location performance.

1 INTRODUCTION

Efficient and accessible voting is essential to ensure an open democratic process. U.S. polling places are complex and unique systems (e.g., the infrequency of use, varying levels of participation, and American with Disabilities Act [ADA] requirements) making election preparation difficult for election officials (e.g., elected or appointed) who oversee the resource allocation and setup for every in-person location in their given jurisdiction. In-person voting locations are considered as a set of subsystems within a hierarchical system of jurisdictions. Therefore, there are various points at which a singular abnormality within a system can create a chain reaction and extend the time required to vote.

Basic simulation models and queuing theory have been applied in election administration for resource allocation planning (Edelstein and Edelstein 2010; Stewart 2015; Stewart and Ansolabehere 2013). Meanwhile, election preparation remains notoriously difficult for administrators due to several factors: (i) appropriateness of common techniques to their jurisdiction, (ii) availability and scarcity of granular data (Spencer and Markovits 2010), (iii) systematic and empirically validated guidelines to support decision-making beyond heuristics (Stewart 2015), and (iv) the accessibility of advanced simulation techniques incorporating facilities layout planning to produce robust and comprehensive resource allocation models. These gaps proliferate, compound, and exacerbate inequalities and inefficiencies, leaving operational inefficacies and vulnerability to unexpected events (e.g., machine breakdowns, voting errors, arrival pattern variability) (Stewart and Ansolabehere 2013; Kimball 2013).

Technology, inside in-person polling locations, has provided unprecedented opportunities for improved data collection, processing, and granularity. The technology implementation, however, has resulted in some circumstances in which voters experienced long lines and delays during elections. These experiences create circumstances disenfranchising active voters, discouraging new voters, and compounding voting errors (Burden and Milyo 2015; Stewart and Ansolabehere 2013). This disenfranchisement indicates the necessity for further innovation in the methods available for election planning and operations. While this discussion has begun (e.g., Stewart 2015; Olabisi and Chukwunoso 2012), research focuses predominantly on resource allocation and line management. The purpose of this study is to apply innovative methods (i.e., discrete event simulations) and statistical analyses to investigate in-person polling location layouts to determine their impacts on voting and initiate the discussion on the interaction between layout and resource allocation in election systems.

2 LITERATURE REVIEW

Current modeling practices in election administration do not consider how the layout and physical dimensions of space impact resource allocations, nor how they impact voter flow, or voting wait times. Standard modeling practices typically model layout as an unconstrained feature; in other words, space capacity for in-person voting will meet demand. Although a useful modeling tactic as long as that feature does not impact performance, it is not realistic. Additionally, election administrators have anecdotally discussed how the orientation of stations may impact voter flow, but no empirical research exists. While the optimization of physical space allocation is generally well-researched, formally referred to as facilities layout planning (FLaP), its applications have generally focused on scenarios in manufacturing (Das 1993; Francis et al. 1992), transportation systems (Edwards 2004; Manataki and Zografos 2009; Li 2000; Bruzzone and Signorile 1998), and healthcare facilities (Arnolds and Gartner 2018; Holst 2015; Vahdat et al. 2019). Polling locations are housed in various facilities, each with their own set of constraints and opportunities. Frequently used in-person voting locations include cafeterias, gymnasiums, auditoriums, or large halls, customarily located within schools, community centers, senior living facilities, and churches. These locations, although practically desired based on their space, are realistically selected as long as that facility or any facility, for that matter (e.g., city halls, libraries, museums), is willing to host an election. Therefore, there is a complex set of facilities utilized by election officials, and the layout considerations within each of these facilities differ and are potentially unique.

FLaP framed problems are commonly studied through deterministic optimizations and heuristics, which take into account flow information (Tompkins et al. 2010), while discrete-event simulation (DES) employs stochastic methods to approximate random variation (e.g., human behavior and process variability) (Banks et al. 2010). Researchers have investigated hybridizing deterministic layout optimization techniques with simulated flow data from discrete event simulations (Vahdat et al. 2019) and developed methodologies for determining a robust layout design that performs well under variable demand conditions (Acar et al. 2009). These methodologies have implications for election planning to optimize voter path, layout configuration, and the resources allocated to balance day-of operations.

