Stackelberg Model of Anti-terrorism Resource Allocation in Express Transportation Security Checks

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Abstract. The problem of anti-terrorism security checks of express transportation becomes more and more severe under the Internet shopping model. In this paper, a Stackelberg game model of anti-terrorism resource allocation in express transportation security checks is built to discuss, in terms of single and multiple routes, the optimal resource allocation of express company (defender) including physical security measures, in-box sensor technology, non-intrusive security measures at terminal distribution sites and handover course. It shows that, for the single route, express company should trade off the security costs among the first, second and third level security measures, and should allocate the same security costs of physical security measures for every distribution site. For the multiple routes, the transportation route that terrorists insert the hazardous materials has the lowest probability of physical security measures, and therefore is utilized by terrorists. Thus, the optimal allocation plan of security resources should be the same security costs of non-intrusive security measures at the final distribution sites (the third level security measure) among each transportation routes.

1 Introduction

Generally speaking, terrorism refers to deliberately violent acts that cause panic. It is aimed at the non-combatants (civilians) or disregarding their safety for religious, political or ideological purposes [1]. Since the September 11th incident, terrorism has become a major challenge facing all countries in the world, and has profoundly affected the evolution of international relations and the world's political structure. In order to achieve their political goals and wreak greater havoc, terrorists are continuously increasing their attacks and expanding their impact. The violent terrorist incident on Tiananmen Square in Beijing on 10. 28th in 2013, the severe violent terrorist case at Kunming Railway Station in China on 3.1st in 2014, and the severe violent terrorist case in Urumqi on 5. 22nd in 2014 showed increased violent destructiveness. The "East Turkistan" terrorist forces have continuously strengthened its characteristics including their association with international terrorist organizations [2]. It is worth noting that some terrorist attacks in recent years have presented the escalation and diversity of terrorist methods. Among them, terrorist means of aircraft [3], railways [4], shipping [5] and express transportation have attracted the great attention of global governments. According to current statistics, the annual growth rate of my country's express logistics market has been over 30% since 1990, three times the average growth rate of China's GDP during the same period [6]. The rise of Internet shopping consumption mode has further promoted the rapid growth of the express delivery business. In 2013, there were cases

of death caused by YTO Express (a native logistics company) illegal receipt and delivery of hazardous chemicals in China, and the explosion of express parcels in Hangzhou, Zhejiang on August 14th. On September 30th, 2015, 17 express package explosions occurred in Liucheng County, Liuzhou City in Guangxi Province, causing 7 deaths and 2 missings. Although the above-mentioned incidents had been ruled out the possibility of terrorist acts, security checks have been strengthened to ensure transportation safety during express transportation so as to prevent terrorists from implanting explosive weapons and dangerous chemical weapons by express transportation and from causing great panic and economic losses to the society. This issue has attracted great attention from relevant departments.

Since the 9·11 terrorist attacks, the issue of terrorism has received great international attention, and a large number of relevant research documents have emerged. Research perspectives on terrorism issues include analyzing terrorist acts from the perspective of psychological analysis [7], of quantitative analysis models to study the socio-economic roots of terrorism [8, 9], of complex network technology the structural characteristics of terrorist networks [10] and of the optimization model to study the combinatorial optimization of anti-terrorism measures [11, 12, 13, 14]. Among them, Zhuang Jun et al. used a game theory model to study the game between the government and terrorists between defense and attack, including the coordination of counter-terrorism and natural disasters in consideration of endogenous attackers' effort level [15], and offensive and defensive strategies for confidentiality and fraud [16], etc. Regarding the issue of

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improving transportation safety measures to prevent terrorist attacks, Zhong Pengyun and others constructed a cascading failure model of dangerous goods transportation networks under serial terrorist attacks [17], and Niyazi Onur Bakir researched the deployment of anti-terrorism resources from the perspective of container routes [18].

