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A SIMULATION-OPTIMIZATION APPROACH TO IMPROVE THE ALLOCATION OF SECURITY SCREENING RESOURCES IN AIRPORT TERMINAL CHECKPOINTS

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ABSTRACT

In this research, a simulation based optimization strategy is developed to improve the operation of airport security screening checkpoints (SSCPs). The simulation based optimization strategy aims to improve any airport's SSCP operations by providing a flexible modeling approach to decide optimal checkpoint configurations and their corresponding workforce allocations. Simulation based optimization is a suitable technique for problems involving data uncertainties that evolve over time, requiring important system decisions to be made prior to observing the entire data stream. This is indeed the case in SSCPs, where the passenger arrival times are difficult to predict and requirements for equipment and human resources must be scheduled in advance. The team explicitly included the uncertainties associated with future passenger arrivals and availability and performance levels of the resources in computing staffing and system configuration decisions. The proposed simulation based optimization strategy provided a 31.4% improvement for the passengers' cycle time when compared to a benchmark scenario.

1 INTRODUCTION

In the last two decades, airlines have been a target of numerous terrorist attacks (Duchesneau and Langlois 2017). These threats have generated an increased attention toward improving aviation security. The mission of the Transportation Security Administration (TSA) is to protect the transportation systems in the US to guarantee freedom of movement for people and commerce (TSA 2018). TSA's current technology resources for aviation security consist of approximately 14,000 total deployed units of transportation security equipment (TSE) at 440 airports. To fulfill its security responsibilities, TSA must be able to efficiently allocate technology and human resources to respond to changing operational needs of their numerous airport facilities. Current security regulations at checkpoint terminals tend to increase passenger wait times when airports become crowded. The inconvenience in wait times have made air travel less attractive for passengers (Rossi et al. 2018; Reese et al. 2017). Finding the right balance between a good passenger experience in the form of short wait times without compromising the security goals is very difficult. These factors, among others, make planning for the optimal allocation of airport security screening resources in airport terminal checkpoints a significant challenge.

The goal of this research is to derive models and policies to support the efficient management of resources at airport security checkpoints. This paper *develops a simulation based optimization procedure to improve the waiting time and queue performance at airport security checkpoints considering multiple equipment and staffing levels.* Simulation based optimization is a suitable technique for problems involving data uncertainties that evolve over time, requiring important system decisions to be made prior to observing the entire data stream (Pérez et al. 2013; Pérez et al. 2021; Pérez and Dzubay 2021). This is indeed the case

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in airport security checkpoints, where the passenger arrival times are difficult to predict and requirements for equipment and human resources must be scheduled in advance. The proposed methodology explicitly considers the uncertainties associated with future passenger arrivals and availability of the resources in computing resource schedules and area assignments.

The proposed research emphasizes the importance of airport security screening checkpoints in safeguarding the American people and our homeland. The results of this research are expected to enhance the operational effectiveness of airport security checkpoints by developing new decision-making models that will leverage technology and knowledge. Equipping these facilities with better planning tools will allow for better-informed downstream resource allocation decisions. The resulting models and methods will support operational decisions that will increase the potential of airport facilities to meet the organizational objectives of multiple operational scenarios.

The rest of the paper is organized as follows. In Section 2, a review of closely related work is presented. The methodology including a detailed description of the problem situation is presented in Section 3. Section 4 discusses the experimentation which includes the computational results and discussion. Finally, Section 5 provides concluding remarks and recommendations for resource allocation and service management in security screening checkpoints (SSCPs).

2 LITERATURE REVIEW

The problem of improving the flow of entities (i.e., passengers and checked baggage) at airport security screening checkpoints has received limited attention within the operations research and management science community. Papers have been published for this problem which mostly utilize simulation, queuing, and optimization models to evaluate multiple scenarios under specific assumptions. This section reviews articles addressing the security screening checkpoint problem which are more closely related to the proposed research and frames the intellectual contribution.