While methods in layout optimization and DES have expanded significantly over the last several decades, operations researchers have only started incorporating space in their simulation models (Taylor et al. 2013). These spaces are still left unconstrained; thus, the impact of flow and layout is relatively new in DES and particularly for election administration. Jamali et al. (2020) reviewed computerized hospital layout optimization modeling techniques and found them limited by their scope and lack of data, an issue in many application areas involving human movements such as airports, transportation systems, and polling locations. DES provides an avenue for generating this type of data (Sanchez 2018). There is a growing area of optimization research that uses stochastic objective functions and/or stochastic constraints (Hosseini-Nasab et al. 2018). Advanced metaheuristic methods for solving more complex models have increased the modeling methods available for election administrators, yet how to best use these techniques is not well understood.

Additionally, election administrators and planners typically use “Rules of Thumb” (Stewart 2015, p.13) based on personal experience to arrange and recommend layout choices per statutes or ADA requirements (Arnolds and Nickel 2015). Assessing the impact of layout decisions prior to Election Day(s) remains challenging for election administrators, however, rapidly developing technology provides an avenue for doing so as the computational and financial expenses of data-driven methods decrease. Among these technologies, simulation is a well-suited method for investigating the one-off nature of election processes if adequately tuned with/by election administrators allowing for the analysis of facility operational performance. These data-driven methods are especially useful for addressing challenges with sizable human impact and capital costs while informing layout decisions. Thus, we propose adding layout considerations in the DES modeling framework to assess the in-person voting process’s performance. This study presents a novel investigation on the use of layout in a single vote center by studying how layout methods impact polling location performance.

3 CASE STUDY

To investigate the impact of layout decisions on the operations of an in-person voting location, a Los Angeles County (LAC), California vote center was selected as a case study. With LAC being home to more than 5.5 million registered voters (California Secretary of State 2020) and having implemented a new set of voting equipment for the 2020 Presidential Primary, the question of how to best layout a vote center is a critical election planning component. First, a general representation of the observed vote center was developed and verified. Data collected from manual observations of the election process were fit to probability distributions, when applicable, for input into the simulation model. A simulated representation of the vote center was then coded using *Simio* software Version 11.197.19514. This baseline model was then verified utilizing known process behavior and validated based on observed time studies. An experimental design varied the vote center’s layout and flow to identify the impact of such changes.

3.1 Conceptual Modeling

The system investigated was a LAC vote center in operation during the 2020 Presidential Primary Elections. A vote center is an in-person polling location where voters from several precincts go to cast their votes. According to the California Voter’s Choice Act (S.B. 450 2016 [enacted]), LAC vote centers allow any voter within their county to cast a vote within any of their locations (1,000 for this specific election). The observed election took place on Election Day—Super Tuesday, March 3, 2020—representing the highest per day voter turnout of LAC’s voting period of 10-days.

Voting throughout LAC requires either a one-step, two-step, or three-step process, depending on a voter’s eligibility. For a registered voter who is dropping off a pre-marked ballot (i.e., vote by mail), the one-step system requires they insert their ballot into a secure lockbox. This one-step process was excluded from this analysis as this process is independent of the overall system. For a registered voter, it is a two-step process of (step 1) identification and ballot printing at check-in, followed by a one-station ballot marking and ballot-scanning process (step 2). Under specific conditions (e.g., same-day registration), voters file a provisional ballot in a three-step process: (1) check-in, (2) ballot marking, and then (3) return to the check-in station to finalize their ballot. Regardless of the type of voter, equipment for check-in and ballot marking is identical. Figure 1 illustrates these voting processes within the system.