In response to the current safety accidents and major hazards of express transportation in China, the relevant 15 departments jointly decided to carry out the cleanup and rectification of dangerous explosives, delivery logistics and conflicts and disputes nationwide from October 2015 to the end of March 2016. Resolve special actions will be taken to rectify all kinds of hidden dangers that affect public safety and social stability, ensuring the stability of society and the safety of people's lives and property. Among them, vigorous steps have been taken to strengthen the safety and standard management of delivery logistics, and comprehensively promote the implementation of the sealing of consignments after prior inspection, the real-name registration of postal logistics activities, and the X-ray security inspection system for mail and express mail [19]. However, due to the rise of new models of Internet shopping at home and abroad, domestic and foreign academic circles still lack relevant research literature on the issue of express transportation anti-terrorism. Aimed at the current security risks of express transportation in China, this article draws on Niyazi Onur Bakir's maritime or railway container security inspection model, and studies the optimal security inspection resource allocation of express companies and relevant government security departments from the perspective of Stackelberg game, that is, how to allocate the limited security inspection resources more reasonably in each link of defense to reduce the losses caused by the attackers (terrorists) illegally implanting explosive weapons and dangerous chemicals into the express packages.

2 Basic hypothesis of the model

Express delivery companies (defenders) and terrorists (attackers) constitute a classic Stackelberg game model. In this model, the defender first chooses the defense strategy, the attacker can observe the defender's security defense strategy, and then choose the weaker point to drop explosive weapons and dangerous chemicals. The goal of

terrorists is to maximize the damage caused by weapon implantation and the goal of the express company is to allocate limited defense resources reasonably to minimize the cost of each security level and the total loss caused by the attacker. Due to the relatively low security of traditional express security inspections that rely on manpower, X-ray security inspection equipment for mail is generally installed. Therefore, there are four different levels of security checks to verify the safety of express products (as shown in Figure 1). Among them, any security feature that is cracked can be used by terrorists to cause losses. Only the four layers of security measures can work together to achieve defense effect.

The first level of security inspection is physical manual security inspection. This method includes certain staff to unpack and inspect and cameras to monitor. However, due to the limitation of human resources and the effectiveness of the monitoring scope, the physical security inspection cannot cover each express package, and it cannot detect 100% of explosive weapons and hazardous chemicals. The second level of security inspection is sensor induction security inspection. Express parcels need to be transported through different stations through multiple modes of transportation (high-speed, rail, sea) from the sender to the final recipient so the installation of sensors (mail express X-ray machines) can screen out the dangerous goods at express transportation sites; the third level of security inspection is non-invasive security inspection when goods arrive at the distribution site of the final delivery city. Non-invasive security inspection equipment including handheld radioisotopes identification equipment, X-ray and gamma-ray security inspection; the fourth-level security inspection is the non-invasive security inspection at the recipient's delivery site, and the security inspection equipment is the same as the third-level equipment. Here, explosive weapons and hazardous chemicals are only considered when they are implanted at the site, and not implanted during transportation. If explosive weapons and hazardous chemicals are implanted at a site that is not detected by the physical and manual security inspection of the current site, then the physical security inspection of the future sites will not be able to detect them. Figure 1 shows the specific security inspection process that expresses delivery needs to go through during the transportation process and the probability of detecting terrorist implanted dangerous goods in each security inspection program.

Fig. 1 Diagram of the possibility of the anti-terrorism security check during delivery transportation

3 Scenario 1: Game analysis of a single express route

3.1 Single route game model

Table.1 parameters of the model

symbol	meaning
p_i	Probability that the defender will detect dangerous goods at the first level of security at i site
q	Probability that the defender will detect dangerous goods at the second level of security at i site
a	Probability of detecting dangerous goods through the third-level security inspection before reaching the final distribution site
b	Probability of detecting dangerous goods through the fourth-level security inspection at the shipping site before reaching the recipient
e	Economic losses caused by express mail explosion or hazardous chemical leakage
s	Probability of the attacker's successful remote manipulation of the explosion at the marketing(distribution) site
m	Probability of being attacked on the spot by the attacker after reaching the recipient
$c(p_i)$	Site i maintains the cost of the first-level security inspection, the technical parameter is α_i
$c(q)$	Site i maintains the cost of the first-level security inspection, the technical parameter is β
$c(a)$	Site i maintains the cost of the first-level security inspection, the technical parameter is κ
$c(b)$	Site i maintains the cost of the first-level security inspection, the technical parameter is λ
π_i	Probability of successful terrorist attack at i site.

