Proceedings of the 2014 Industrial and Systems Engineering Research Conference
Y. Guan and H. Liao, eds.

Modeling the Impact of Patron Screening at an NFL Stadium

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Abstract

The Department of Homeland Security identifies stadium safety as a crucial component of risk mitigation in the US. Patron screening poses difficult trade-offs for security officials: rigorous screening prevents weapons from entering the structure, but it also creates lines that become security hazards and may be infeasible if patrons are to get into the stadium within a few minutes of the beginning of the game. In order to quantitatively inform venues about how different screening procedures will affect their venue, we developed a patron screening model together with security personnel at a National Football League (NFL) stadium. Our model specifically addresses the speed of screening using different procedures: walk-through magnetometers, wandings, and patdowns. We then created a real-time simulation of queue formation using the physical arrangement of gates at the stadium. This allowed for analysis based on different patron screening procedures and configurations. We validated our model and simulation using ticket scan data and security director experience. Our approach is generic enough for any stadium and has been used to explore inspection protocols at multiple venues including an NBA arena. We also successfully demonstrated our work to NFL Security.

Keywords
security, stadium queuing, discrete simulation,

1. Introduction

Safety is a major concern at public venues such as stadiums. Many venues including those for sporting events, music concerts, theme parks, malls, and other public venues screen participants as they enter. The goal of screening is to improve safety inside the venue by preventing patrons from bringing in weapons such as knives, guns, and explosive devices.

In screening patrons, venues face an important balance between security, cost, and patron convenience. Better security measures mean that fewer unwanted items enter a venue. However, more accurate security procedures, such as magnetometers, take up larger amounts of space, need additional personnel, and require more training. All of these present additional one-time and ongoing costs to a venue. Additionally, more stringent security checks often result in longer screening wait times, which could dissatisfy patrons. Longer lines themselves are now considered security hazards in the wake of the Boston Marathon bombing. Security personnel recognized that crowds of uninspected patrons could easily be the target of a similar bombing attack.

Working with a National Football League (NFL) stadium, we built a model and simulation of patron arrival times, screening rates, and queue clearance. This tool allowed the venue to make informed what-if analyses about the feasibility and requirements of different screening procedures. The venue then made quantitatively-informed decisions by combining the results of our screening simulation, what is known about the accuracy of different screening procedures, and the other screening tradeoffs listed above.

In designing our model and simulation, our goal was to create a flexible and accurate approach for comparing screening procedures at any venue. Our contributions as described here are:

- A venue-independent formulation to describe patron screening
- A description of how we implemented these formulations for a specific venue
- An explanation of how this information allowed our venue to make an informed decision about patron safety

2. Related Work

2.1 Other Research

Our research was heavily influenced by earlier simulation work involving sports stadiums and other large venues. This work has been primarily concerned with modeling evacuations of such venues. We mention in particular the work of Regal Decision Systems (http://www.regaldecision.com/), supported by the Department of Homeland Security (DHS), which also supported our work. Their REGAL Evac is a discrete event simulation model developed to evaluate evacuation plans and pedestrian flow for any facility, producing results in the form of 3D animation. This has been applied to a variety of NFL stadiums.

Mention should also be made of the work at the University of Southern Mississippi Center for Spectator Sports Safety and Security (NCS^4), which is also supported by DHS. The book [4] gives an overview of many aspects of sport stadium security and safety, including ingress and egress. An example of work from NCS^4 is [6], which gives a GIS-based football stadium evacuation model using macro-simulation for University of Southern Mississippi's football stadium.

In [3], the authors present a simulation of a stadium that is based on section by section computer drawings.

In a different approach, [9] uses a 2-dimensional cellular automaton approach to simulate evacuations from large and complex structures. This in turn is based on a rather extensive literature that brings behavioral factors into the analysis of crowd behavior, in particular in evacuation situations (see e.g., [8, 10]). In the latter, the authors present a multi-agent based framework for simulating human and social behavior during emergency evacuation.

