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Physics of Decision for Polling Place Management: A Case Study from the 2020 USA Presidential Election

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Abstract**—**In the context of the global pandemic, the practical management of the 2020 presidential election in the USA was a strong concern. To anticipate and prepare for this election accurately, one of the main challenges was to confront: (i) forecasts of voter turnout, (ii) capacities of the facilities and, (iii) potential configuration options of resources. The approach chosen to conduct this anticipative study consists of collecting data about forecasts and using simulation models to work simultaneously on resource allocation and facility configuration of polling places in Fulton County, Georgia's largest county. This article presents the results of the simulations of such places facing pre-identified potential risks. These results are oriented towards the efficiency of these places according to different criteria (health, trust, comfort). Then a dynamic framework is introduced to describe risks as physical forces perturbing the efficiency of the observed system. Finally, the main benefits and contributions resulting from this simulation campaign are presented.

Keywords**—**Performance, decision support, simulation, artificial intelligence, risk management, election, pandemics, information system.

I. INTRODUCTION

POLLING places, where electors cast their votes in person, have long been recognized to be core to the efficiency, convenience, and integrity of election systems all across the world. They are so ubiquitous that they have become taken for granted. Yet they are complex facilities subject to intense scrutiny, huge uncertainty, and severe disruptions. This paper focuses on intelligent risk management for these polling places to support their design, sizing, and operation for high performance from their multiple stakeholders' perspectives under such uncertainty and disruption.

Intelligent systems with the ability to detect, predict, and make decisions are very useful in the field of management science [1]. In the risk management area, due to dealing with unforeseen events, the necessity of such systems is undeniable. Intelligent Risk Management (IRM) systems are able to identify risks as early as possible and implement appropriate strategies to manage them.

This paper leverages the Physics of Decision (POD) IRM framework introduced in [4]. This original framework considers that risks can be seen as physical forces applied to the system which may push or pull it in its performance space by varying the system's KPIs (Key Performance Indicators) [2]. The framework guides decision-makers in assessing the risks that may happen to a system. Fig. 1 describes the framework, including its components and the relationships between them.

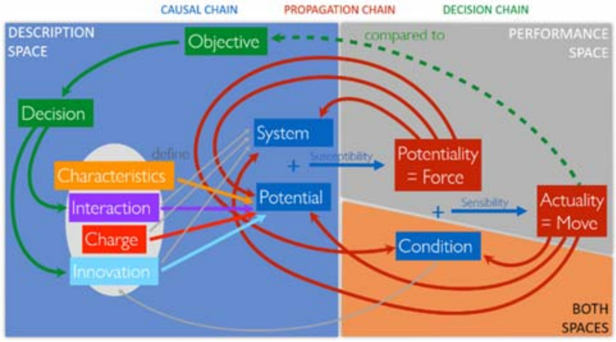

Fig. 1 IRM framework

In the POD framework, the considered system is facing some potentials. These potentials include: (i) Characteristics, i.e., the environmental potentials of the system including contextual changes such as weather or flows of voters, (ii) Interactions, i.e., flows of goods or information between partners, (iii) Charges, i.e., mandatory system costs including allocated resources, time, running costs, etc., and (iv) Innovations, i.e., some initiatives dedicated to modify or improve the structure or the behavior of the system. The susceptibility of the system to the surrounding potential generates some potentialities (i.e., risks or opportunities considered as physical forces). These potentialities might be activated by conditions which trigger the forces and change the system's performance: the potentialities become actualities and change the performance of the system. By comparing actualities to the actual objectives of the system, managers take some decisions to minimize the difference between the current state of the system and its objectives. A detailed definition of the components and their relationships is given in [3], [4].

The main objective of this article is to introduce a data-driven simulation-model and POD based IRM system for polling places and to investigate its value using a case study from the largest county in the U.S.A., that is Fulton County in Georgia, in the 2020 presidential election.

The remainder of this paper is organized as follows: Section II highlights related existing research works and scientific contributions. Section III describes the IRM framework and its principles. Section IV deals with the implementation through the simulation of the case study. Section V examines the results of the simulation-based investigation for the polling place in the McCamish Pavilion, in the Georgia Tech campus in Atlanta. Finally, Section VI concludes this research work and provides avenues for further research.

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II. BACKGROUND AND RELATED WORKS

The events of 2020 set the stage for one of the most important presidential elections in the history of the United States. In addition to the polarized politics and security concerns, high likelihood of voter participation and public health concerns due to the COVID-19 pandemic made the 2020 presidential elections more important, and yet more complex, than ever. The June 2020 primary elections in Georgia gave a preview of how poorly the election system can perform under these complexities if planning and design were not adjusted to reflect the increased risks. At some polling locations, voters endured 5-hour wait in queue [5]. Judges ordered 20 counties to extend their operating hours to accommodate the higher turnout and the slower processes [6]. Clearly, Georgia was not prepared for a pandemic election with the potential for historic voter turnout. Johnson et al. [7] studied political shifts due to COVID-19 in the 2020 election. Blendon et al. [8] show the implications of the 2020 election for the US health policy. This paper deals with the performance of polling places under uncertainty and disruption risks, and the management of the potential forces (Risks and Opportunities) to evaluate the performance of the polling places.