During the check-in process, voters provide information to poll workers to ensure eligibility; no form of identification is required in the State of California. The information is processed with an electronic poll book, KNOWiNK Poll Pad® (a modified touchscreen tablet that accesses the voter registration database), which indicates to a specialized ballot printer what ballot information to print. The ballot is then printed per voter, based on their specific ballot for where they are registered, and handed to the voter. After this process, the voter locates a Voting Solutions for All People (VSAP) ballot marking device (BMD) (i.e., an electronic voting booth in which voters insert their ballot and digitally mark their ballot using a LAC specifically designed touchscreen interface). Once ballot marking is completed on the BMD, the voter's marked ballot is printed for review. The voter then casts their ballot by reinserting it into the BMD's integrated scanner and verifying its submission on the BMD's interface. For provisional voters, they return to check-in, insert their ballot into an envelope, fill out the required information on that envelope, and then cast them into a secure lockbox. Once their vote is cast, the voter is free to exit the system. The setup of the vote center is performed by LAC Registrar-Recorder/County Clerk's office crews; however, the planned layout design decisions and equipment positioning/orientation are not clear.

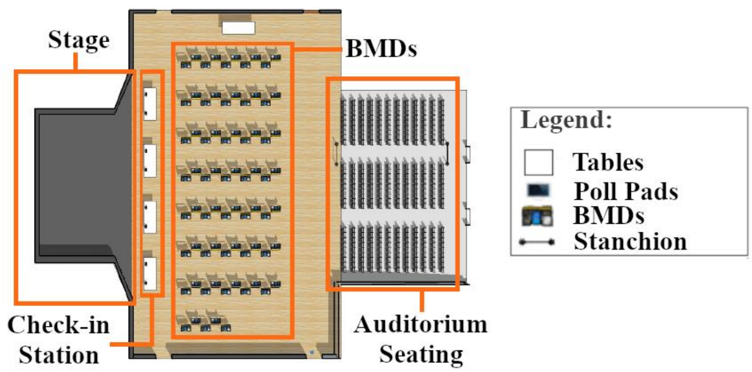

Figure 1: Diagram of the LAC Vote Center

3.2 Model Inputs

The primary inputs into the system simulation included arrival behavior, processing times, equipment counts, and station availability. Voter arrivals were separated by voter type of provisional and non-provisional. A combination of observational time studies and electronically generated data were collected. Despite the majority of the voting process generating transaction logs that outline the events that occur on each device within the voting system, the accessibility of these logs to individuals outside of the County Election Board is delayed until election authentication and verification processes are completed. Time studies were performed on the check-in processes and the ballot marking processes to supplement data for the initial system analysis. Counts were extracted from log files that were available from Poll Pads® to determine the total number of provisional and non-provisional voters.

Processing times were determined by generating distributions representative of the data collected through manual observations from the check-in (n = 506) and ballot marking and scanning (n = 304) processes. Distributions were fit using the *fitdistrplus* package in *RStudio* in which various distributions were automatically fit and compared to the data using P-P plots and Q-Q plots. The resulting distribution fit for the check-in process was a log-logistic distribution with a shape of 3.532 and a scale of 107.191. The ballot marking and scanning process fit a log-logistic distribution with a shape parameter of 3.521 and a scale parameter of 339.560.

Other critical model inputs included arrival rates into the system and voter pathing logic. Due to the formation of a line outside of the vote center, the arrival of new voters could not be directly observed during data collection. To account for this, literature investigating voting systems were used to generate an estimated expected turnout pattern. It is generally accepted that voters will arrive at polling places primarily early in the day as well as in the mid-afternoon (Edelstein 2006; Yang et al. 2014; Yang et al. 2009). The turnout rates presented in Yang et al. (2009, p.3143) assume 47% of voters arrive prior to 11:00 a.m. with another peak in the mid-afternoon (i.e., 24% between 11:00 a.m. to 3 p.m.). The arrival behavior presented in Yang et al. (2009) was used for the estimation of the arrival pattern in this study. Adjustments were made to hourly rates to match the queue observed during data collection which formed prior to check-in and lasted from 8:00 a.m. to 10:00 p.m. Arrivals within hours followed a nonhomogeneous Poisson process and all arrivals ended at 8:00 p.m as per LAC law.

During data collection, equipment counts and equipment availability were recorded. Seven Poll Pads® were used throughout Election Day. A total of 75 BMDs were present within the vote center, however, only 64 were in use throughout the day. Of the 64 devices, 53 were available for use from 7:00 a.m. to 5:00 p.m., after which all 64 were available. The remaining 11 BMDs were not in use due to a line forming behind the devices with a direct line of sight to the touchscreen interface. For voter privacy, these devices were shut down, and their use was prevented.

