Reliability Engineering and System Safety 165 (2017) 292–301

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

N-stage security screening strategies in the face of strategic applicants

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ARTICLE INFO

Keywords:
Optimal security screening policy
Imperfect *N*-stage screening
Queueing theory
Game theory

ABSTRACT

From one perspective, tighter security screening has the benefit of deterring adversary passengers and enhancing safety. However, this approach can also produce congestion problems for normal passengers. Adapting to screening policies, both adversary and normal passengers decide their application strategies to the security system to maximize their payoffs, which in turn affects the security agent's payoff. This paper integrates game theory and queueing theory to analyze an *N*-stage imperfect screening model that considers reject or pass decisions, in which applicants have the chance to be passed or rejected at each stage of the system. An imperfect three-stage screening model is numerically illustrated. Furthermore, the application probabilities, screening probabilities and approver's payoff as functions of the number of screening stages are analyzed. This paper provides some novel insights on screening policies and the optimal number of screening stages which would help security screening policy makers.

1. Introduction

Since September 11th, 2001, stricter security screening policies have been applied to many fields, including aviation security screening [11,22], visa issuance [31], and cargo inspection [28,24]. However, many errors continue to occur during the screening processes or failure probability in the reliable systems [14,13,29,30]. Several scholars have developed approaches to minimize the probability of inspection error. [19] determined the number of groups, the fractions of passengers and the assignment of various ID check or scanner stations to minimize the number of false alarms in an airport security systems which need to satisfy the false clears requirement. [23] classified passengers into several classes based on their perceived risk levels to maximize the total security subject to passenger assignments in order to find the optimal sensor thresholds. [25] used deterministic integer models for a sequential stochastic security design problem to maximize the total security probability by considering the process of purchasing screening devices at the first stage for cost minimization and how to screen passengers with different assigned risk levels at the second stage.

Game theory has been widely applied to study conflict and cooperation among decision-makers, including security problems. [8] introduced game theory's application to military problems. [4] studied the interaction between a governmental security agency and a terrorist organization under a sequential Non-Cooperative Game, in which government infers the passenger is a terrorist or not by signaling and terrorist decides to hide certain attributes. [15] analyzed a strategic defense and attack game in series and parallel reliability systems, where the investments, contest intensity and evaluations of the value for each component are considered. [12] identified the different optimal screening policies based on the probabilistic risk by chance and strategic risk by adverse party. In that approach, [12] spread defense resources to minimize the potential damage level to the most vulnerable site is the best strategy when facing the discrete strategic risk. [10] proposed two optimal inspection policies that discuss balancing the probability of being inspected and average delay time, and considering the adversary strategic gaming behavior for detecting illicit nuclear materials. For the airport screening security, [6] considered the passenger profiling strategy, it is found that the two-profiling setup is better than the no-profiling setup in the perspective of total expected security cost, inspection rate of normal passengers, and attacker detection rate in the face of attacker's gaming. [21] proposed a multi-objective approach for selection of an efficient security system under an imperfect information game between defender and attacker, where the probability of a successful defense, the acquisition, and operational costs are considered. [1] analyzed the optimal resources allocation between intelligence gathering and screening in providing airport security under a game between the government and a terrorist, considering the situations of attack probability, cost-reducing innovation, economy development, efficacy, and enhanced punishment. [5] analyzed the optimal resource allocation for the critical infrastructure security by using the target-oriented utility theory, which considers the deterrence probability and defensive investment.

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http://dx.doi.org/10.1016/j.ress.2017.04.019
Received 24 August 2016; Received in revised form 23 March 2017; Accepted 13 April 2017
Available online 19 April 2017

Through estimating the expected waiting times, queueing theory has been widely applied to security congestion problems. For example, [34] applied the Stackelberg game to find the optimal inspection strategy for detecting a nuclear weapon in an 11-layer shipping container security system. The port congestion and an overall budget are then balanced, where queueing network congestion is quantified by the steady-state sojourn time distribution. [35] balanced congestion and security safety and proposed an optimal staffing policy, where the average queue length is confined to a certain range. [2] analyzed the strategic interaction between the U.S. Bureau of Customs and Border Protection (CBP), trading firms, and terrorists in a game-theoretic framework to reduce inspection-driven congestion and proposed a strategic delay for CBP, where a M/G/1 queueing model is applied for the secondary inspections. [20] applied a more generic model with a Batch Markovian Arrival Process (BMAP) and phase types (PH) services, and two types of multi-server models to estimate border crossing delay in a way of economic and social costs.

a multi-stage screening process has been applied in many fields, such as product testing, and visa processing. for example, for the visa application, an applicant starts with scheduling a visa interview, and waits for his application to be reviewed by a consular officer. based on the background of the visa applicant, the visa officer determines whether the applicant is eligible for a visa, whilst at the same time considering whether security advisory opinion (sao) is needed. if sao is needed, there will be an inter-agency mantis check process initiated, where the applicants' information is checked using a technology alert list. there is a chance that the applicant is approved after the check clearance process. however, if the applicant is not approved, the consular officer would directly issue or deny visa to the applicants. in the airport security process, some passengers are considered suspicious after passing the first security check. they then need to pass additional checks to clear security. in some countries, based on political and cultural issues, some passengers need to have multi-stage screening to go through the airport's security. in the us, passengers make a reservation at the airport, where their data is sent to the reservation system. the cbp network interface transmits data from air carriers to secure flight. in the office of transportation vetting and credentialing transportation vetting platform (tvctvp), there are processes including id authentication and terrorist data screening with capps i rules. after background screening, passengers can check in for flight. normal and selected passengers undergo normal screening at the security checkpoint, where the selected passengers are met by law enforcement for additional clearing processes. those that fail the process would be denied access.