Simulations of crowd behavior that take into account social groupings are also relevant to stadium evacuation and egress from large structures. In [13], the authors study the effect of design decisions on the flow of agent movement and how agent egress is affected by the environment in real world and large scale virtual environments. Their work supports grouping restrictions between agents (e.g., families or other social groups traveling together). The work in [12] models human crowds for real-time, graphics-based applications and develops novel algorithmic methods that allow for crowd behavior on non-planar surfaces and uniquely-realistic social dynamics. This work is also relevant to inspection processes, where social groups coming together might conceivably be modeled as units.

While there is robust literature on simulations for evacuation and egress from stadiums and similar large facilities, there is much less literature on inspections. Primarily, such literature has been devoted to airports. For example, [2] estimates the impacts of the United States Visitor and Immigrant Status Indicator Technology Program (US-VISIT) in terms of traveler wait times and queue lengths, using simulation. The model developed uses data from the Los Angeles International Airport. Also, [5] develops a discrete event simulation of security screening operations at an idealized airport, based on composite data from two real life airports. The goal of this work is to gain insight into the impacts of security screening configurations and to identify the optimal inspection time. They used arrival time data from Customs and Border Protection for two airports, Atlanta and Tampa, as well as service time data from the Tampa Airport, to build the data for their idealized airport. They also used physical configurations for inspections at the time shortly after the September 11th attacks. The model used a "typical" one hour inspection period, while ours uses 14 different examples to give a variety of scenarios. Their model takes into account the need for secondary inspections, which they assume occur in 20% of the cases. Our model instead builds in the total time needed for an inspection, including secondary inspections, into one parameter.

The work in [11] applied discrete event simulation modeling to understand the operational dynamics of passenger security screening in conjunction with the re-design of the passenger checkpoint at Baltimore-Washington International Airport. They used a time-motion study to gather data of minimum, maximum, and mode times for each step in the inspection process. Customer arrival volumes and patterns were captured using the departure schedule and the airline loading factors. In contrast to our work, this model considered the many steps of airport processing of customers, for example comparing ticket counter queues to curbside check-in queues, whereas our work concentrates solely on the actual inspection process and does not consider the many other aspects of stadium security such as behavioral analysis in the parking lots, sensors and detectors, license plate readers, etc.

2.2 Information about Different Screening Procedures

To compare different screening procedures, we did extensive observation at the NFL venue we worked with and also viewed film of their screening. We compared our data with that gathered at another NFL stadium and also with security personnel at the venue we worked with.

In general, patdowns and magnetometer walk-throughs take about the same amount of time, while wanding takes considerably longer. There is also great variation in times taken over patrons, as well as variation in the amount of time needed for wanding and patdowns from one inspector to another. The weather makes a difference too.

Magnetometers are thought to give the most accurate information, followed by wanding and patdown. Moreover, patrons often find magnetometers less invasive than wandings and patdowns and most patrons are familiar with them since they are used in airports. We also heard that it is easier to train staff to use magnetometers than to do wandings and patdowns and the results are more consistent. However, there are some important disadvantages to magnetometers. They require significantly more space to use, space that is at a premium when other potential uses of it are concerned. They require more staff to use. Also, the equipment needed (the magnetometers) is significantly more expensive than other screening methods. Finally, their performance is degraded in bad weather.

Because wanding takes longer than patdowns, in the past some NFL stadiums found it difficult to wand all patrons before entry if they had the goal of getting all patrons into the stadium close to kickoff time. Thus, when the queue to enter the stadium got too long, they switched from wanding to the faster patdown inspections.

Our models and simulations were aimed at determining how much time it would take to get all patrons into the stadium under a given method of inspection. In this paper, we discuss three alternatives that we considered: 100% wanding, 100% magnetometer use, and wanding until the queues got too long, followed by patdowns. The simulations can and have been used to evaluate other combinations of procedures. Another issue we analyzed was how many inspection lanes were needed to achieve the goal of getting patrons into the stadium close to kickoff time. Due to the space limitations and cost considerations for magnetometers, this was an important issue. Finally, we started with the goal of getting all patrons into the stadium by 5 minutes after kickoff time, but the results of our simulations easily allow us to modify this goal.