Instability is mainly related to mainstream requirements such as security, privacy, compliance, and capability [9]. Managing risk has always been a challenge in most areas of management. The variety of areas and perspectives have led to different approaches to risk management: Cost-Benefit Analysis and Risk-Benefit Analysis (CBA and RBA) [10], Hertz-type simulation, Hazard and Operational study, Failure Mode and Effects Analysis (FMEA) [9], Fault Tree Analysis, and Event Tree Analysis (FTA and ETA) [11], Monte Carlo and Expert Systems [12], [13]. The POD framework leveraged in this paper for application to polling places, inspired by the physical laws, is an innovative approach to cover a large spectrum of risk management techniques and opens the doors to apply the intelligent tools to deal with the complexity of relationships between risk factors and big data [14].

Simulation is an increasingly significant methodological approach to theory development in the literature focused on strategy and organizations [15]. The systematic combination of simulation methods with empirical research is a powerful tool in risk management research. The design of simulation models is strongly linked to the type of system under study. Generally, four important distinctions between types of simulation techniques can be made. These distinguished techniques are (i) Deterministic versus Stochastic, (ii) Static versus Dynamic (iii) Continuous versus Event-Driven, and (iv) Quantitative versus Qualitative [16]. In recent decades, agent-based simulation models have increasingly been utilized, to capitalize on their Agent-based simulation models have been more popular in recent decades as a result of their capacity to replicate interactions between members of an organization or across multiple organizations in a virtual environment where "agents" make decisions and communicate with one another [17].

In this paper, stochastic simulation, quantitative agent-based modeling, and event-driven dynamic are used for polling places as it fits the complexity, context and essence of polling places with their various interacting objects (building components, voting machines, scanners, etc.) and agents (voters, volunteers, staff, etc.). Such simulation modeling is embedded into the physics-based risk management framework so as to simulate the voting process in the polling places during election days and to assess and mitigate the potential risks related to the voter flow, equipment failures, and long waiting time for the voters, as notably influenced by the polling place configuration in terms of resources and layout.

III. PHYSICS-BASED IRM

A. General Perspective of IRM framework

A system can be destabilized by unforeseen changes. These changes mainly refer to the variation of system parameters and consequently, deviation from the system's expected trajectory. The expected trajectory depends on the considered case, but this is often the targeted, planned or most probable one. Any deviation from that trajectory is considered a risk for the system. System attributes define the different situations of the system. Identifying these attributes, their relationship, and their level of security is required to design a smart system. The POD framework introduced in Section I defines two spaces in which a system can be positioned [12].

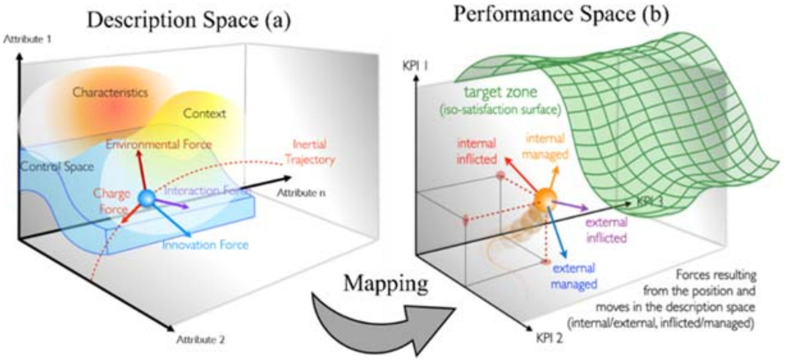

Fig. 2 POD IRM framework spaces. (a) Description Space, (b) Performance Space

The Performance Space, depicted on Fig. 2 (a), describes the performance of the system in a given state by locating it relative to KPIs, with risks and opportunities being shown as force vectors in that referential. The Description Space, depicted on of Fig. 2 (b), represents the system's states by locating it relative to axes defined according to its significant attributes. Some attributes are changed at certain times by decision-makers to control the deviation of trajectories. The degree of changes for each attribute is determined by system constraints in the Control Space, which is basically the "easy to access" subpart of the Description Space.

The relationship between the two spaces is determined by a function of Attribute(s) to KPI(s), which maps *Description Space* to *Performance Space*. This function can be straightforward or complex [3], [4]. In cases where equations between the two spaces can be determined, it would be possible to analyze the data and deviations from the normal trajectory caused by the forces. Otherwise, this function should be determined differently, notably through simulation experiments as in this paper, so as to generate the data from which the unknown relationships between attributes and KPIs can be inferred.

B. Problem Statement

Polling places can be conceptualized as complex discrete event logistics systems. Their complexity stems from the fact that they are constrained in resources, fraught with variability and uncertainty in voter arrival pattern and resource reliability, and subject to high public scrutiny. Performance is assessed along several criteria such as efficiency, security, voter experience, accessibility, etc. The design and operation of polling places are critical when faced with such multi-criteria performance expectations in modern democracies, and get increasingly more critical when adding such criteria as voting safety in the midst of the COVID-19 pandemic, and voting process trustability, as challenged in 2020 USA Presidential Election.