Additional assumptions were required to account for observed behaviors that could not be included in the model due to a lack of data and the inability to track specific processes. It was assumed that voters would successfully cast the first ballot that they were given; thus, one ballot per person. While this is not representative of the actual election, it was difficult to track observationally when a voter must surrender or void an incorrect ballot and obtain a new one. Therefore, it was assumed that non-provisional voters would never backtrack to the check-in stations and potentially be relabeled as provisional voters. It was also assumed that voters would not pass each other prior to the check-in station, i.e., the queue will follow first in first out (FIFO), but they may pass one another when on the same path to a BMD or an exit. In practice, LAC vote centers also allow voters to drop-off mail-in ballots to secure lockboxes within the vote centers. This subsystem was predominantly isolated from the other voting processes in terms of arrivals, queuing, and processing; thus, it was excluded from the simulation models.

3.3 Model Coding

A DES model was created in *Simio* to represent the LAC vote center. The approach for modeling focused less on an exact representation of the vote center, which would be practically impossible due to data availability, but focused instead on approximating its behavior. Even with an approximated system representation, the impact of system changes provides useful, relative performance differences (Banks et al. 2010) as long as the model logic is representative. Therefore, an estimated diagram of the vote center was generated within *Simio*. The model space was then populated with servers to represent check-in and BMD processes with a single server representing up to two check-in stations or eleven BMDs, respectively.

Routing logic was developed to ensure that the provisional voters returned to the check-in before exiting the system. Voter paths were modeled based on the observations during data collection with optional routes available. Paths before check-in did not allow passing as voters were checked-in following a FIFO strategy, however, paths beyond the check-in did allow passing so that voters could access any available BMD or exit. Exit routes (paths) were optional, with shorter paths preferred by voter entities. For all paths, a standard walking speed of 1.4 m/s (*Simio* default value) was used.

3.4 Verification and Validation

The model was verified by observing the 2D and 3D visual simulation provided in *Simio*. System representation was judged by the routing and travel behavior taken by entities throughout the system. Priority was placed on the prevention of non-provisional voter backtracking, appropriate queue formation, and equipment selection logic. When entity and processing behaviors were reasonably representative of the LAC vote center, the model was validated. The validation method predominantly compared simulated results with descriptive statistics of the observational data. Key measures for validation included the average processing times at the check-in and BMDs and the queue formation behavior prior to check-in. The resulting average processing time for the simulated check-in process was 2.161 minutes, an average of averages over 100 replications ($n_1 = 100$), which was not statistically different from the observed average check-in time of 2.223 minutes ($n_2 = 500$) with a 95% confidence interval on the difference of (-0.242, 0.028) (i.e., two-sample t-test with $p = 0.121$). The average simulated BMD processing time was 6.861 minutes, an average of averages over 100 replications ($n_3 = 100$), which was not significantly different from the observed average of 6.783 minutes ($n_4 = 300$) with a 95% confidence interval on the difference of (-0.923, 0.313) (i.e., two-sample t-test with $p = 0.332$). To further validate the determined arrival pattern and check-in processing behavior, the queue length was observed throughout the simulation run and compared to actual line counts taken throughout data collection. While the exact count of voters in the queue differed between the simulated election and the observed election, the pattern of queue behavior and its relative magnitude were sufficiently similar (i.e., the queue formed at 8:00 a.m. and was maintained until approximately 10:00 p.m.).

3.5 Experimental Design

Seven simulations implementing alternative layout strategies (Table 1) were developed and compared to the baseline model to investigate the impact that layout has on vote center performance. Each simulation model included the same data inputs for all parameters (i.e., arrival patterns, resource quantities, and processing times) and included the implementation of common random numbers for each processing distribution. System parameters, such as resource quantities, were left unchanged in order to not confound the influence of the layout on system performance. Simulations were run for 16 hours, representing the time from the opening of the polls (i.e., 7:00 a.m.) to the last voter in the system leaving (i.e., approximately 11:00 p.m.). Arrivals ended at hour 13 (i.e., 8:00 p.m.) per law. Each model was replicated 100 times to achieve enough observations to generate a 99.3% confidence interval (CI), resulting from a Bonferroni corrected 95% CI on the desired performance metrics (Banks et al 2010, p. 477).