2.1 Analytical Methods

An analytical model is a mathematical abstraction that can be extended to address various specific problems under certain assumptions. In some cases, an exact solution to the problem can be derived and a result can be obtained in various conditions. An analytical model can provide a generic way to get performance results for various input parameters through a mathematical formulation. Queuing models have been employed to improve system design while analyzing trade-offs between risk and congestion. Gilliam (1979) reports one of the earliest works on studying airport screening operations by employing steady state queueing results. Leone and Liu (2011) analyze a single lane airport security checkpoint using a two-stage serial open queueing network of M/M/1 queues. Zhang et al. (2011) also use a stylized two-stage queuing network to analyze trade-offs between customer service and security levels at security screening lines. Lee and Jacobson (2011) present optimal passenger assignment policies to classes under steady-state and transient conditions using a multiclass queueing system of parallel servers with a single server dedicated exclusively to a single class. Stolletz (2011) models airport security screening operations as a nonstationary M(t)/G/c(t) queue and computes time-dependent performance measures at airport terminals. Hanumantha et al. (2020) present an approach that combines a causal (nonlinear) mechanistic prediction with machine learning models to forecast passenger arrivals at security screening checkpoints. The authors also proposed a model for the allocation of resources that uses the results of the proposed forecasting methods.

2.2 Simulation Methods

Simulation is a modeling tool that allows users to exercise control over a set of experimental variables while measuring their impact using specific performance measurements or responses. Simulation is used for various reasons including training, testing, experimentation, analysis, acquisition, planning, and intelligence support. Simulation modeling is useful to model complex systems under stochastic parameters that analytical models cannot tackle due to factors such as problem size. The security screening checkpoint problem is one of those cases since it consists of various queueing mechanisms and arrival patterns within the airport. Van Boekhold et al. (2014) have used simulation modeling to study passengers' access in airport facilities. The authors provided a simulation model to assess the operational efficiency of the passenger processing system with a sole emphasis on the screening of passengers and their carry-on baggage. This study sought to define an acceptable wait time threshold, as well as provide general recommendations with respect to screening approach, screening procedures, and screening equipment. Pendergraft et al. (2004) developed a discrete-event simulation to capture "curb-to-gate" activities of passengers with the goal of facilitating passenger checkpoint redesign. Wilson et al. (2006) presented a 2-dimensional spatially-aware discrete event simulation model that incorporates physical space concerns, passenger behavior, and queueing dynamics aiming to perform what-if analyses in security checkpoint layout decisions. Chen et al. (2015) developed a fast and simple simulation model that provided insight into the key performance indicators of an airport for different strategies across different futures. Ruiz and Cheu (2020) developed a detailed simulation model for a security screening checkpoint of the Phoenix Sky Harbor International Airport (PHX). The authors tested multiple scenarios considering multiple layout configurations and different passenger arrival rates.

Although some related work exists, no previous research has considered a simulation based optimization strategy to study the dynamic allocation of airport security screening resources in airport terminal checkpoints. Existing analytical and simulation methods mostly rely on simplified assumptions in terms of passenger arrival patterns and resource performance. The proposed technique presents a balanced approach between realism and applicability that makes this research unique.

3 METHODOLOGY

3.1 Security Screening Checkpoint Problem Description

Security screening checkpoints (SSCPs) are used in airport terminals to screen travelers. TSA uses a layered screening method to verify that all items brought on board of an aircraft are safe. The operation of SSCP is a challenging process. The operation requires multiple resources and equipment to perform various activities such as document verification and multiple levels of inspection for passengers and carry-on items. A typical SSCP has multiple stations and lanes with queues. The first group of stations serving the passengers are the travel document checkers (TDCs). Once documents are checked, passengers proceed to the screening lanes which consist of conveyors with X-ray machines, Advanced Imaging Technology (AIT) body scanners, and walk-through metal detectors (WTMDs). Transportation Security Officers (TSOs) and screening equipment are positioned in stations within the security lanes. The operation of SSCPs is challenging given the multiple sources of uncertainty. For instance the time at which passengers arrive at the SSCP prior to departure is uncertain. To keep SSCP lanes short in this uncertain environment, TSA dynamically opens and closes screening lanes and TDC stations. However, maintaining multiple lanes open for long periods of time is not economically efficient, whereas having few lanes open may lead to long passenger wait times. Therefore, models to determine optimal SSCP configurations have an important impact on TSA operations.