3. Theory

Our goal in modeling patron screening was two-fold: to create a flexible model that could be used in other venues and to answer the specific questions of our venue. Our model has three components: the arrival of patrons to the venue, the screening procedure, and the resulting build-up and clearance of the queue. We discuss each of these in turn.

3.1 Arrival Time

The first key to modeling patron screening is to model the arrival of patrons at the security screening point for the event. Patrons do not arrive at a constant rate, which makes this an important component of the model. We will often refer to the rate of patron arrivals at the screening point as simply the *arrival rate*.

Based on data provided by our venue and discussions with the venue's security personnel, we observed that the arrival rates followed the same general trend for all the events we considered, and each arrival rate could be viewed as having four distinct time periods. In the first time period (well before kickoff), the arrival rates were small and insufficient to form a line. Without loss of generality, we modeled the arrival rate at this time to be a small constant value. In the second time period (closer to kick-off), the arrival rates would begin increasing. The arrival rates would then peak and begin decreasing, which marked the third time period. Shortly thereafter, the arrival rates became small and again insufficient to form a queue. Just as in the first time period, we modeled this range to be a small constant value.

For our purposes, we define the arrival rate to be a continuous piecewise linear function that inputs the time t (in minutes) and returns the number of patrons arriving at that time (see Figure 1). While this function is obviously a very simplified approximation of real patron arrival rates, it was sufficient for producing accurate results from our model.

For a given event, we define the patron arrival function $arr(t)$ to be the number of patrons arriving at the gate for screening between time t and time $t+1$:

$$arr(t) := \begin{cases} c & \text{if } t < t_1 \\ b_i(t-t_1)+c & \text{if } t_1 \leq t < t_2 \\ b_d(t-t_2)+b_i(t_2-t_1)+c & \text{if } t_2 \leq t < t_3 \\ b_d(t_3-t_2)+b_i(t_2-t_1)+c & \text{if } t \geq t_3 \end{cases} \tag{1}$$

where t_1, t_2, and t_3 are the transition times between the time periods and c, b_i, and b_d are constants such that $c \geq 0$, $b_i > 0$, $b_d < 0$, and $b_d(t_3-t_2)+b_i(t_2-t_1)+c \geq 0$. Note that t_1, t_2, t_3, c, b_i, and b_d are all constant parameters specific to the venue and the event (see Section 4.1). In addition, it is assumed that variable $t \geq 0$ represents time in minutes and that $t = 0$ corresponds to 60 minutes prior to kickoff. It is important to re-emphasize that $arr(t)$ is the total number of patrons arriving at time t for a particular entrance gate, which has many screening lines, and not for a particular line.

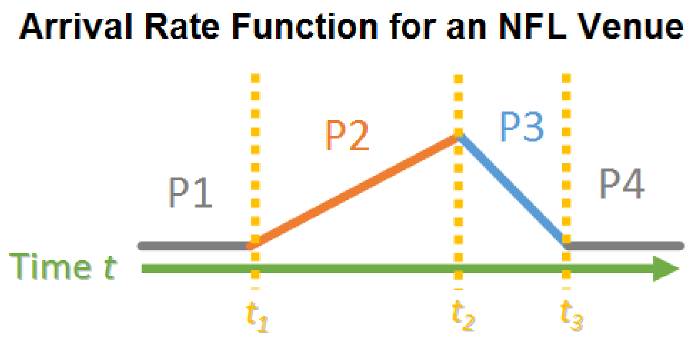

Figure 1: Model for patron arrivals (function $arr(t)$) at the venue's screening point.