This article mainly focuses on assessing the capability of polling places to perform in high-risk contexts, as impacted by resource constraints, equipment breakdowns, and COVID-19 safety considerations. The case studied in this research encompasses polling places within Fulton County in the state of Georgia, the largest county in the USA, in the context of the 2020 Presidential Election. In these polling places, voters make their selection on the ballots using Ballot Marking Devices (BMDs), then cast their ballot by scanning it. This article examines one specific polling place among those studied, the McCamish Pavilion which is an indoor arena located on the campus of the Georgia Institute of Technology in Atlanta. The major focus of the case study is ascertaining the bottlenecks and rupture points in the polling place system where issues may emerge from the perspective of the POD-based IRM framework.

IV. METHODOLOGY

A. McCamish Pavilion Layout and Voter Flow Forecast

The results presented in this article are connected to other contributions from collaborators on this global project: McCamish polling place layout has been designed and optimized by a Facility Capacity and Layout Design Team to decide on the number and location of equipment (BMDs, scanners), helpdesks, registration check-in stations, observers, etc. This physical layout of the place has been defined by allocating the space to the equipment while maintaining social distancing for voters. Similarly, the voter flow between 7:00 and 21:00 each day from early voting to the final day voting has been estimated by the Scenario Forecasting Team based on the historical data and voter surveys conducted throughout 2020. In the article, the focus is on the most probable and high turnout scenarios that were studied. Fig. 3 shows the layout and voter flows for the McCamish polling place. These results are considered as input for the current work.

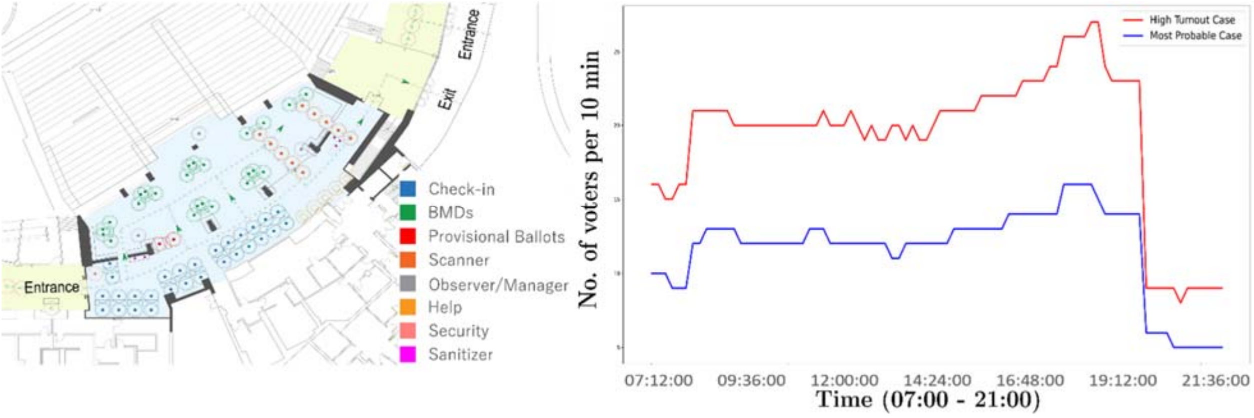

Fig. 3 McCamish Pavilion polling place layout and Voter flow

B. Voting Process

The voting process is modeled to begin with the entry of voters from the entrance on the site of the McCamish polling place. Once in the building, voters move around the McCamish basketball court and then enter the polling place. The check-in process is to validate the eligibility of the voters and to register them with poll pads. A voter needing guidance on the voting process is referred to the helpdesks (estimated 3% of the total voters). Otherwise, the next step is for the voter to mark the ballot at one of several available BMDs. These BMDs are located in a specific part of the polling place (each collection of 2 or 4 BDMs is considered as one BMD carrier). The final step is for the voter to scan the ballots using a scanner. Each voter's choice is marked on one or more ballots that pass through the scanner, which creates an electronic image of each ballot, interprets it, and tabulates the votes. Fig. 4 shows the schema of the voting process with the Pedestrian library of the AnyLogic© simulation software used in this study.

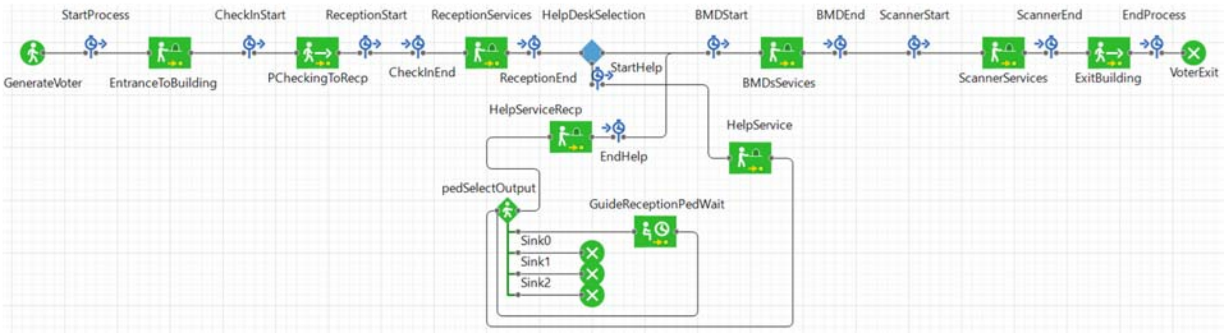

Fig. 4 Voting Process modelled for the McCamish polling place

AnyLogic© Pedestrian Library is dedicated to simulating pedestrian flows in a "physical" environment. The Pedestrian Library allows the creation of flexible models, collects basic and advanced statistics, and effectively visualizes the modeled process to validate and present it. In models created with the Pedestrian Library, pedestrians move in continuous space, reacting to different kinds of obstacles (walls, closed doors, etc.) and other pedestrians. Besides, this library makes it possible to model voter's behavior (reflecting the real speed of their walking according to their age), physical distance between voters as a precaution against the virus transmission (and present density of voters on a heatmap), cameras at different locations on the layout (for the manager of the place, security, and observers to track the voters and check the density of voters on the place in 2D and 3D. Fig. 5 presents these functionalities with the Pedestrian Library.