While there is a vast amount of advanced research and algorithms dedicated to optimizing facility layouts (e.g., Sherali et al. 2003; Amaral 2006), a non-combinatorial approach was applied to the development of alternative layouts for experimentation because the goal was to test a set of feasible options. These layouts were developed by following recommended best practices for polling location design (e.g., U.S. Election Assistance Commission n.d.; Center for Civic Design 2014), ideas proposed by election administrators and election experts (i.e., separating the processing of provisional voters), and general foot traffic best practices (i.e., avoiding cross-traffic). The purpose of determining layout alternatives using realistic options is based on accessibility. It was out of the scope of this paper to develop layout optimization methods for generating layout alternatives to use in a DES. Table 1 lists and describes the layout alternatives and provides the figure reference.

To measure each alternative's performance, two measures were considered: the average time in the system (ATS) and the maximum time in the system (MTS). These measures were selected due to their relevance to the election domain, where past elections have been criticized for lengthy times to vote (e.g., Harmon et al. 2015; Arnsdorf 2018; Cassidy et al. 2018). Each alternative's measures are compared to the *Baseline* model to determine the margin of improvement achieved by the layout alteration.

Each variation in the experimental design is explored individually and results are compared based on relative performance. The time-based metrics (i.e., ATS and MTS) are considered due to the observation of voters waiting several hours to vote in the LAC vote center. By assessing ATS and MTS, we can identify potential opportunities for system improvement that do not require additional resources within a vote center but do assist in achieving the national goal stating that no voter should have to wait longer than 30 minutes to cast a vote (Bauer et al. 2014). All results are presented considering a Bonferroni corrected alpha (i.e., α_i = 0.05/7 = 0.007 for the comparison of models to an existing system, where K = 8 and C = 7). Utilizing relative performance assessment techniques, the differences in the mean performance metrics (i.e., ATS and MTS) are determined and compared (Banks et al 2010, p. 476-477).

Table 1: Description of model alternatives.

Model	**Figure**	**Description**
Baseline	3.a	A path was located from the entrance door to the check-in stations through an aisle of unused BMDs. Paths connected each check-in station to each aisle of BMDs. Each aisle of the BMDs was connected to several exit paths.
Moved Check-in Station	3.b	The location of the BMDs and check-in stations were switched. Paths lengths were adjusted as necessary; however, no paths were rerouted.
Looping Voter Path	3.c	Paths were removed or relocated to allow voters to enter from only one door and exit through only one, separate door. Paths did not cross one another.
Separated Provisional Processing	3.d	The check-in process was separated so that five Poll Pads® processed only non-provisional voters while two Poll Pads® processed only provisional voters. The line leading to the check-in station was separated so that each type of check-in (i.e., provisional and non-provisional) had its own line.
Looping Voter Path and Moved Check-in Station	3.e	Combined the relocation of voting equipment present in the *Moved Check-in Station* model and the altered voter paths as defined in the *Looping Voter Path* model. Non-provisional voters flow through the system with no opportunity to backtrack, while spending no time queued within a BMD aisle.
Moved Check-in Station and Separated Provisional Processing	3.f	The location of the BMDs and check-in stations were switched and the check-in line was separated for provisional voters. Provisional voters were processed at a separate check-in station.
Looping Voter Path and Separated Provisional Processing	3.g	Paths were removed or relocated to allow voters to enter from only one door and exit through only one, separate door. The line for check-in was also separated for provisional and non-provisional voters. Provisional voters were processed at a separate check-in station.
Looping Voter Path, Moved Check-in Station, and Separated Provisional Processing	3.h	The location of BMDs and check-in stations were switched and paths were removed or relocated to allow voters to enter from only one door and exit through only one, separate door. Check-in queues and stations were separated for provisional and non-provisional voters.