3.2 Queue Length

The next piece of our model determines the size of the queue at any given time t. We will consider the queue at a particular entrance gate and will denote the number of lines (for screening) at the gate by N. It is important to note that the queue length refers to the total number of patrons awaiting screening in all N lines. This is analogous to the previously defined function $arr(t)$, which is the number of patrons arriving at time t at the gate. We define the function recursively as

$$Q(t) := \begin{cases} arr(t-1) - scr(t-1) + Q(t-1) & \text{if } t > 1 \\ 0 & \text{if } t = 0 \end{cases} \tag{2}$$

where $arr(t)$ is the arrival function from the previous section and $scr(t)$ is a screening rate function to be defined later. More specifically, in this paper, the screening function $scr(t)$ will be one of the functions from $\{WP(t), W(t), M(t)\}$, each of which will be properly defined in the upcoming sections. It is important to note that $Q(t)$ and $scr(t)$ will be mutually recursive. For example, the queue length at time t will depend on the number of patrons screened at time $t-1$. On the other hand, the number of patrons screened at time t depends on the queue length at time t since it cannot exceed the queue length.

Of course, this function allows us to determine the time when the queue for an event is cleared. This *queue clearance time* is a key parameter in one of the quantitative goals for inspection and will be discussed in greater detail in Section 3.4.

3.3 Screening

We next modeled the screening of patrons. In our work with our venue, we discovered some key points that were needed to make a model flexible enough for their needs and the needs of other venues. First, the screening time of patrons varies from person to person. Second, the screening time for different screening methods varies as well. For our purposes, we consider three different screening methods: patdown (P), wanding (W), and magnetometer (M).

For each of these screening methods, we will be concerned with the number of patrons screened per minute, which we may refer to as the *screening rate*. For patdown screening, we first define L_P (resp. U_P) to be the lower bound (resp. upper bound) on the time, in seconds, it takes a single security staff person (screener) to screen one patron. Similarly, for wanding screening, we define L_W (resp. U_W) to be the lower bound (resp. upper bound) on the time it takes to screen one patron. Also, for magnetometer screening, we define L_M and U_M to be the lower and upper bound screening times for one patron. Each of these lower/upper bounds will be constant parameters determined from real event data (see Section 4.1).

For each screening method, we define a random variable for the number of patrons screened by a single screener in one minute starting at a specific time (in minutes). More precisely, for some time t (in the same "minutes format" as before), let the random variable $Y_P(t)$ be a number chosen randomly from the uniform distribution $[L_P, U_P]$ and representing the average screening time per patron (in seconds) by one staff member using patdowns from time t to time $t+1$. We define a second random variable $X_P(t) := 60/Y_P(t)$, which represents the average number of patrons screened by one staff member using patdowns from time t to $t+1$ (i.e., in one minute starting at time t).

Analogously for wanding, we define the random variable $Y_W(t)$ to be a number chosen randomly from the uniform distribution $[L_W, U_W]$, and define the random variable $X_W(t) := 60/Y_W(t)$, which represents the average number of patrons screened by one staff member using wanding from time t to $t+1$.

Similarly for magnetometers, the random variable $Y_M(t)$ is chosen randomly from the uniform distribution $[L_M, U_M]$, and we define the random variable $X_M(t) := 60/Y_M(t)$, which represents the average number of patrons screened by a single magnetometer from time t to $t+1$. Although modeling our screening rates based on uniform distributions is a very simplified approximation, it was sufficient for producing accurate (and realistic) results from our model.

There were three specific inspection/screening methods our venue was interested in, and they are common screening methods at other venues as well. The first is "wanding & patdown", where the venue screens by wanding only until a certain time (when the queue reaches a certain length) and then switches to patdown only. The second is "wanding only", where the venue screens only through wanding. The third is "magnetometer only", where the venue screens only through magnetometers. It is assumed that the venue will only use one of these three inspection methods during a single game. Only these three inspection methods were considered for our venue, but it should be noted that our model and approach can be readily adapted to other combinations of screening procedures (e.g., magnetometers only with a switch to patdowns). Combinations of different procedures can even be considered by defining the random variables to sample from a more complicated distribution (than the uniform one).

3.3.1 Wanding & Patdown

The first screening method we present is the wanding and switch to patdown method. In this screening procedure, patrons are screened using the slower, but more effective wanding method until the queue reaches a certain length. When that happens, security switches to the faster patdown technique. This switch prevents the line from becoming so long that it becomes a security vulnerability, and also aims to ensure that patrons get into the stadium close to the kickoff time. Whether any venues will use this procedure in the future is uncertain.