Model parameter settings are shown in Table 1. Assuming that there is only one transportation route for express delivery in the city where the sender and recipient are located, and there are multiple sites on this route. These sites can be companies, express delivery truck warehouses, highway rest areas, and storage containers. These sites can be planted with explosive weapons and

dangerous chemicals by terrorists. Terrorism will choose the most vulnerable sites to implant explosive weapons and dangerous chemicals. Suppose the economic loss of the defender (courier company, etc.) after the explosion is e . For the convenience of analysis, suppose that the economic loss of the defender is the profit of the attacker. On this route, express delivery from site 1 to site n

recipients, site 1 to site $n-2$ can be courier companies, express delivery truck warehouses, highway rest areas, shipping terminals for storing containers, and $n-1$ and n respectively represent the distribution site and recipient of the final express delivery. Therefore, the attacker can choose any site from 1 to $n-1$ to implant explosive weapons and dangerous chemicals. If i' indicates the site where the attacker can implant weapons, then $i' \in (1, \dots, n-1)$. If it has not been detonated when it reaches the recipient, the attacker can also choose to attack on the spot. The specific line model diagram is shown in Fig. 2.

Fig.2 diagram of anti-terrorism security check of the single express line

In order to effectively prevent terrorist attacks during express delivery, the defender needs to conduct corresponding physical and manual security checks (first-level security checks) at each site, so the probability of a successful terrorist attack at site i is $\pi_i = 1 - p_i q a [(1-s)b + (1-s)(1-b)(1-m)]$. If other variables remain unchanged, if $p_u > p_v$, then $\pi_u < \pi_v$, that is, the higher detection rate p of a certain site in the first-level method corresponds to the lower probability of successful attack.

The relationship between the defense cost of the four-layer security check and the probability of successful detection meets the properties $c(0)=0$, $c' > 0$, $c'' > 0$ and $\lim_{x \rightarrow 1} c(x) = +\infty$. Refer to reference 18 and other related materials, the function form can be specifically set as:

$$c(p_i) = \frac{1}{(1-p_i)^{\alpha_i}} - 1, \quad c(q) = \frac{1}{(1-q)^{\beta}} - 1, \\ c(a) = \frac{1}{(1-a)^{\kappa}} - 1 \text{ and } c(b) = \frac{1}{(1-b)^{\lambda}} - 1.$$

3.2 Analysis of the defender's equilibrium

The best strategy for terrorists is to choose a certain site i' to attack to maximize their benefits:

$$U = \max_{i' \in (1, \dots, n-1)} \pi_{i'} e \quad (1)$$

Given the optimal strategy i' of the attacker, the expected cost of the defender is:

$$u(p_1, p_2, \dots, p_{n-1}, q, a, b) = \sum_{i=1}^{n-1} c(p_i) + c(q) + c(a) + c(b) + \pi_{i'} e \quad (2) \\ = \sum_{i=1}^{n-1} \frac{1}{(1-p_i)^{\alpha_i}} + \frac{1}{(1-q)^{\beta}} + \frac{1}{(1-a)^{\kappa}} + \frac{1}{(1-b)^{\lambda}} + \{1 - p_{i'} q a [(1-s)b + (1-s)(1-b)(1-m)]\} e - (n+2) \\ \text{s.t. } p_i \geq p_{i'}, \forall j \neq i', j \in (1, \dots, n-1)$$

Find the first derivative separately, get:

$$\frac{\partial u}{\partial p_j} = \alpha_j (1-p_j)^{-(\alpha_j+1)} \quad (3)$$

$$\frac{\partial u}{\partial p_{i'}} = \alpha_{i'} (1-p_{i'})^{-(\alpha_{i'}+1)} - q a [(1-s)b + (1-s)(1-b)(1-m)] e \quad (4)$$

$$\frac{\partial u}{\partial q} = \beta (1-q)^{-(\beta+1)} - p_{i'} a [(1-s)b + (1-s)(1-b)(1-m)] e$$

$$\frac{\partial u}{\partial a} = \kappa (1-a)^{-(\kappa+1)} - p_{i'} q [(1-s)b + (1-s)(1-b)(1-m)] e$$

$$\frac{\partial u}{\partial b} = \lambda (1-b)^{-(\lambda+1)} - p_{i'} q a (1-s) m e$$

Since the above-mentioned second-order derivatives are all greater than 0, and in the formula (3),

$$\frac{\partial u}{\partial p_j} = \alpha_j (1-p_j)^{-(\alpha_j+1)} > 0, \text{ and therefore the minimum}$$

cost of the defender is reached at the lower boundary point. According to the constraints, it can get: $p_j^* = p_{i'}$.