The screening process within a SSCP starts with a queue in front of the TDC stations where passengers wait until their documents are verified and their identity is confirmed. Then, passengers are directed to a second queue in the primary inspection area. Here passengers must place their carry-on items on a conveyor belt that feeds an X-ray inspection machine. After placing their items on the conveyor belt, travelers are scanned by an AIT body scanner. If the body scanner inspection is not completed successfully, travelers undergo a secondary inspection by a TSO. Similarly, carry-on items are subjective to secondary inspections if the X-ray scan alerts TSOs. Passengers will proceed to exit the SSCP after completing all the inspections successfully. Figure 1 presents a flowchart that describes the screening procedure for non-PreCheck travelers.

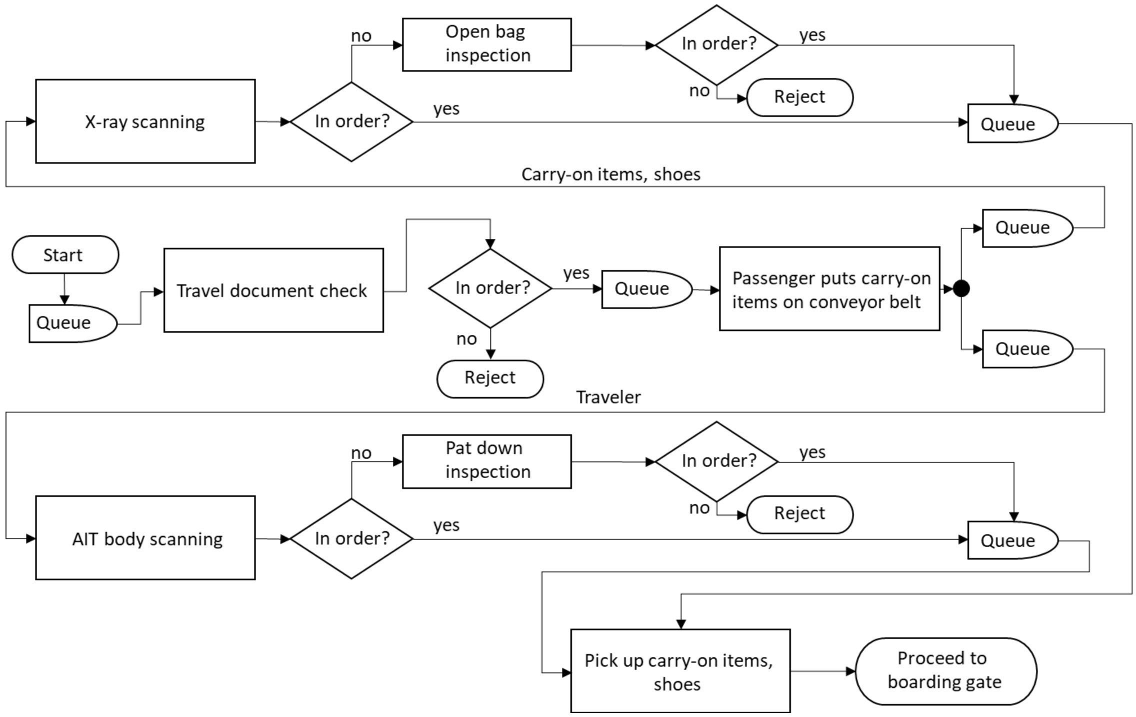

Figure 1: Screening procedure flowchart

3.2 Simulation Model

The simulation based optimization methodology implemented in this research uses the discrete-event simulation model developed by Ruiz and Cheu (2020) which represents the operation of a single checkpoint at the Phoenix Sky Harbor Airport (PHX). The simulation model was implemented in SIMIO (Pegden 2007) and includes the screening procedures described in Figure 1. Figure 2 shows the configuration of a checkpoint. There are two screening lanes with one travel document checker (TDC) reserved for PreCheck passengers. At maximum capacity, there are six screening lanes and six TDCs allocated to general boarding passengers. An average of four TSOs are needed per screening lane to manage travelers and to operate the conveyors with X-ray machines, AIT body scanners, and WTMDs.