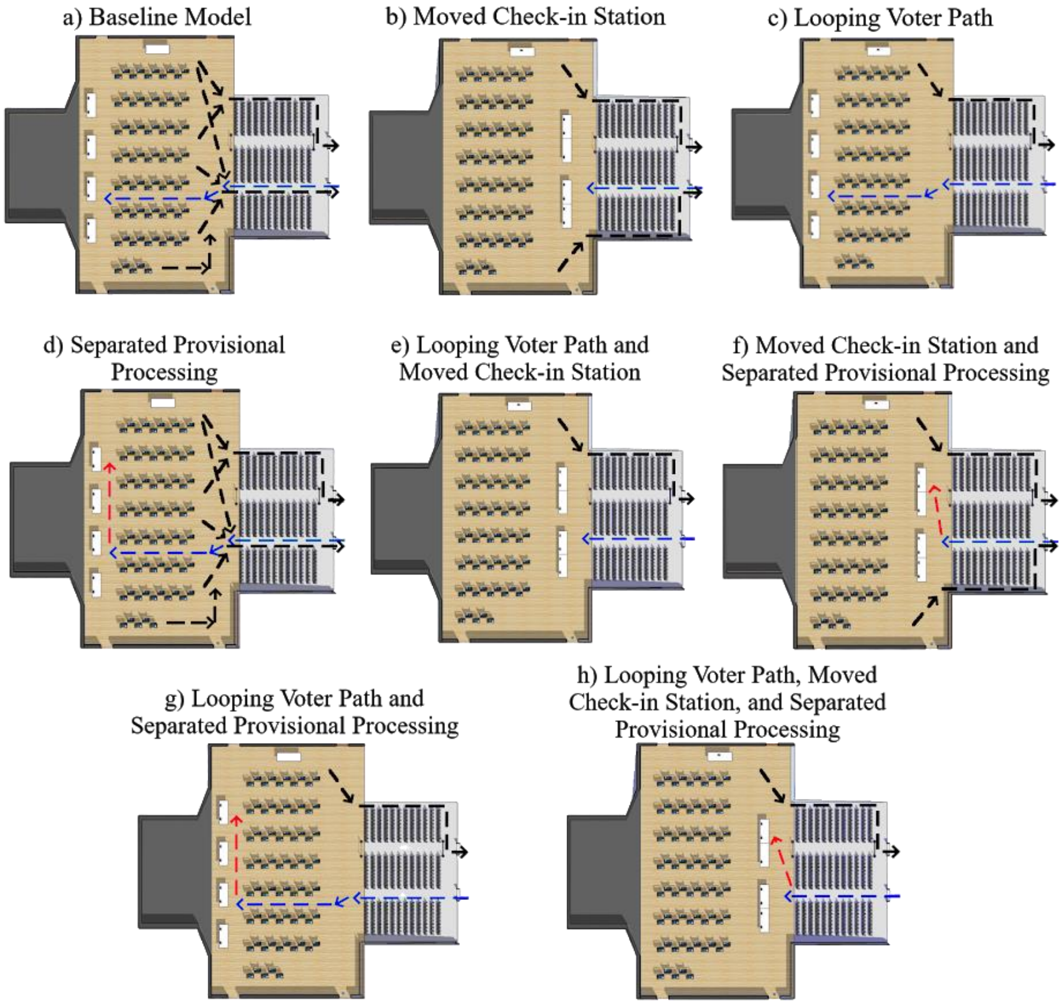

Figure 3: Model variations included in the experimental design. Blue lines are voter entry paths, red are provisional voter paths, and black are exit paths.

4 RESULTS

Results are reported in terms of the change in time (in hours), as well as the percent change in ATS and MTS, presented in Table 2. There was no significant difference from the *Baseline* model to the *Moved Check-in Station* model. The 99.3% CI on the difference in ATS of the *Moved Check-in Station* model compared to the *Baseline* model was (−8 minutes, +2 minutes). Whereas, the 99.3% CI on the difference in MTS was (−18 minutes, +9 minutes) from the *Baseline* model. Considering that both the ATS and MTS confidence intervals contained zero, no significant difference was indicated.