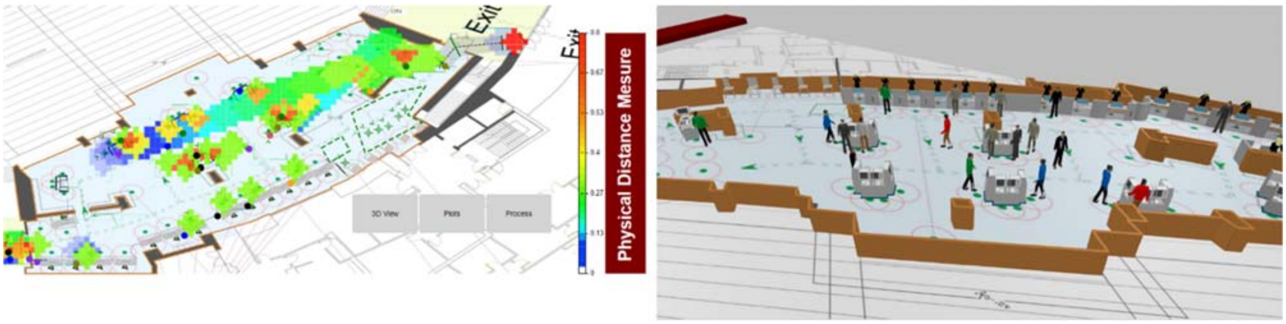

Fig. 5 2D and 3D outputs of McCamish layout for heatmap and cameras

C. Data Sources and Scenarios

The simulation utilized various parameters as attributes in the Description Space conceived by the Scenario Forecasting Team. That team has also defined some Disruption Scenarios. The main potential disruptions are related to the voters (agents), and the services (number of operational BMDs for instance). The goal is then to evaluate the probable forces of the modeled risks and their impact on the system trajectory in the Performance Space to reflect a realistic simulation of the election day voting process.

The simulation uses the following mobility and physiology related variables for every single agent. Initial speed (uniform (0.3, 0.7) m/s), comfortable speed (uniform (0.5, 1) m/s), the diameter of agent (uniform (0.4, 0,5) m), and the physical area around an agent (1 m^2).

In pedestrian flow models, services refer to a collection of comparable physical service objects (turnstiles, ticket vending machines, security checkpoints, check-in counters, etc.). In the pedestrian model, there are two sorts of space markup forms to design services: There are two types of service: (i) service with lines and (ii) service with area. Service with Lines is used to define service(s) with queue(s) where pedestrians wait in a queue line till the service becomes available. Service with Area has the same properties as Service with Line but the pedestrians wait chaotically in a specific area instead of queue. The simulation uses the Service with Line to put the voters in queues to respect the physical distance between them. The queue choice policy for all services is the closest queue (the queue that is closest to the service).

The number of resources for the McCamish layout is suggested by the Facility Layout Design Team. In some scenarios, the results show deficiency in resource allocation, which is a force (risk) on the KPIs. In other scenarios, the results show slack in capacity utilization, which is an opportunity to share the resources with other polling places. For such services, the simulation assumed Recovery Delay time (required time for the voters to use them again). Table I summarizes the service parameters reflected in the simulation.

TABLE I
ATTRIBUTES OF SERVICES FOR SIMULATION CAMPAIGN

Type	No	Service Time	Recovery Delay
Primary Checking	1	Uniform (10,20) sec	0
Check-in	5	Optimistic: Normal $(2, 0.5^2)$ min Probable: Normal $(3.5, 0.75^2)$ min Conservative: Normal $(5, 1^2)$ min	Uniform (5,15) sec
BMDs[1]	15	Optimistic: Normal $(7, 1.75^2)$ min Probable: Normal $(8, 2^2)$ min Conservative: Normal $(9, 2.25^2)$ min	Uniform (0,5) sec
Scanners	2	Uniform $(20, 40)$ sec	Uniform (0,5) sec

The attributes' values can vary in some specific ranges because of the degrees of liberty for the polling place considering, space, cost. These variations are considered in the control space of Description Space (Fig. 2). Besides, the voter turnout can vary (Fig. 3) and impacts the KPIs. The voter turnout is out of control and is considered as "Characteristic". The voter turnout's impact on KPIs is considered as "Environmental Force" in Fig. 2.

According to the objectives of the polling place, these variations impact the polling place's performance. The scenario team considered different possible scenarios to implement in the simulation and study their impact on the system's trajectories in the performance space. Table II provides illustrative distinct possible disruption scenarios for the election day at the McCamish polling place.