We first define the time at which the switch from wanding to patdown occurs. Let q_s be the threshold number of patrons in the queue that, when exceeded, will prompt the switch. This is a constant parameter based on the event occurring at the venue (see Section 4.1). We define the switch time t_s as

$$t_s := \min(\{t \ : \ Q(t) \geq q_s\}). \tag{3}$$

We note that in general, $t_1 < t_s < t_2$. We now define $WP(t)$ to be the function giving the number of patrons screened at time t (i.e., in the interval between t and $t+1$):

$$WP(t) := \begin{cases} \min(Q(t),\ \lfloor N \cdot X_W(t) \rfloor) & \text{if } t < t_s \\ \min(Q(t),\ \lfloor N \cdot X_P(t) \rfloor) & \text{if } t \geq t_s \end{cases} \tag{4}$$

where N is the number of screening lines at the gate and $\lfloor x \rfloor$ denotes the *floor* of the real number x. The minimizing function ensures that the number of patrons screened does not exceed the number of patrons in the queue. Observe that this function is mutually recursive with $Q(t)$ (in this case, $scr(t) \equiv WP(t)$ in Equation 2).

3.3.2 Wanding Only

The next screening method is a wanding-only approach. We define $W(t)$ to be the function giving the number of patrons screened through this inspection method at time t (i.e., in the interval between t and $t+1$):

$$W(t) := \min(Q(t),\ \lfloor N \cdot X_W(t) \rfloor) \tag{5}$$

where N is again the number of screening lines at the gate. Again, the minimizing function ensures that we do not screen more people than are in the queue. Observe that this function is mutually recursive with $Q(t)$ (in this case, $scr(t) \equiv W(t)$ in Equation 2).

3.3.3 Magnetometer Only

The final inspection method is the magnetometer-only screening approach. We define $M(t)$ to be the function giving the number of patrons screened through this inspection method at time t (i.e., in the interval between t and $t+1$):

$$M(t) := \min(Q(t),\ \lfloor N \cdot X_M(t) \rfloor) \tag{6}$$

where N is again the number of screening lines at the gate. Observe that this function is mutually recursive with $Q(t)$ (in this case, $scr(t) \equiv M(t)$ in Equation 2).

3.4 Queue Clearance

Recall that the queue length function $Q(t)$ (in Equation 2) allows us to determine how many people are in the queue at any given time t. We are specifically interested in when this queue length becomes 0 after the arrival rate peaks. We will denote the queue clearance time by t_c and observe that

$$t_c := \min(\{t :\ Q(t) = 0,\ t \geq t_2\}). \tag{7}$$

Recall that t_2 represents the time where the arrival rate peaks and begins to decrease. This time will often be just before the event start time.

Since our arrival rate function $arr(t)$ is piecewise linear with non-positive slope for $t > t_2$ (see Figure 1), we observe that for time $t > t_c$, the queue length $Q(t)$ will be negligible (that is, patrons arriving at the gate will have nearly no wait time to be screened).

We now have a flexible model of patron arrivals, screening, and queue clearance for a venue. We now explain how we implemented this model for the specific NFL venue we worked with.

4. Implementation

4.1 Choice of Parameters

The various parameters that were previously discussed were chosen to best represent our specific venue during NFL games. The venue in question did not have patron arrival data explicitly, but it was able to provide us with patron throughput data for 14 games. This throughput data gave the times when tickets were scanned.

The venue used a wanding & patdown approach for the events in our data set. It was clear from ticket data when there was a change from the slower wanding screening method to the faster patdown screening method because of a noticeable sudden increase in throughput. Immediately before (and immediately after) the sudden jump in throughput, the throughput (number of patrons entering per minute) actually momentarily stops increasing. These two points, where the throughput briefly plateaus, are used to approximate the average wanding time and the average patdown time. Since we also knew the number of screening lines, this allowed us to compute the average screening time for wanding and for patdowns for each game.