Some researchers considered a multiple-period game for security problems [26]. For example, [18] analyzed a series system for the optimal distribution of the defense resources, where the defender protects genuine elements and deploys false elements in the first period and the attacker then attacks in the second period. [32] considered a dynamic incomplete information multiple-period game, where the defender can update information on an attacker's target valuation in a Bayesian way. [16] modeled repeated games of strategic defender and attacker in complex and dependent systems, where the unit costs of defense and attack, and the contest intensity for other targets in the second period are dependent on the successful probability of attack on one target in the first period. [37] modeled a multiple-period signaling game with incomplete information between defender and attacker based on optimal resource allocation, considering secrecy and deception strategies for defender and balancing capital and expenses budgets for defense investments. [17] illustrated three scenarios: (a) a defender and attacker (agents) move simultaneously in one-period game; (b) the defender moves first in a two-period game; and (c) the attackers move first in a two-period game to suggest the importance of proactive defense when considering multiple attackers. However, there are some researchers who applied multiple-stage inspection to study security problems. For example, [9] analyzed the multi-stage game between a customs officer and a smuggler to introduce the assumption that the smuggler can escape capture by means of side payment. [7] built up the security relevant information model and present a multi-stage network attack analysis, capturing the trust relationships, vulnerabilities, and attacker capabilities. [36] proposed a two-stage inspection policy for the U.S.-Canadian border inspection, where the first-stage inspection needs to be complete and the second stage is selective. [27] analyzed the approver and passengers' strategic behaviors based on queueing theory and game theory in a two-stage imperfect model. The novelty of this research is to extend the one-stage model [33] and two-stage model [27] to an imperfect N-stage screening model. Different from [27] where the system can only reject suspect passengers at the final stage, this paper allows passengers to be rejected, passed or further screened at each stage system. In this paper, two types of screening error probabilities (the adversary applicants are screened as “good”, and normal applicants are screened as “bad”) are considered in an imperfect N-stage screening system. N-stage queueing theory is applied in a game-theoretic screening model to determine the optimal screening policies from the perspective of the approver, while balancing the safety and congestion tradeoff from a cost-effectiveness perspective. In addition, we further analyze the N-stage screening model to find the optimal number of screening stages under a discriminatory screening policy.

This paper is devoted to the development and application of screening policy/methods for the enhancement of thesecurity/safetyand reliabilityofcomplex N-stage technological system in airline screening transportation system. The paper involves the analysis of security and congestion issues related to the reliability of complex airline screening systems and presents mathematical methods to get theoretical results. The methods in this paper involve the parameter uncertainties and sensitivity analysis, operator screening policy decision system, and mixed probability strategies. The remainder of this paper is structured as follows: Section 2 introduces an imperfect N-stage screening model that considers pass and reject decisions, and the approver's and applicants' optimization problems; Section 3 provides the approver's and applicants' corresponding best responses by performing numerical sensitivity analyses, and an imperfect N-stage screening analyses; Section 4 concludes this paper and provides future research suggestions. The Appendix provides the proofs of the propositions.

2. *N*-Stage screening model

A N-stage screening model that considers reject and pass decisions is introduced. In particular, Section 2.1 introduces the notations used throughout this paper; Section 2.2 describes the system process in an N-stage screening model that considers reject and pass decisions; and Sections 2.3 and Sections 2.4 provide the optimization problems for the approver and applicants.

2.1. Notation

Table 1 shows the notations used throughout this paper, including five decision variables (screening probability at the first stage Φ_1, probability of screening ‘Good’ applicants at the ith stage Φ_{iG}, probability of screening ‘Bad’ applicants at the ith stage Φ_{iB}, normal and adversary applicant's application probabilities $P_G(\mathbf{\Phi})$ and $P_B(\mathbf{\Phi})$, respectively,) three utility functions (approver's objective function $J(\mathbf{\Phi}, P_G, P_B)$, normal applicants' objective function $u_G(\mathbf{\Phi}, P_G, P_B)$, and adversary applicants' objective function $u_B(\mathbf{\Phi}, P_B)$), and twenty three parameters (expected waiting time W, approver's reward for admitting each normal applicant R, approver's penalty for admitting each adversary applicant C, normal and adversary applicants' rewards if passed r_G and r_B, respectively, adversary applicant's penalty if rejected c_B, waiting cost per unit time for normal applicants c_W, arrival rate of all potential normal and adversary applicants Λ_G and Λ_B, actual arrival