TABLE II
SIMULATION DISRUPTION SCENARIOS

Type	Description
DS1	1 BMD carrier outage during peak hours
DS2	1 BMD machine outage during peak hour
DS3	Three BMD machines outages at varying hours
DS4	Entire IT system failure during peak hour

V. EXPERIMENTS AND RESULTS

The main experiments are centered on the risk-affected performance of the McCamish polling place in different aspects such as equipment capacity requirements, health, trust, and comfort. In the perspective of the IRM framework, deviations from the inertia trajectory (i.e., the most probable scenario) are considered as forces. Attributes of the voters (agents), the number of services and their significant times (system time and recovery delay) are considered in the Description Space. There are different KPIs to provide to the decision-makers of the McCamish, such as: (i) Number of active voters, (ii) Number of waiting voters, (iii) Number of completed votes, (iv) Total voting time and (v) Utilization of each service (Check-in, BMDs, and scanners). These KPIs are considered as dimensions of the Performance space.

According to the POD framework, the first and foremost trajectory is the inertia trajectory which is the reference trajectory to study different possible scenarios. The voter flows and different service time levels are considered to track the inertia trajectory of the place. As mentioned earlier, two scenarios are considered for voter flow: most probable and high turnout. Three levels for the service time are: Optimistic, Probable, and Conservative. Combining voter flow scenarios and service time scenarios leads to six possible inertia trajectories (see Fig. 6).

According to the Description space and control subspace, some attributes are "Charge" for the polling place. "Charge" refers to uncontrolled attributes that impact the performance: for example, attributes of voters (speed, diameter, social distance) and services time (system time and recovery delay time). In general, all the running costs are Charge as well. However, some attributes like the number of BMDs, number of scanners, and number of polling pads (Check-in) result from managers' decision and vary from user-specified minimum to maximum in the control space. In this section, simulation has been run four times based on the values suggested by the forecast team and the average results are as follows.

A. Inertia Trajectory (Baseline)

The results related to the inertia trajectory are for *Most Probable* and *High Voter Turnout* with three different levels for service times. Depicted in Table III, the results show average performance on election day.

TABLE III
RESULTS FOR MOST PROBABLE AND HIGH TURNOUT VOTER FLOW AND PROBABLE/OPTIMISTIC/CONSERVATIVE LEVELS FOR THE SERVICE TIMES

Attribute	Probable		Optimistic		Conservative	
Check-In (n)	5		5		5	
Help Desk (n)	5		5		5	
BMD (n)	15		15		15	
Scanner (n)	2		2		2	
KPI	Most Probable	High Turnout	Most Probable	High Turnout	Most Probable	High Turnout
Voters in Place (n)	8.92	14.28	7.82	12.78	9.88	12.34
Waiting Voters (n)	0.4	1.2	0.34	1.01	0.43	0.72
Completed Votes (n)	972	1607	974	1607	970	1186
Voting Time (min)	18.88	26.05	16.99	18.2	22.39	79.47
Check-In Utilization	22%	71%	10%	28%	47%	98%
BMD Utilization	46%	68%	39%	59%	52%	64%
Scanner Utilization	31%	58%	33%	60%	31%	39%

The results of the Most Probable voter flow columns show that the place is definitely receptive to the expected values for

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[1] The considered BMD carriers include 2 and 4 BMDs

the McCamish. The service utilization levels are relatively low (in the worst case, Check-In: 47% BMD: 52%, Scanner: 33%). Conservative level of Check-In utilization compared to the probable and optimistic levels negatively increased (10%, 22%, 47%) but still enough to serve the voters. Most of the voters have been served. The worst case is the conservative level for which 970 out of 978 voters (total voters) have voted (99%).

The results of the High turnout level clearly are different from Most Probable level. This conclusion is based on Check-In utilizations in probable and conservative levels (71%, 98%), the Voting time (26 min, 79 min), and the voting rate (e.g., 73% in conservative level, 1186 out of 1618 voters (total voters) have been served). However, if the service time is optimistic, the results show that McCamish is able to serve the high turnout voter flow (Voting time: 18.2 min, Check-In utilization: 28%, Completed vote: 99%). This result absolutely highlights the force of the efficiency of the BMDs, Scanner as well as the speed of the voter in the voting process.

As a conclusion, if McCamish place could have enough space to receive more than 15 people (on average), considering the social distance between voters and also officers, receptors, etc., McCamish would need more Check-In resources. This result could be deduced from the utilization of the BMDs and scanners (at max 68%).

Fig. 6 shows the inertia trajectories for most probable (First row) and high turnout (Second row) voter flow for the following KPIs: (i) Number of voters in the place (First column), (ii) Number of waiting voters (Second column), and (iii) Number of completed votes (Third column). More probable values are highlighted in gray parts.