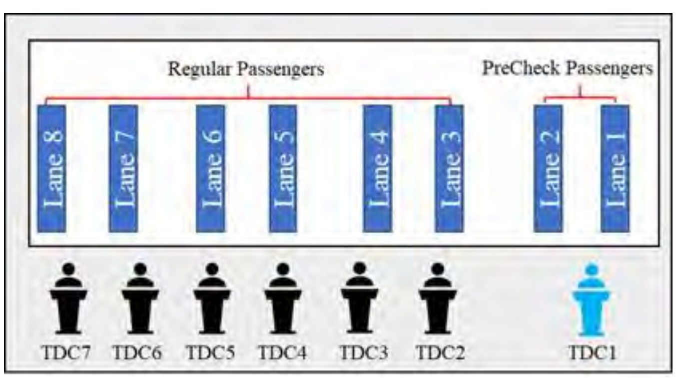

Figure 2: SSCP example configuration

In this work, the original simulation model (Ruiz and Cheu 2020) was extended and modified to include the features needed to implement the simulation based optimization method. The modifications include: 1) discretizing the interarrival times using 15-minute time periods, 2) representing the airport operation for an entire day (i.e. originally the model only represented one hour), and 3) consider the impact of the different work shifts on available TSOs as illustrated in Figure 3.

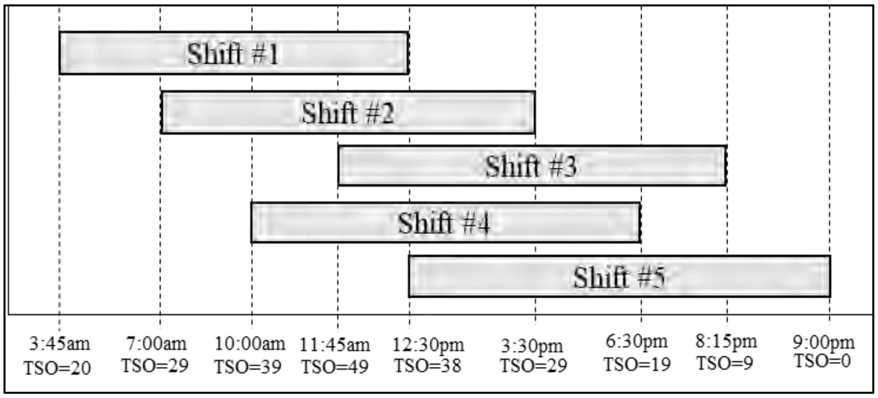

Figure 3: Example of TSO shifts allocated to a check point for a single day

Simulation models are usually used within the context of a decision-making process, evaluating different possibilities for the model's controls and how these possibilities affect the system. Simulation environments can be developed to support experimentation allowing users to enter input values and run multiple replications to return system performance metrics. This is done by varying several different input value combinations eventually leading to an improved solution (Perez et al. 2020). This strategy only works well for simple models. However, that is not the case of a typical SSCP. This research uses the OptQuest optimization add-in available in SIMIO to program the scheduling optimization models within the platform (Sturrock and Pegden 2011). The simulation based optimization technique is used to search for the input controls that optimize the evaluated objective function.

3.3 Simulation Based Optimization Strategy

In this section, a simulation based optimization technique is presented to evaluate the waiting times and queue performance at airport security checkpoints under multiple equipment and staffing levels. Simulation based optimization is a suitable technique for problems involving data uncertainties that evolve over time, requiring important system decisions to be made prior to observing the entire data stream. This is indeed the case in airport security checkpoints, where the passenger arrival times are difficult to predict and requirements for equipment and human resources must be scheduled in advance. In general, a simulation optimization problem is formulated as follows:

- ξ : the randomness in the system (e.g., passenger demand)
- x : the set of decision variables (e.g., number of TDCs and screening lanes open at each 15-min interval)
- $f(x,\xi)$: the performance metric for one replication of the simulation (e.g., average passenger cycle time)
- Θ : the search space (e.g., maximum number of TSOs per shift is less than 10)
- $\min_{x\in\Theta} f(x)$: is the model where $f(x) = Ef(x,\xi)$

The team investigated two optimization models for resource allocation in airport security screening checkpoints. The objective function of the first model is to minimize each regular passenger's cycle time at the checkpoint. The second model minimizes the number of passengers in queue before the TDCs. Both optimization models were constrained by the number of TSOs available per 15-minute time-period as illustrated in Figure 3. The optimization models provide a plan to allocate resources in the SSCP based on the performance feedback provided by the discrete-event simulation model, the objective function, and the set of available shifts and TSO requirements at each station of the SSCP. The optimization models were implemented using the OptQuest Add-In in SIMIO (Sturrock and Pegden 2011).