For patdowns, the average screening times per patron generally ranged from 6 to 8 seconds, depending on the game. For a specific game, if the average patdown time was τ_P seconds per patron, then we set $L_P = \tau_P - 1$ and $U_P = \tau_P + 1$. Similarly for wandings, the average screening times per patron ranged from 12 to 15 seconds. If the average wanding time was τ_W seconds per patron, we set $L_W = \tau_W - 2$ and $U_W = \tau_W + 2$, since there appeared to be more variation in the wanding times than the patdown times. The security personnel at our venue felt that these numbers were accurate based on their personal experience.

The magnetometer times were less concrete since there was much less data available. Based on observations and discussions with various other venues, we assumed that average magnetometer screening times per patron would range from 5 to 7 seconds. This can obviously differ substantially from venue to venue depending on the sensitivity of the magnetometers and how they are implemented in the screening process. Based on our assumptions, though, if the average magnetometer screening time is τ_M seconds per person, we set $L_M = \tau_M - 1$ and $U_M = \tau_M + 1$. These parameters are summarized in Table 1. Note that the average and lower and upper bounds on these screening times will vary from event to event.

Screening Method	**Lower Bound (L)**	**Upper Bound (U)**
Patdown	$\tau_P - 1$ seconds/patron	$\tau_P + 1$ seconds/patron
Wanding	$\tau_W - 2$ seconds/patron	$\tau_W + 2$ seconds/patron
Magnetometer	$\tau_M - 1$ seconds/patron	$\tau_M + 1$ seconds/patron

Table 1: Lower/Upper bounds for each screening method where the average screening times for patdowns, wandings, and magnetometers are τ_P, τ_W, and τ_M, respectively.

Next, we needed to compute the constant parameters for the patron arrival function $arr(t)$ (see Section 3.1). Recall that a different arrival function must be produced for each event/game. For each game, we did the following. We first computed the maximum throughput rate R_T during the whole screening process. This should approximately be the average patdown rate. Since wanding takes approximately twice as long as patdowns, we found the time at which the throughput hit $R_T/2.1$ (that is, slightly less than the wanding rate) and this time was determined to be t_1. Similarly, we found the time after the peak throughput where the throughput decreases down to $0.6R_T$ and determined this time to be t_3. Based on the data and observations, the throughput value of $0.6R_T$ appeared to be a reasonable measure of when the arrival rates became insufficient to develop a queue. Finally, based on the throughput data and the values for t_1 and t_3, we approximate t_2 (which is generally shortly before kickoff). From there, we fit the piecewise linear function $arr(t)$ to the given data set to determine the constant parameters b_i, b_d, and c in Equation 1.

In addition, actual observations enabled us to estimate the patron density per square foot in a crowd as well as the average length of the queue when the screening method is switched from wanding to patdowns. This allowed us to estimate that there were 2,000 patrons in the queue at the main entrance gate when this switch occurred. This sets our final parameter $q_s = 2000$.

In sum, the choice of parameters for our model was based on a combination of game data from the venue, actual observations of the screening procedures, frequent discussions with the venue's security personnel, and derivations from other data.

4.2 Discrete Simulation

We then coded our model into the ARENA simulation package [1, 7]. Developed by Rockwell Automation, ARENA allowed us to both encode our simulation parameters and create a straightforward graphical view of how the lanes and queues formed and cleared (see Figure 2.) By running the simulation repeatedly, we could determine the time t_c of Equation 7 for the queue to clear for a given set of parameters. We describe the results of this simulation in Section 5.

4.3 Flexibility of Implementation

One of the key goals of our implementations was to create a flexible screening model. There are numerous venues that are deeply concerned about security and the best ways to screen their patrons. Since nothing in our approach requires that the venue be an NFL stadium, these other venues can be analyzed as well. Similarly, other screening procedures and screening functions than $WP(t)$, $W(t)$, and $M(t)$ could be used.

The process for doing analysis on other venues is straightforward. For the specific venue, one needs to determine the appropriate fixed parameters and construct an arrival function $arr(t)$ for specific events that they have data for. By considering different screening protocols and varying the number of screening lines, one can do what-if experiments for their specific venue.