In order to analyze the equilibrium probability, let the first derivative of equation (4) be zero to obtain the minimum cost, we can get:

$$\alpha_{i'} (1-p_{i'}^*)^{-(\alpha_{i'}+1)} = q^* a^* [(1-s)b^* + (1-s)(1-b^*)(1-m)] e \quad (5)$$

$$\beta (1-q^*)^{-(\beta+1)} = p_{i'}^* a^* [(1-s)b^* + (1-s)(1-b^*)(1-m)] e \quad (6)$$

$$\kappa (1-a^*)^{-(\kappa+1)} = p_{i'}^* q^* [(1-s)b^* + (1-s)(1-b^*)(1-m)] e \quad (7)$$

$$\lambda (1-b^*)^{-(\lambda+1)} = p_{i'}^* q^* a^* (1-s) m e \quad (8)$$

After analysis of the above format, reducing s , the probability of successful terrorist attacks will help increase $p_{i'}^*$, the probability of physical manual security inspection, q^* , the second-level security inspection probability, and a^* , the third-level security inspection probability. According to formula (8), when the attacker's long-range explosive ability s is weak and the economic loss e increases, it will promote the improvement of the fourth layer of security b .

Proposition 1: In the Stackelberg model of anti-terrorism security check for express transportation on a single route, given i' , the optimal strategy of the attacker, the minimum expected cost of the express company (the defender) satisfies: $p_j^* = p_{i'}$

$$\lambda (1-b^*)^{-(\lambda+1)} = p_{i'}^* q^* a^* (1-s) m e$$

$$\alpha_{i'} p_{i'}^* (1-p_{i'}^*)^{-(\alpha_{i'}+1)} = \beta q^* (1-q^*)^{-(\beta+1)} = \kappa a^* (1-a^*)^{-(\kappa+1)}$$

Analyze the first condition $p_j^* = p_{i'}$, $\forall j = i', j \in (1, \dots, n-1)$: the courier company (defender) should deploy physical and manual (first level) security checks with the same security checks at each site before reaching the final recipient. Otherwise, if different security checks lead to different detection probabilities of dangerous goods, the attacker will choose to implant dangerous goods in the weakest link, which will increase the cost of the defender.

Analyze the second condition $\lambda (1-b^*)^{-(\lambda+1)} = p_{i'}^* q^* a^* (1-s) m e$: Under the circumstance that the probability of detecting dangerous goods at the first three levels of security inspection is

established, if s decreases, b^* will increase. In other words, when the attacker's long-range explosive ability is weak, the fourth-level security check should be strengthened, and the fourth-level security check should be appropriately increased. This can effectively reduce the loss of the attack; if m is increased, b^* will become bigger. In other words, when the success rate of terrorist attacks on the receiving site increases, the cost of the fourth level of security should be strengthened to prevent problems before they occur.

Analyzing the third condition $\alpha_i p_i^* (1 - p_i^*)^{-(\alpha_i+1)} = \beta q^* (1 - q^*)^{-(\beta+1)} = \kappa a^* (1 - a^*)^{-(\kappa+1)}$, the proof of this condition can be found in reference 18. It can be concluded that the defender should weigh the cost of security checks at the first, second, and third levels, and balance the costs of the first, second, and third levels can effectively increase the possibility of dangerous goods detection and reduce defense costs.

4 Scenario 2: Game analysis of multiple express routes

4.1 Flow chart of multiple express routes

A more common situation: express parcels can pass through different express routes to different distribution sites in the city where the final recipient is located. The

express company can choose one of the routes to reach its corresponding distribution site and then deliver it to the recipient. Therefore, the attacker can plant dangerous goods at any site, and the defender should consider setting up anti-terrorism security checks at all sites to detect the safety of express packages.