4 EXPERIMENTATION

4.1 Design of Experiments

This section provides a discussion of the statistical experiments performed using the simulation based optimization technique. As stated in Section 3.1, to keep SSCP queues short, TSA dynamically opens and closes screening lanes and TDC stations. The process of opening and closing stations depends on the number of TSOs available per time period. Keeping multiple lanes open for long periods of time is not economically efficient, whereas having few lanes open may lead to long passenger wait times. Therefore, the purpose of the experimentation is to evaluate the performance of the *simulation based optimization strategy* in terms of allocating TSOs to SSCP stations dynamically in a normal day of operation. In this study, 15-minute time windows were considered for the opening and closing of stations. The *simulation based optimization strategy* is compared against two policies named *benchmark policy strategy* and *best-case policy strategy,* which are described next.

- *benchmark policy strategy*: this strategy serves as a lower bound performance for the computational study. The *benchmark policy strategy* follows the industry practice and opens the same number of TDCs and screening lanes given the number of TSOs available per time period. The total number of TSOs per time-period is limited by the number of shifts available and the number of TSOs per shift as illustrated in Figure 3.
- *best-case policy strategy*: this strategy serves as an upper bound performance for the computational study. The strategy assumes a fully staffed checkpoint during the entire day.

In addition to the *simulation based optimization strategy*, three responses were considered to measure the performance of the three resource allocation strategies discussed above. The responses studied in this research are: 1) average passenger cycle time in the SSCP, 2) average SSCP throughput, and 3) utilization of TDCs. The experimental results will allow decision makers to identify interventions for improving the performance of the system. In addition, the results will provide the necessary insight for the development of guidelines for security screening checkpoints. The guidelines will recommend a checkpoint set-up based on predicted passenger arrival patterns for a specified time period.

4.2 Computational Results

Table 1 shows the computational results for the three strategies considered. The results include the average cycle time, throughput, and TDCs utilization. As expected the *best-case policy strategy* reported the best performance. The *simulation based optimization policy strategy* provided a 31.4% improvement for the passengers' cycle time when compared to the *benchmark policy strategy*. However, the results show that there is a room for improvement between the *best-case policy strategy* and the *simulation based optimization policy strategy*. Based on our experiments, additional TSOs must be added to the schedule in the *simulation based optimization strategy* in order to close the gap with the *best-case policy strategy* .

Table 1: Computational results for regular passengers

	Regular Passenger		Utilization					
Strategy	**Cycle time (min)**	**Throughput**	**TDC2**	**TDC3**	**TDC4**	**TDC5**	**TDC6**	**TDC7**
Best-Case	8.53	5175	46.06	35.46	29.44	25.60	23.11	21.03
Benchmark	26.59	5095.3	48.88	41.41	35.60	30.09	30.24	24.74
Sim-Opt	18.25	5125	53.93	47.33	41.74	28.24	27.15	24.86

Note: Utilization is relative to the total time each TDC is open

Figure 4 illustrates the performance of the three strategies in terms of average cycle time per hour for regular boarding passengers. The *best-case strategy* shows the best performance with a maximum cycle time per hour reported of about 10 minutes. The *benchmark strategy* reported a maximum cycle time per hour of about 42 minutes. The *simulation based optimization strategy* improved the performance of the *benchmark strategy* by decreasing the maximum cycle time per hour by about 15 minutes.

