Simulation of Dynamic, Risk-Based Aviation Security Screening Policy Performance

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Introduction & Motivation

- Investigate aviation security screening operations based on perceived passenger risk
- Passenger Screening Techniques
  - Uniform screening
    - Passenger risk perceived equally
    - All passengers could pose a threat
  - Selective screening
    - Select passengers perceived as higher risk
    - Most passengers do not pose a threat
    - Directs specialized resources to high-risk passengers
    - More cost-effective strategy to employ

Research Goals

- Design and evaluate a dynamic, risk-based passenger screening policy for airport checkpoints
  - Effectively utilize security resources
  - Maximize security system effectiveness
- Perform queueing analysis to compare stochastic versus deterministic passenger assignment policies
- Provide flexibility to respond to changing threat environments

Dynamic, Risk-Based Screening Policy

- Multiple Objectives
  - Maximize security (number of threat items detected)
  - Minimize expected time passengers spend in system
- Queueing Analysis
  - Sample the screening process at time of each passenger arrival
  - Interarrival times, Δ_i, distributed exponential(λ)
  - Realizations, $\delta_i = t_i - t_{i-1}$
- Formulate security system as a stochastic process
- Minimize weighted cost function to create balance between dual objectives, $0 \le \eta_1 \le 1,\ 0 \le \eta_2 \le 1$

$$\begin{aligned} &\text{minimize} && C(t_i) = (1-\eta_1)C^Z(t_i) + \eta_1\left((1-\eta_2)C^W(t_i) + \eta_2 C^P(t_i)\right) \\ &\text{subject to} && 0 \le p_m(t_i) \le 1, \qquad m = 1,2,\ldots,M \\ &&& \sum_{m=1}^{M} p_m(t_i) = 1 \end{aligned}$$

- Solve nonlinear program for $p_1(t_i), p_2(t_i), \ldots, p_M(t_i)$

$$C^Z(t_i) \equiv \left(1 - \sum_{m=1}^{M} \frac{L_m - L_1}{L_M - L_1} p_m(t_i)\right)^2$$

Expected number of detected threat items

$$C^W(t_i) \equiv \left(\frac{\sum_{m=1}^{M} p_m(t_i) E[W_m(t_i)] - \omega^*}{\max_{m=1,2,\ldots,M} \{E[W_m(t_i)]\} - \omega^*}\right)^2$$

Expected amount of time passenger *i* spends in the security checkpoint

$$C^P(t_i) \equiv \frac{1}{M-1} \sum_{m=1}^{M-1} \left(1 - \frac{p_m(t_i)}{p_1^*}\right)^2$$

Optimal assignment probability error, $p_m(t_i) - p_m^*$, where p_m^* is the optimal solution to the deterministic (static) assignment policy

Aviation Security Currently in Practice

- Computer Assisted Passenger Prescreening System (CAPPS)
  - Selectees - those not cleared by CAPPS
  - Nonselectees - those cleared by CAPPS
- Secure Flight (announced in 2004)

www.tsa.gov

- Registered Traveler (RT) program
  - Expedited screening process for RT members

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- Checkpoint Evolution
  - People
    - Travel Document Checker (TDC)
    - Visible Intermodal Prevention and Response (VIPR)
    - Screening Passengers by Observation Technique (SPOT)
  - Process
    - Self-Select program
    - Create positive, friendly environment

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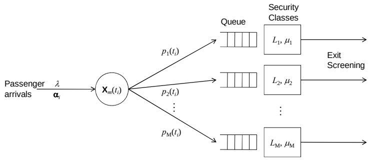
  - Technology
    - Advanced Technology (AT) Imaging Systems
    - Bottle Liquid Scanners (BLS)
    - Millimeter Wave (MMW) passenger imaging