The *Looping Voter Path* model was not significantly different from the *Baseline* model. The 99.3% CI on the difference of ATS compared to the *Baseline* model was (−5 minutes, +5 minutes), with the 99.3% CI on the difference in MTS was (−13 minutes, +13 minutes). Due to both the ATS and MTS CI containing zero, the *Looping Voter Path* model was not significantly different from the *Baseline* model.

The *Separate Provisional Processing* model resulted in a reduction in ATS between 28.59% and 43.44% (99.3% CI, 18.83 minute to 28.61 minute reduction), realizing a significant difference when compared with the *Baseline* model. The model's MTS was between 7.86% and 27.30% less (99.3% CI, 10.39 minute to 36.12 minute reduction) than the *Baseline* model's. These results indicate a significant difference in performance between the *Separate Provisional Processing* model and the *Baseline* model.

Table 2: Performance differences relative to the *Baseline* model.

Model	**Change in ATS (hrs)**	**Percent Change in ATS**	**Change in MTS (hrs)**	**Percent Change in MTS**
Baseline (a)	-	-	-	-
Moved Check-in Station (b)	-0.051 ± 0.088	-4.66 ± 8.04	-0.077 ± 0.231	-3.50 ± 10.50
Looping Voter Path (c)	-0.003 ± 0.085	-0.28 ± 7.73	-0.003 ± 0.219	-0.14 ± 9.95
Separated Provisional Processing (d)	0.395 ± 0.081*	36.02 ± 7.42*	0.388 ± 0.214*	17.58 ± 9.72*
Looping Voter Path and Moved Check-in Station (e)	-0.012 ± 0.089	-1.06 ± 8.13	-0.026 ± 0.225	-1.20 ± 10.20
Moved Check-in Station and Separated Provisional Processing (f)	0.336 ± 0.086*	30.61 ± 7.85*	0.360 ± 0.217*	16.31 ± 9.83*
Looping Voter Path and Separated Provisional Processing (g)	0.378 ± 0.081*	34.41 ± 7.40*	0.394 ± 0.209*	17.88 ± 9.48*
Looping Voter Path, Moved Check-in Station, and Separated Provisional Processing (h)	0.330 ± 0.085*	30.05 ± 7.77*	0.356 ± 0.217*	16.17 ± 9.84*

Note: * $p < 0.007$. Calculated as (*Baseline* - *Option*), negative values are an increase in time, positive values are a reduction in time.

Of the four combined models, three demonstrated an estimated significant difference in ATS and MTS compared to the *Baseline* model. The only combined model that demonstrated no significant difference in ATS and MTS from the *Baseline* model was the *Looping Voter Path and Moved Check-in Station* model. The *Moved Check-in Station and Separated Provisional Processing* model resulted in a percent change in ATS 99.3% CI (+22.76%, +38.47%), meaning a 15.00 minute to 25.33 minute reduction in ATS and an MTS 99.3% CI (+6.48%, +26.14%) also leading to an 8.57 minute to 34.57 minute reduction in MTS when compared to the *Baseline* model. The 99.3% CI for the ATS of the *Looping Voter Path and Separated Provisional Processing* model was (+17.79 minutes, +27.54 minutes), indicating a 27.01% to 41.81% reduction compared to the *Baseline* model's ATS. The MTS of the *Looping Voter Path and Separated Provisional Processing* model also demonstrated a significant difference from the MTS of the *Baseline* model with a reduction of between 11.12 and 36.20 minutes. The final combination model, *Looping Voter Path, Moved Check-in Station, and Separated Provisional Processing* model, demonstrated reductions in time between 22.28% and 37.82% (i.e., 14.68 minutes and 24.91 minutes) on the ATS and between 6.33% and 26.00% (i.e., 8.37 minutes and 34.40 minutes) on the MTS when compared to the *Baseline* model.