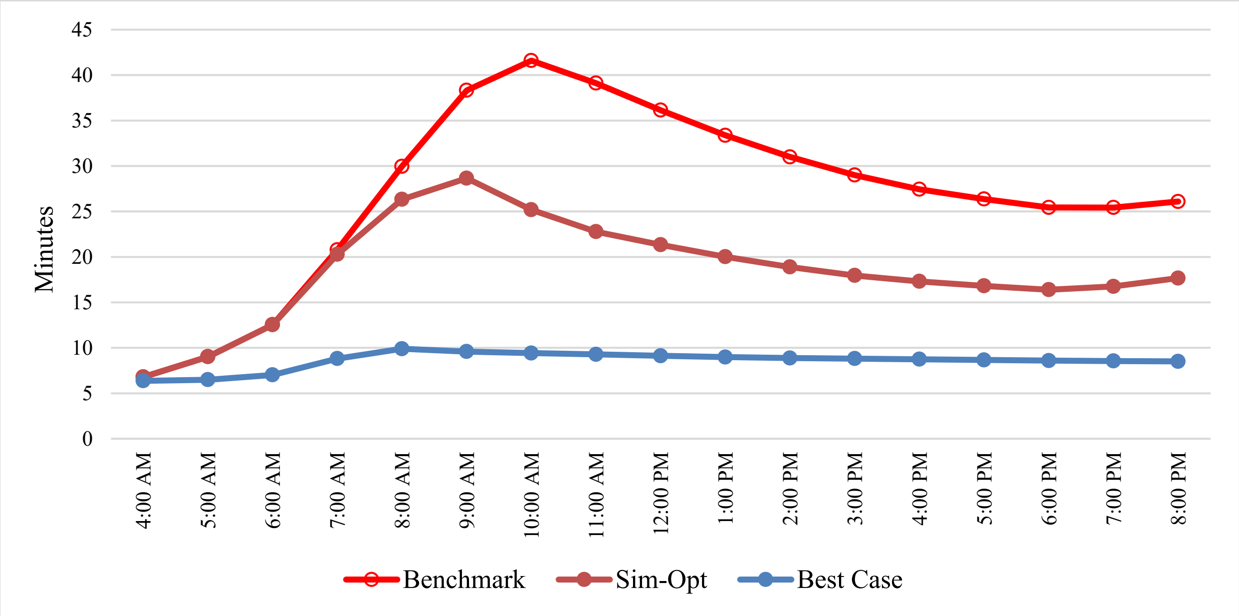

Figure 4: Regular passengers cycle time per hour

As stated earlier, in order to reduce the gap between the *simulation based optimization strategy* and the *best-case policy strategy* additional TSOs are needed in the checkpoint. The following experiments consider the *simulation based optimization strategy* with additional TSOs. Two additional *simulation based optimization* strategies are considered:

- **Reactive strategy:** Considers adding a new shift with 8 additional TSOs starting at 7:30am, when cycle time is more than 20 minutes.
- **Proactive strategy:** Considers adding a new shift with 8 additional TSOs starting at 6:30am, when cycle time is more than 10 minutes (i.e., 6:30am).

Table 2 shows the computational results for the *best-case*, *reactive*, and *proactive* policy strategies. The results include the average cycle time, throughput, and TDC utilization. As expected, by adding the additional shifts using the *reactive* and *proactive* strategies the cycle time improved and the gap decreased when compared to the *best-case policy strategy*. In terms of throughput and utilization the *reactive* and *proactive* strategies reported similar values when compared to the *best-case policy strategy*. The *reactive* and *proactive* strategies reported similar overall results. However, the daily cycle time averages hide the effect of peak times.

Table 2: Computational results for regular passengers and extra shift

	Regular Passenger		Utilization					
Policy	**Cycle time (min)**	**Throughput**	**TDC2**	**TDC3**	**TDC4**	**TDC5**	**TDC6**	**TDC7**
Best Case	8.53	5175	46.06	35.46	29.44	25.60	23.11	21.03
Reactive	10.96	5175	60.47	51.93	44.14	33.49	30.85	28.47
Proactive	9.70	5175	58.31	49.14	41.83	33.47	30.79	28.42

Note: Utilization is relative to the total time each TDC is open

To further investigate the differences between the *reactive* and *proactive* policies, Figure 5 and 6 illustrate the performance of the *best-case*, *simulation based optimization*, *reactive*, and *proactive* strategies in terms of cycle time and number of passengers waiting per hour for regular passengers. Both figures show that the *proactive strategy* almost matches the *best-case strategy* results with a maximum cycle time per hour reported of about 10 minutes and with a maximum number of passengers waiting in queue of about 12. These results provide good managerial insights for the allocation of TSOs in airport checkpoints, showing that adding resources in a proactive way (i.e., before a predicted passenger surge) can reduce the maximum passenger waiting time per hour by about 33% with respect to the reactive strategy. These results also support the use of data analysis and modeling techniques for checkpoint management at airport facilities.