5. Results

With a model and simulation, we were able to do what-if analysis for our venue. Our venue was well aware of the security and cost implications of different screening methods but wanted to know how a change would affect the number of lanes needed and the queue clearance time. Specifically, the venue wanted to know if a screening/lane combination would clear the queue within five minutes of the event start, i.e., when $t = 65$.

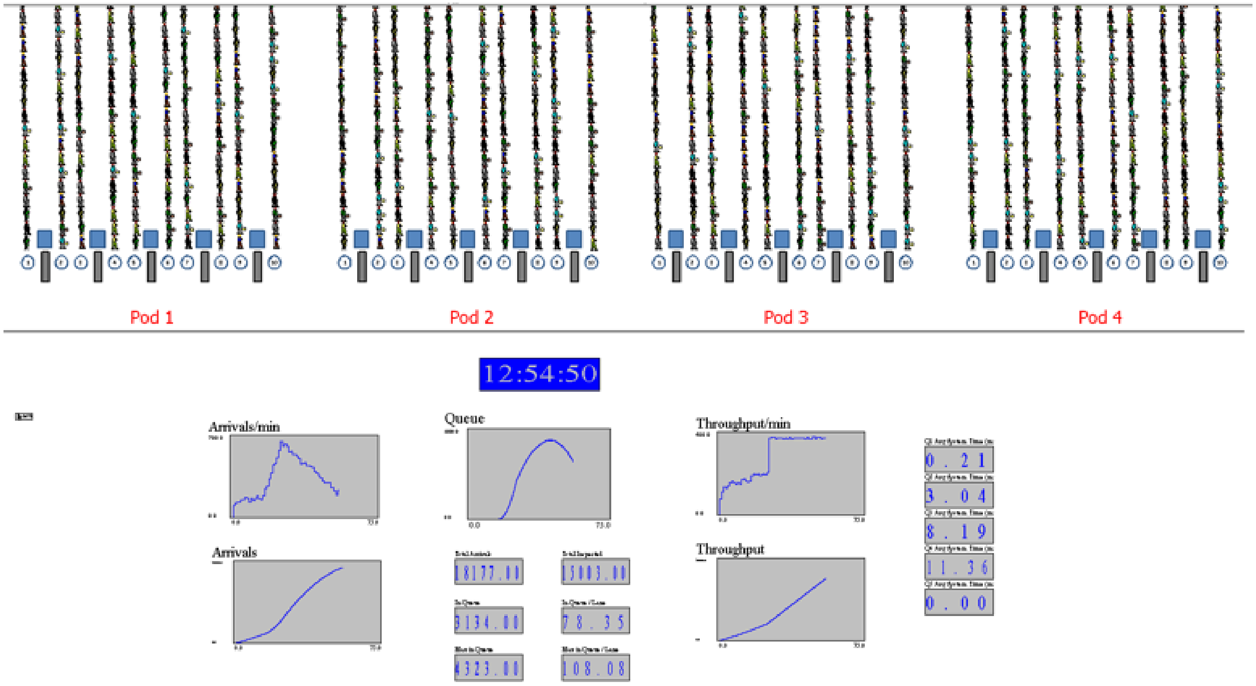

Figure 2: Screenshot of ARENA software simulating the arrival and screening of patrons. At the top are four simulated gates, each with its individual line of waiting patrons and security personel. At the bottom are the various statistics available during the simulation. These include the current time (this simulation was for a 1pm kick-off), graphs of arrival rate, arrivals, the queue length, throughput rate, and throughput. Note that in this example the throughput rate jumps because a the simulation is using a wanding & patdowns approach.

In order to address this, we ran simulations for each of the 14 events for which we had ticket data. We compared how different screening and lane combinations compared to the base case of wanding & patdowns. The base case was the queue clearance time using the wanding & switch to patdown method in use at the venue at the time of the event.

After running the simulation, we scored each event/lanes combination, starting with the goal of clearing the queue by $t = 65$ minutes, i.e., 5 minutes after kickoff. The score was one of three scores based on its projected clearance time and its comparison to the clearance time base case. If the clearance time was worse than the base case and did not meet the clearing goal it was labeled worse. If the clearance time was comparable to that of the base case but still did not meet the 65 minute goal, then the method was labeled neutral. If the clearance time met the clearance goal it was labeled acceptable.