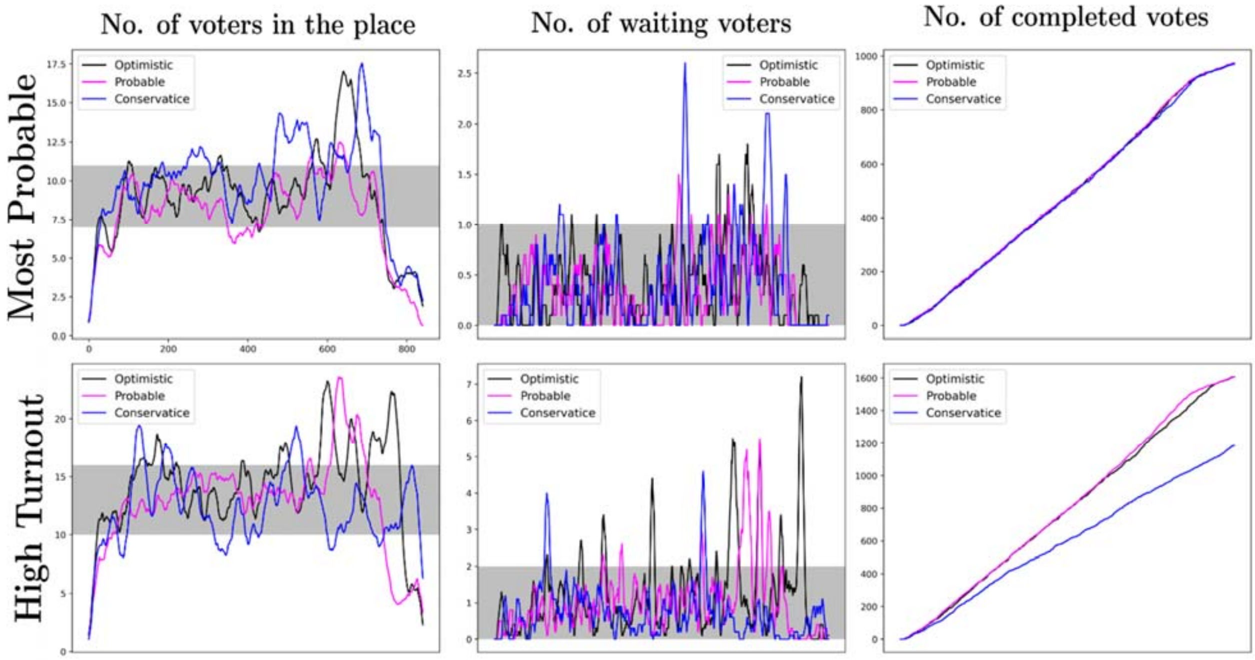

Fig. 6 Inertia Trajectories for McCamish layout

B. Forces of Disruption Scenarios

Four Disruption Scenarios are here investigated for the McCamish place (see Table II). Scenarios DS1, DS2, and DS3 are related to the BMDs break down (scenario DS4 is related to massive IT failure, see below). According to the results in Table III, the BMDs utilizations do not affect too much the KPIs. The results for the worst case (DS1: 1 BMD carrier outage during peak hours) are provided in Table IV.

TABLE IV
DS1: 1 BMD CARRIER (4 BMD MACHINES) OUTAGE DURING PEAK HOURS (AVG., 4 P.M. – 5 P.M. AND 5 P.M. – 6 P.M.)

Attribute	Probable		Optimistic		Conservative	
Check-In (n)	5		5		5	
Help Desk (n)	5		5		5	
BMD (n)	15		15		15	
Scanner (n)	2		2		2	
KPI	Most Probable	High Turnout	Most Probable	High Turnout	Most Probable	High Turnout
Voters in Place (n)	9.13	16.01	7.48	13.77	10.6	14.05
Waiting Voters (n)	0.53	1.93	0.42	1.4	0.79	1.14
Completed Votes (n)	971	1606	972	1607	970	1284
Voting Time (min)	19.06	24.78	16.62	18.63	22.89	81.81
Check-In Utilization	22%	70%	10%	25%	50%	98%
BMD Utilization	45%	73%	37%	63%	54%	69%
Scanner Utilization	32%	58%	33%	58%	32%	43%

The comparison of Tables III and IV shows that the BMDs failure does not change the results too much (we obtained almost the same results). This is an obvious result because the BMDs serve the voters who passed the Check-In, since the Check-In number is low, consequently, the BMDs utilization is almost the same. The last scenario DS4 is the failure of all the IT systems during peak hours. The results are provided in Table V.

TABLE V
DS1: 1 DS4: ENTIRE IT SYSTEM FAILURE DURING PEAK HOUR (AVG., 4 P.M. – 5 P.M. AND 5 P.M. – 6 P.M.)

Attribute	Probable		Optimistic		Conservative	
Check-In (n)	5		5		5	
Help Desk (n)	5		5		5	
BMD (n)	15		15		15	
Scanner (n)	2		2		2	
KPI	Most Probable	High Turnout	Most Probable	High Turnout	Most Probable	High Turnout
Voters in Place (n)	9.01	15.95	7.93	14.33	10.3	13.31
Waiting Voters (n)	0.72	1.75	0.64	2.45	0.53	0.85
Completed Votes (n)	972	1566	972	1605	970	1171
Voting Time (min)	26.28	38.78	22	28.6	34.71	89.67
Check-In Utilization	33%	80%	20%	39%	57%	98%
BMD Utilization	43%	74%	37%	59%	53%	68%
Scanner Utilization	34%	57%	33%	58%	33%	40%

DS4 negatively affects the Voting time and the Utilizations of voting devices. These results are quite intuitive because the entire system shuts down. This means the voters need to spend more time to go through. Besides, the influx of the voters after the failure increases the utilization of the services.

Based on the forces of failures, managers can add more resources to bottlenecks or take out the extra resources to share with other polling places. The IRM framework provides this possibility by presenting the Inertia trajectory and its deviations because of forces at some specific time. The framework can also study the deviated trajectories because of different disruptions (BMDs, poll pads, scanners, etc.) and their impact on the performance trajectory. The simulation results provide an overview of the mapping between two spaces (relationships between Attributes and KPIs) (see Fig. 2).