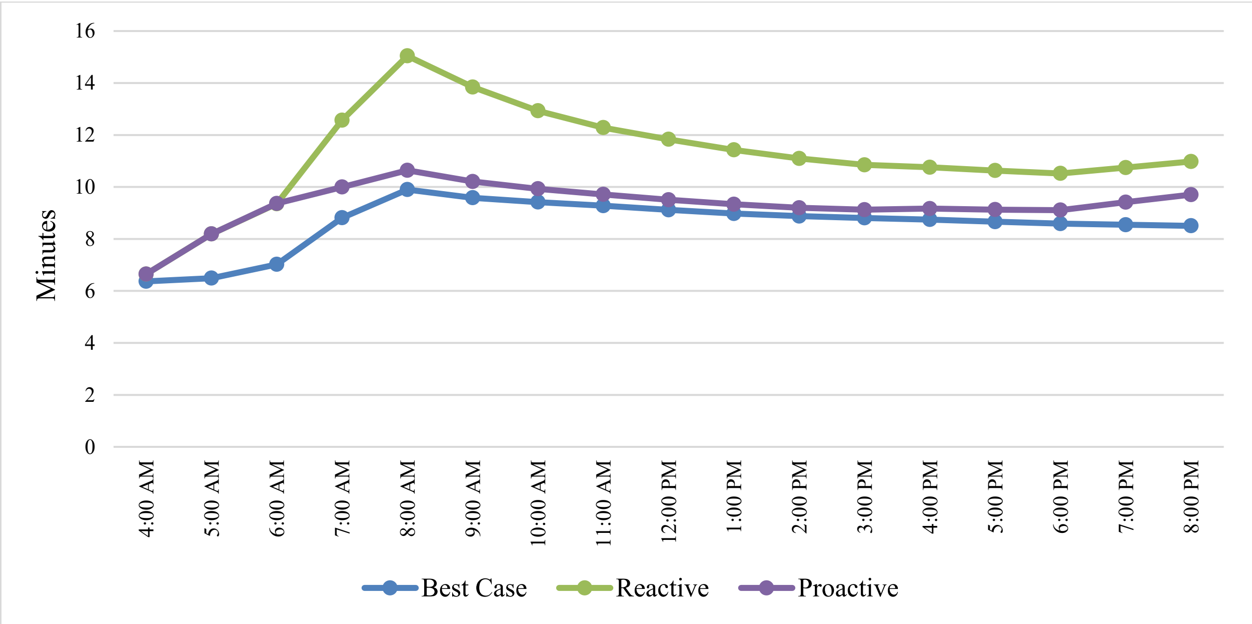

Figure 5: Regular boarding passengers cycle time per hour considering the reactive and proactive strategies