Suppose the courier chooses one of t final distribution sites to be delivered to the recipient, where i represents a certain distribution site $i \in (1, \dots, t)$, the i -th distribution site corresponds to $m(i)$ express lines, and (j, i) represents the j -th route of a distribution station, $i \in (1, \dots, t)$, $j \in \{1, \dots, m(i)\}$, k represents a station on a certain transportation route, $k \in (1, \dots, n)$. p_{kji} indicates the probability of detecting dangerous goods at the site (k, j, i) physical manual security inspection (first-level security inspection). When $k, j=0$, $p_{0,0,i}$ means the probability of detection of dangerous goods through the first-level security inspection at the final distribution point i . $c(p_{kji})$ represents the cost of the first-level security inspection, similarly, its function form is set as $c(p_{kji}) = \frac{1}{(1-p_{kji})^{\alpha_{kji}}} - 1$; the cost of the other three-level security inspection method is the same as the corresponding cost in a single line. The express flow chart of multiple routes is shown in Figure 4.

Fig. 4 Diagram of anti-terrorism security check of multiple express routes

4.2 Analysis of the defender's equilibrium

$$U = \max_{k \in (0, \dots, n), j \in \{0, \dots, m(i)\}, i \in (1, \dots, t)} \pi_{kji} e = \pi_{(k^0, j^0, i^0)} e \quad (9)$$

First analyze the profit of the attacker. Assuming that the proceeds of terrorist attacks at the site (k^0, j^0, i^0) are maximized: U . Given the optimal strategy of the attacker,

the expected cost of solving the defender is:

$$u(p_{kji}, q, a, b) = \sum_{i=1}^t \left(\sum_{j=0}^{m(i)} \sum_{k=0}^n \frac{1}{(1-p_{kji})^{\alpha_{kji}}} + \frac{1}{(1-a)^{\alpha}} \right) + \frac{1}{(1-q)^{\beta}} + \frac{1}{(1-b)^{\gamma}} + \pi_{(k^0, j^0, i^0)} e \quad (10)$$

$$= \sum_{i=1}^t \left(\sum_{j=0}^{m(i)} \sum_{k=0}^n \frac{1}{(1-p_{kji})^{\alpha_{kji}}} + \frac{1}{(1-a)^{\alpha}} \right) + \frac{1}{(1-q)^{\beta}} + \frac{1}{(1-b)^{\gamma}} + \left[1 - p_{k^0, j^0, i^0} q a_{k^0, j^0, i^0} [(1-s)b + (1-s)(1-b)(1-m)] \right] e - (n+1) \sum_{i=1}^t \{m(i), i\} - 2t - 1$$

$$s.t. \quad \pi_{k^0, j^0, i^0} \geq \pi_{kji}, \quad \forall (k, j, i) \neq (k^0, j^0, i^0), \quad i \in (1, \dots, t), \quad j \in \{0, \dots, m(i)\}, \quad k \in (0, \dots, n)$$

Find the first derivative of (10) expected cost:

$$\frac{\partial u}{\partial p_{kji}} = \alpha_{kji} (1 - p_{kji})^{-(\alpha_{kji}+1)} \quad (11)$$

$$\frac{\partial u}{\partial p_{k^0 j^0 i^0}} = \alpha_{k^0 j^0 i^0} (1 - p_{k^0 j^0 i^0})^{-(\alpha_{k^0 j^0 i^0}+1)} - q a_p [(1-s)b + (1-s)(1-b)(1-m)]e \quad (12)$$

$$\frac{\partial u}{\partial q} = \beta (1-q)^{-(\beta+1)} - p_{k^0 j^0 i^0} a_p [(1-s)b + (1-s)(1-b)(1-m)]e \quad (13)$$

$$\frac{\partial u}{\partial a_p} = \kappa (1-a_p)^{-(\kappa+1)} - p_{k^0 j^0 i^0} q [(1-s)b + (1-s)(1-b)(1-m)]e \quad (14)$$

$$\frac{\partial u}{\partial a_i} = \kappa (1-a_i)^{-(\kappa+1)} \quad (15)$$

$$\frac{\partial u}{\partial b} = \lambda (1-b)^{-(\lambda+1)} - p_{k^0 j^0 i^0} q a_{i^0} (1-s)me \quad (16)$$