5 DISCUSSION AND CONCLUSIONS

This study's results indicate that the layout and processing strategies utilized within vote centers impact the amount of time voters spend within a vote center. These findings indicate the possibility of reducing the time to vote with no additional financial requirements from election administrators. Long lines and times to vote are a concern in elections due to the expectations that voters will balk if their threshold to wait is exceeded, which effectively disenfranchises them (Piras 2009; Yang et al. 2014). Research has demonstrated that voters have a maximum amount of time that they are willing to wait before reneging, however, even those who wait for "as long as it takes" (Stewart and Ansolabehere 2003, p.2) may experience disenfranchisement (Stewart and Ansolabehere 2003). To further demonstrate the importance of reducing wait times, under-resourced and underrepresented communities, in particular, experience longer than average times to vote (Pettigrew 2017; Allen and Bernshteyn 2006). This preliminary analysis has demonstrated that wait times may be reduced with no additional resources or financial expenses.

Of the models with a single variation, the *Separated Provisional Processing* model demonstrated the single most significant reduction in both the ATS and MTS compared to the *Baseline* model. The three combined models that had *Separated Provisional Processing* also demonstrated a significant reduction in the ATS and MTS when compared to the *Baseline* model. The separation of the processing of provisional voters was the one consistent variation amongst the models that differed significantly from the *Baseline* model. This model variation allowed for the majority of check-in stations to be utilized by voters undergoing a two-step process, thus never needing to return to check-in. Therefore, provisional voters undergoing a three-step process could form an isolated queue when returning to check-in that would not obstruct other check-in stations. The process separation also allowed for the separation of the queue leading up to the check-in stations from the vote center entrance. In the *Moved Check-in Station* model, the *Looping Voter Path* model, and the combined *Looping Voter Path and Moved Check-in Station* model, no significant difference was realized when compared to the *Baseline* model.

Despite the lack of statistical evidence that the *Looping Voter Path* and *Moved Check-in Station* models impact the amount of time all voters spend within the vote center, there may be other unconsidered performance measures that would demonstrate a benefit from these changes. Potential examples may include congestion, utilization, an increased perception of clarity of the overall system, reduced travel distance, reduced anxiety, increased usability, and accessibility of the system due to a more intuitive flow. Additionally, perceived voter privacy may also benefit from these changes as the *Baseline* model included a line of voters waiting to check-in formed within an aisle of BMDs. The lack of privacy meant that people had the potential to interact with others who were actively voting, which is strongly discouraged, and that several BMDs rendered inactive due to their orientation (i.e., with the screen facing the check-in queue). Another unconsidered benefit of the *Moved Check-in Station* model, and the combined models that include the same equipment layout variation, is that the BMDs incur an increased capacity of eleven units, accounting for the BMDs that needed to be inactive due to privacy concerns.

These initial findings identified significant differences between a combination of process and layout strategies for vote center performance. Additional research must be performed to provide a clearer understanding of the relationship between facilities layout planning and routing and processing strategies and their combined impact on vote center performance. Some limitations in this study that provide future work opportunities include the consideration of multiple locations with varying layout constraints. While this study identified significant impacts on ATS and MTS for a particular vote center, other vote centers' performance may experience different results. Additionally, the study of a location with additional historical data, while uncommon, would allow the incorporation of additional events and occurrences that occur within the modeled vote center. Not all occurrences could not be modeled despite their presence in the observed vote center (e.g., ballot marking errors, machine breakdowns).

Other opportunities for future research include the consideration of different performance measures in addition to time in system measures, a more extensive range of model variations, and the comparison of how facilities layout planning impacts vote centers versus traditional polling places. To further innovate in the area of facility layout planning for election administration, facility layout optimization techniques are critical. By further layering established and advanced techniques for system design and assessment, many challenges that election administrators and voters face can be overcome. Future work that addresses vote centers more generally include the development and applications of advanced queueing studies. While basic queueing theory has previously been applied to election systems, the advancement of these techniques can holistically provide a better understanding of election systems and provide insight into election resource allocation.

The results of this study indicate that the consideration of facilities layout, processing, and routing, as well as the development of their applied methods, can ensure that people can cast their vote effectively and efficiently. Traditional methods employed to reduce voter wait times simply added more equipment or proposed the opening of additional voting locations, however, future research in this area may identify vote center set up techniques and layouts designs that dramatically reduce vote times and incur no additional costs to implement.

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