To study the possible trajectories, the simulation, considered disruption scenarios for all services (Check-In, BMDs, and Scanners). The high turnout voter flow with probable level for the services are selected as attributes in the description space. Besides, three KPIs have been chosen for the performance space: (i) Number of voters in the place, (ii) Number of waiting voters and (iii) Voting time. The results in Tables I-III showed that BMDs and Scanner utilizations were quite low, so we considered more Check-Ins to study the forces due to these two resources. Besides, in this section, the simulation data are from 3 p.m. to 8 p.m., as the most variations and disruptions are for this interval. The results are provided in Fig. 7.

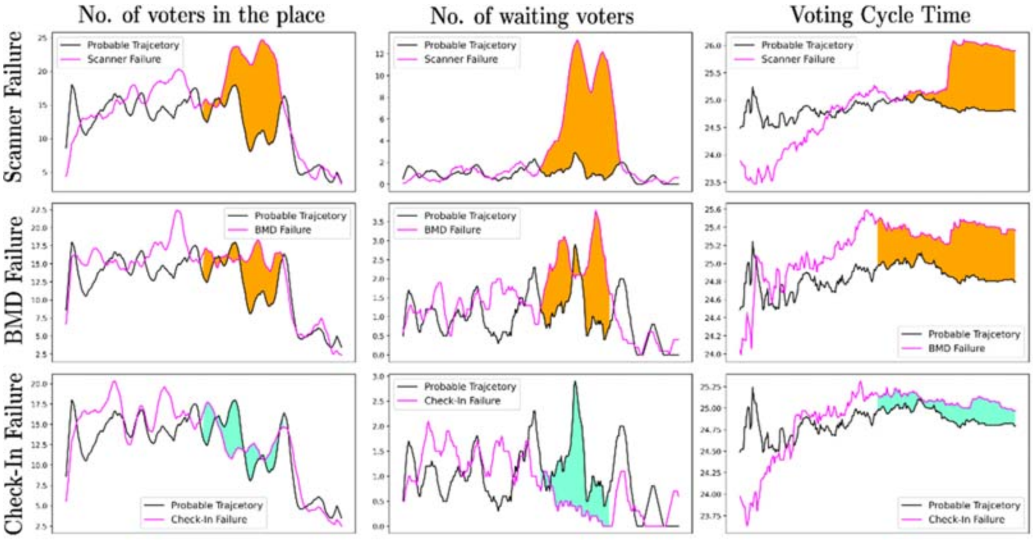

Fig. 7 Inertia trajectories vs. Failure trajectories (3-8 p.m.) for McCamish layout, Note: The plots have been smoothed because of high oscillation and noisy points due to the agent's movement in the place

The orange parts in Fig. 7 show the forces for BMD and Scanner failure and their impact on the most probable values. The values for the failure trajectories should be negatively more than the Inertia trajectories, while some parts do not follow this rule. The reasons are the impact of the stochastic values (Section IV) for the attributes and the low impact of the failure in these specific parts (First and second rows in Fig. 7). The force of Check-In resources is represented on the third row in Fig. 7. The greater values of Inertia compared to the Check-In failure in some parts indicates that this force does not affect significantly the KPIs and the green parts are the effect of stochastic values for the attributes.

The summary for the presented results for the McCamish layout considering possible disruption scenarios are as follows: (i) McCamish with the suggested values for the number of services (BMDs, Scanners, and Check-In) in the case of most probable voter turnout is sufficient and close to the targets. According to Tables III-V, the worst performances are: Voting time: 34.71 mins, Completed votes: 99%, BMD utilization: 54%, Check-In utilization: 57% and Scanner utilization: 34%. (ii) In the case of the possibility of more than 16 voters in the McCamish, there is an opportunity to have better performance by injecting more poll pads into the place. On the other hand, the high voter turnout flow has a huge impact on the KPIs while the impact of the services' time is not negligible. In the case of the optimistic level, the performance of the McCamish is high, even better than the most probable turnout in some cases. Here are key results: Voting time 29 mins, Completed votes 99%, BMD utilization 63%, Check-In utilization 39%, and Scanner utilization 60%. These interesting results indicate that efficiency of the equipment and adequate knowledge of the voter in the voting process (to keep the services' time on optimistic level), significantly improve the performance of the polling places.

The performance space gives an overview of the KPIs to the decision-maker while it would be more helpful to have a comparative image of the polling place performance. To reach this objective, the KPIs should be examined on the same scale in the performance space. The performance spaces in Fig. 8 are presented for the following KPIs: (i) Number of voters waiting for the scanner, (ii) Number of voters waiting for BMD and (iii) Completed votes, and (v) Voting time (just in the third space). Besides, the disruptions for the performance spaces are as follows: (i) 1 scanner failure at 2 p.m. (ii) 1 BMD carrier failure at 4 p.m., and (i) and (ii) on the same run simultaneously in the third space.