From (13) the first derivative is equal to 0, the equilibrium solution $a_{i^0}^*$ can be obtained. According to equation (14), both the first and second derivatives are greater than 0, so the minimum value will be obtained at the lower boundary point $a_i^* = a_{i^0}^*$. According to (9) the maximization condition $\pi_{k^0 j^0 i^0} \geq \pi_{kji}$, $\forall (k, j, i) \neq (k^0, j^0, i^0)$, $i \in \{1, \dots, t\}$, $j \in \{0, \dots, m(i)\}$, $k \in \{0, \dots, n\}$ we can get $p_{kji}^* \geq p_{k^0 j^0 i^0}^*$, $p_{k^0 j^0 i^0}^* \geq p_{k^0 j^0 i^0}^*$, $p_{k^0 j^0 i^0}^* \geq p_{k^0 j^0 i^0}^*$.

Proposition 2: In the Stackelberg model of anti-terrorism security check for express transportation on multiple routes, given the optimal terrorist attack strategy (k^0, j^0, i^0) , the optimal strategy $(p_{k^0 j^0 i^0}^*, p_{kji}^*, q^*, a_{i^0}^*, a_i^*, b^*)$ of the defender satisfies the following conditions:

$$\alpha_{k^0 j^0 i^0} p_{k^0 j^0 i^0}^* (1 - p_{k^0 j^0 i^0}^*)^{-(\alpha_{k^0 j^0 i^0}+1)} = \beta q^* (1 - q^*)^{-(\beta+1)} = \kappa a_{i^0}^* (1 - a_{i^0}^*)^{-(\kappa+1)} \quad (17)$$

$$\lambda (1 - b^*)^{-(\lambda+1)} = p_{k^0 j^0 i^0}^* q^* a_{i^0}^* (1 - s)me \quad (18)$$

$$p_{kji}^* \geq p_{k^0 j^0 i^0}^*, p_{k^0 j^0 i^0}^* \geq p_{k^0 j^0 i^0}^*, p_{k^0 j^0 i^0}^* \geq p_{k^0 j^0 i^0}^* \quad (19)$$

$$a_{i^0}^* = a_i^* \quad (20)$$

According to formula (17), in the attack route chosen by the attacker, there is still a trade-off relationship between the defender's resource allocation between the first, second, and third-level security checks so as to avoid weak links being used by terrorists. From (19) and (20), a different conclusion can be drawn from a single express line: the first-level security check intensity of each line in multiple lines is not necessarily equal, and the terrorists implant dangerous goods to attack the line has the lowest detection probability and is therefore used by terrorists. However, in the case of loopholes in the physical manual security check (first-level security check), the optimal allocation of security check resources is to arrange the same non-intrusive check (third-level security check) intensity at the final distribution station on each route.

5 Conclusion

In recent years, with the rapid development of e-commerce and the Internet economy, express delivery industry has developed rapidly in China. Moreover, the express delivery industry plays an important role in driving the development of the service industry and increasing labor employment. However, the subsequent emergence of express transportation anti-terrorism security issues has become prominent, and the current domestic and foreign literature has not fully studied this issue. This article constructs a Stackelberg game model for the optimal allocation of anti-terrorism security inspection resources for express transportation. It discusses the performance of express companies (defenders) in physical manual security inspections, sensor induction security inspections, and final distribution sites for single and multiple routes. The non-invasive security method, the non-invasive security method before delivery by the courier to the recipient, and the optimal resource allocation of the four-tier anti-terrorism security check.

The results of this paper show that for a single express route, the express company should balance the cost of physical manual security, sensor sensing security, and non-intrusive security at the final distribution site to improve the anti-terrorism defense system; at the same time, deploy the same security check for each site physical labor (the first level) security check. For multiple express delivery routes, the physical artificial security check probability of the line where terrorists implanted dangerous goods attacked is the lowest, which is used by terrorists. However, in the case of loopholes in the physical manual security check (the first-level security check), the optimal allocation of security check resources is that the final distribution site on each route is a non-intrusive security check method (the third level) with the same security check intensity. In a single line or multiple lines, when the attacker's ability to remotely explode is weak and the success rate of terrorist attacks at the recipient's receiving site increases, the non-invasive inspection of the delivery site of the courier should be increased to reduce economic losses caused by terrorist attacks.

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