5.1 Magnetometer Scenarios

We looked at magnetometer scenarios with 20, 25, 30, 35, and 40 lanes. We observed that with 30 or fewer inspection lanes, only two of the 14 games for which we had data would have had neutral or acceptable clearance times given the goal (both being acceptable). Even with a clearance time of 75 minutes, only one more game would have become acceptable. By contrast, with 35 lanes, all but one game would have become neutral or acceptable (4 acceptable). With 40 lanes, all games would have had a neutral or acceptable queue clearance time, 9 being acceptable. Only one would not have been acceptable with a 70 minute clearance time, but in the worst case, even a 75 minute clearing time goal could not be met. Decisions based on this data suggest the need to balance clearance time goals against the number of magnetometers in which to invest, and also suggest the possibility of finding policies that encourage earlier entrance into the stadium so as to facilitate earlier queue clearance times. This is indeed what some NFL teams have chosen to do, by offering incentives to enter the stadium well in advance, e.g., opportunities to walk on the field, participate in a lottery for prizes, or receive discounted refreshments.

5.2 Wanding Scenarios

Similar to the magnetometer scenarios, we did what-if analysis with a wanding-only approach. Since wanding takes longer than using magnetometers but requires less space, we used 40, 45, 50, 60, 65, and 70 lanes in our simulation.

Our results show that with up to 50 lanes, no games would have had even a neutral result. Two would have been neutral with a 75 minute clearance goal. With 60 lanes, four games become acceptable and three neutral. Even with a 75 minute clearance goal, only one more becomes neutral, though all three previously neutral games become acceptable. Even with 65 lanes, two games remained worse (seven became acceptable). With a 75 minute goal, however, all but two became acceptable (and those remained worse). Moving to 70 lanes, we found that all games became at least neutral (7 acceptable) and all but one became acceptable with a 75 minute goal.

6. Our Venue's Response

Our venue was very impressed with the results of this simulation. Foremost, they felt that the results of our model and simulation mirrored their experience and expert knowledge. Our results also gave them meaningful figures as to how many magnetometers they would need to do a full conversion. Similarly they had access to figures about a wanding-only conversion.

Our venue then had the responsibility of weighing the trade-offs of moving to magnetometers. Advantages would include a possible increase in safety and increase in patron satisfaction. Disadvantages included the extra cost of magnetometers, weather problems, and increased staffing needs. With additional information about how many magnetometers were required to have an acceptable clearance time, the venue was able to study whether a magnetometer approach was even feasible.

Our results were well received. In addition to helping our venue with their decisions, we presented this approach to National Football League Security. We are also using this model to help security at a National Basketball Association arena and are beginning discussions with Major League Baseball.

7. Conclusions and Future Work

In conclusion we believe our model and simulation reached our three main goals: to create a flexible model for screening, to create a simulation for a specific venue, and to help the venue make an informed decision using what-if analysis.

In addition to the success we saw at this venue, this approach can be used at any venue with security screening. As mentioned before, this can include other sporting venues, musical concerts, malls, theme parks, or anywhere that patrons are screened.

In terms of future work, we are interested in more complicated screening procedures and how they would work in our model. For example, a venue might employ a random screening process where more expensive screening techniques are used at random, perhaps after the queue gets too long. The hope is that this would be an effective, though less expensive, deterrent. We are also interested in studying scenarios where the patron arrival function $arr(t)$ has a different form. Some venues have patrons arriving all day with multiple time ranges where the arrival rates peak, which would require quite a different arrival function.

Acknowledgments We would like to acknowledge the Department of Homeland Security Award 2009-ST-061-CCI002-05 to the CCICADA Center at Rutgers University. We would also like to thank our colleagues around the National Football League and other major professional and amateur sports leagues and venues, as well as our colleagues in numerous government agencies, for providing insight and expertise in guiding our research.

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