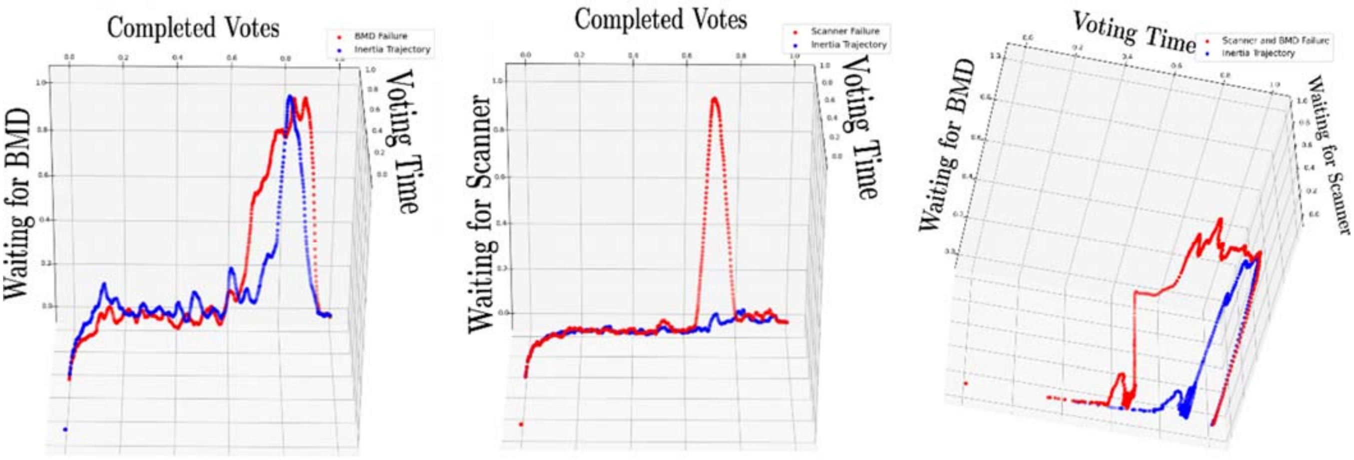

Fig. 8 Scaled Inertia trajectories vs. Scaled Failure trajectories for McCamish layout

On Fig. 8, three 3D performance spaces have been presented, each for different events impacting the polling site. The blue curves represent the inertia performance trajectories (i.e., without any perturbation) while the red ones represent the performance trajectories impacted by the considered events (from left to right BMD failure, Scanner failure and both devices failure). The scale is also different from one diagram to another. It is interesting to notice that the ratio of BMDs for this precise polling site seems to be over-estimated as the failure has almost no impact while the scanner failure is clearly critical (difference between first and second diagrams). Besides, even when both devices are facing issues, the waiting time for BMDs is not significantly impacted (with regards to the inertia trajectory). The comparison between waiting time for BMDs and waiting time for scanner shows a clear warning regarding either the ratio between BMDs and scanners, or the physical arrangement of the polling site (how optimal is the location of the devices). The actual opportunity is to see these trajectories and to compare them to each other. Besides, with measures that could be taken, it is possible to see how they inflict positively the trajectory.

VI. CONCLUSIONS AND PERSPECTIVES

The work in this article presented the application of the POD vision to the election system. The empirical experimentation reported in this paper assesses and quantifies the impact of disruptions to a polling location on the KPIs for the election system. This evaluation is essentially based on a pedestrian-level simulation model, fed on the one hand by voter flow forecasts and on the other hand by the description of the consequences of disruptions on the system's variables.

The obtained results mainly concern the visualization of performance trajectories and the deviations generated by the anticipated disturbances. In the studied case, the actual visualization is made possible because the performance is evaluated according to three dimensions, but this performance could be supervised in much higher dimensions, even if it is not easily visualized (which would not penalize the measurement of the deviation of the performance trajectory generated by the events under consideration).

One important takeaway from this article concerns the use of forecasts: The very next step is to show how real-time data could be used directly to benefit from the presented contributions and provide a live management dashboard for a voting place. The decision-makers could then visualize or monitor the performance of the system live and anticipate the impact of current or future disruption to support their decision-making process.

Three alternative avenues for further research are hereafter introduced. The first concerns the implementation of simulation campaigns covering a wide range of system parameter values in order to cover more widely the space of possibilities in terms of system variability and associated performance. The objective of these simulation campaigns would be to provide the material likely to discover the event's impact variability and the sensitivity of the system to this event. This could allow the modeling of these impacts in the form of formalized forces. These forces impacting the performance of a polling place could thus be anticipated according to different characteristics of both the sites considered and the events identified.

The second avenue concerns the multi-site (and possibly multi-channel) dimension of the electoral system. In particular, it involves investigating the management of voter flows and resource flows holistically at the county or state level, for example. An electoral system's performance would then be aggregated and studied according to the same principles, but the degrees of freedom offered would be much more significant. The forces exerted on the system would have to be studied with a potentially particulate vision in order to aggregate all the forces at the systemic level.

Finally, the third avenue concerns the optimization aspect of the vision proposed in this article. At this stage, the contributions presented allow to use the "trajectory" vision in order to model, evaluate and potentially visualize the deviation of a polling place's performance due to the occurrence of one (or several) risk(s). However, nothing at this stage allows to use the results of a model based on this paradigm of physical forces to develop a management strategy. This said, the exploration of these performance spaces and the forces exerted within them could make it possible to define strategies for moving within this space, benefiting from certain forces and minimizing certain cost functions. These three avenues are part of a generic-scope research roadmap on the POD IRM framework.

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