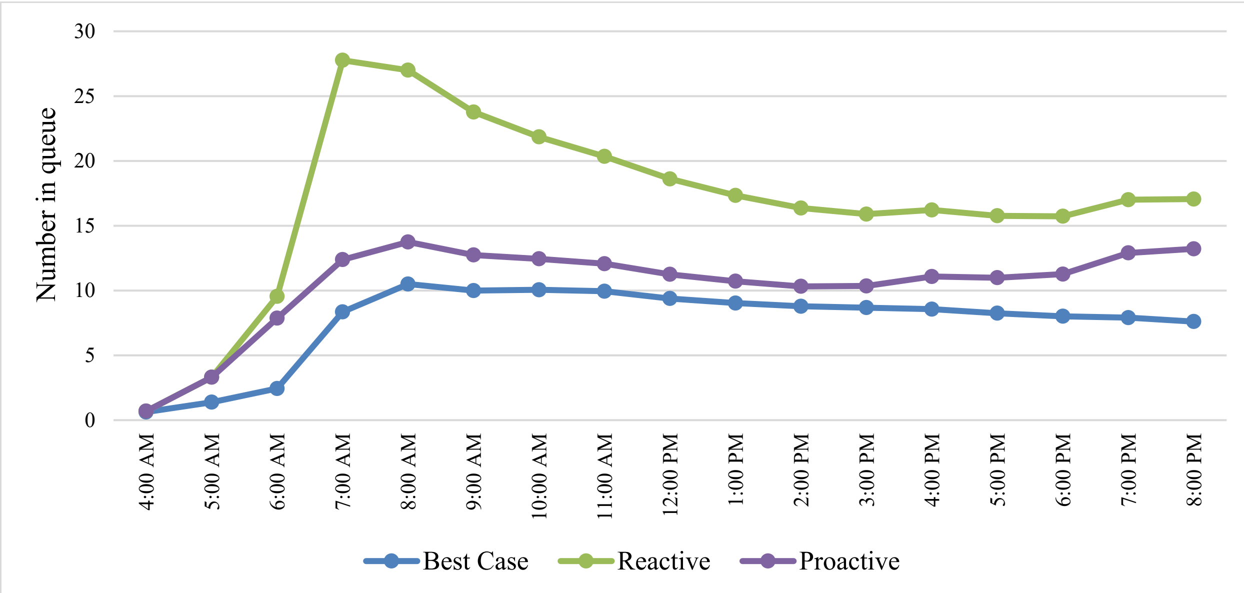

Figure 6: Regular passengers number in queue per hour considering the reactive and proactive strategies

These results allowed the team to identify the number of Travel Document Checker (TDC) stands and the number of inspection security lanes to open per time-period. These factors were used to formulate screening checkpoint configurations for improving the performance in terms of (1) passenger cycle time and (2) queue lengths at the airport security screening checkpoints. Table 3 shows an example of the type of protocols that can be generated using the simulation based optimization technique. The numbers highlighted for the simulation based optimization strategy summarize the changes made by the strategy when improving the *benchmark strategy*.

Table 3: Guidelines and protocols using computational study results

	3:45am to 6:45am		**7:00am to 9:45am**		**10:00am to 3:30pm**		**3:30pm to 6:30pm**		**6:30pm to 8:15pm**	
Policy	**TDCs**	**Security lanes**	**TDCs**	**Security lanes**	**TDCs**	**Security lanes**	**TDCs**	**Security lanes**	**TDCs**	**Security lanes**
Best Case	7	8	7	8	7	8	7	8	7	8
Benchmark	5	3	6	5	7	8	6	5	5	3
Sim-Opt	5	3	**4**	**6**	7	8	6	5	5	3

5 CONCLUSIONS

In SSCPs, several important metrics can be used to measure the traveler's experience, such as the traveler's cycle time and queue lengths. TSA management can control these quality metrics through staffing decisions during the day. In this paper, a simulation based optimization strategy was developed in order to analyze the traveler's processing time in SSCP. The simulation based optimization strategy proposed in this article aims to improve any airport's SSCP operations by providing a flexible modeling approach to decide optimal checkpoint configurations and their corresponding workforce allocations. A set of computational experiments were conducted and analyzed in order to evaluate resource allocation strategies and their impact on the system performance. Several suggestions and implications result from this simulation study:

1- The proposed models and strategies can be used to support other types of decisions such as TSO reallocations and hiring (number and schedule), SSCP expansions, and new screening technology acquisition to improve passenger cycle times.
2- In practice, our models provide evidence that proactive queue management is critical to prevent long queues and wait times, as they prevent queue buildups before peaks in demand. As a result, SSCP re-configuration decisions with their corresponding workforce allocations are critical to maintain short queues and must be executed before expected surges in passenger volumes.
3- Simulation optimization strategies enable quantitative decision making for managing SSCPs.

In our simulation based optimization study, we observed that there would be a need for an additional TSOs at specific time periods during the day. The results can be used as guidelines for deciding when will be appropriate to operate with different levels of staff members. Future research work should focus in integrating and evaluating additional scenarios such as resource sharing between multiple checkpoints and limitations imposed by pandemics such as the COVID-19.

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