Simulation Model and Analysis

1) Generate vector of N passenger interarrival times
2) Construct $M \times 2N$ matrix of checkpoint events, $T(m,k)$ where
   - $m = 0$ indicates the time $T(0,k)$ when the k^{th} event corresponds to a passenger arriving at security
   - $m = 1,2,\ldots,M$ indicates the time $T(m,k)$ when the k^{th} event is a passenger exiting security class m
3) Assign first passenger to security class m based on their realized assessed threat value
   - Compute passenger's service time, and event time for passenger to exit the security checkpoint
   - Reorder passenger's event time for exiting security screening within matrix of checkpoint events
   - Increase queue length for security class m
   - Increment event index k
4) If next event is passenger arrival,
   - Compute the dynamically evolving security class threshold values by solving the NLP
   - Repeat step 3 for subsequent passenger
5) If next event is passenger exiting screening,
   - Decrease queue length for associated security class
   - Increment event index k
6) Repeat until all N passengers have undergone screening

Repeat analysis for 60 independently seeded replications to estimate mean and variance of the number of threat items detected and of the time spent within the screening process

Multi-Level Security Class System



- Independent, sequential passenger arrivals
  - Poisson process with rate $\lambda > 0$
  - passenger i arrives at checkpoint at time t_i
- Security class service times
  - Exponential, with rates $\mu_1 > \mu_2 > \ldots \mu_M > 0$
- Passenger assignments
  - Probability passenger i assigned to class m

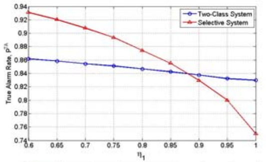
$$p_m(t_i) \equiv P(\mathbf{X}_m(t_i) = 1)$$

  - $X_m(t_i) = 1\ (0)$ if passenger i (at time t_i) assigned to security class $m = 1,2,\ldots,M$
- Queue capacity c_m for security class $m = 1,2,\ldots,M$
- Security classes operate independently
- Assessed threat value α_i of passenger i
  - Quantifies perceived risk resulting from prescreening
- Conditional probability of security class m detecting threat: L_m (i.e., device true alarm rate)

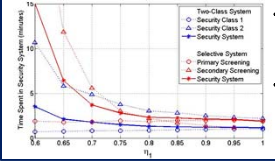
Computational Results

Compare two class (multi-level) system to selective security system

- $F_\alpha(\alpha)$ truncated exponential distribution (over [0,1]),
- Poisson arrival rate: $\lambda = 2.5$ passengers/minute
- Exponential service times: $\mu_1 = 3$, $\mu_2 = 1$ pass./min.
- Security levels: $L_1 = 0.75$, $L_2 = 0.9$
- Security class capacities: $c_1 = 60$, $c_2 = 40$
- Sensitivity of parameter η_1, the balance between security and expedited screening



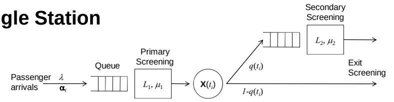
- Selective system designed for maximizing security
- When $\eta_1 = 1$, selective security system less likely to detect nonselectees carrying threat items since these only undergo primary screening



- Two-class (multilevel) security system designed for maximizing passenger throughput
- Selective system requires more time, on average, than two-class system to achieve a similar true alarm rate

Selective-Based Screening Systems

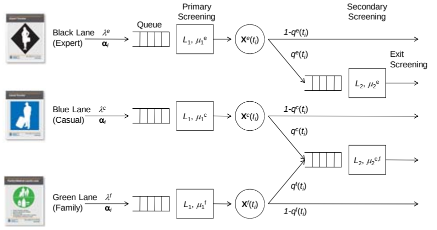
Single Station



- Selectee passengers undergo both primary and secondary screening
- Nonselectee passengers selected based on their assessed threat value, rather than at random
- Conditional true alarm rate for passengers undergoing both primary and secondary screening

$$L_2' = L_1 + L_2 - L_1 L_2$$

Checkpoint Evolution



Conclusions

- Simulation is necessary for estimating the average time a passenger spends in the security system due to the dynamically evolving security threshold values within the risk-based screening policy
- Simulation results demonstrate that a multi-level structure is designed to expedite screening, while a system with primary and secondary screening increases the probability of detecting threat items
- This simulation technique can be used to compare the performance of various alternative security checkpoint designs to analyze the effect on true/false alarm rates and screening times
- Future generalization of model assumptions
  - Non-exponential interarrival, service time distributions
  - Explore alternative security system structures
  - Investigate dependency among security classes
  - Incorporate cost associated with resolving false alarms

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