Optimization Techniques for Baggage and Cargo Screening

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Introduction

- Problem Statement
  - Over 10 million cargo containers and 100 million items of baggage enter the U.S. each year. Manual inspection of each container and item of baggage is not feasible; automated inspection systems using various sensors must be used. How do we locate the best inspection strategy for an automated screening system?

- Problem Motivation
  - The huge volume of containers and baggage entering the US provides an ideal environment for terrorists. There have been a number of terrorist plots to smuggle bombs onboard an aircraft as air cargo with the goal of destroying the aircraft and creating mass causalities. It is also known that terrorists are actively trying to acquire weapons of mass destruction. The U.S. government is aware of these threats and has passed various regulations requiring that all baggage and containers entering the U.S. be screened, however the volume of items makes this a difficult task.
Rise of Containerized Shipping

– Before the 1950's, almost all non-bulk goods were shipped via “break-bulk”, where each item was placed individually into the hold of a ship.

– Break-bulk shipping was slow and expensive; goods often spent more time at the dock than on a ship.

– In 1950's several pioneering companies started using intermodal containers for shipping against stiff government and union resistance.

– Containers greatly reduced times and costs to load and unload ship (cost is less than 1/30 of break bulk).

– Currently 90% of non-bulk cargo is carried in shipping containers.

– Container traffic is forecasted to increase as cost drop due to continued technical improvements (larger more efficient ships, better logistics at dockside)
Rise of Air Traffic and Cargo

– Regular aircraft passenger service started in 1914, while air mail started in 1918, however the volume of cargo and passengers was tiny until aircraft improvements in 1930’s.

– First airliner was Boeing 247 introduced in 1933. First bombing of aircraft (a Boeing 247) occurs in same year.

– Capability of aircraft grew quickly during 1930’s – 1950’s spurred by war and national defense.

– Introduction of jet engines and avionics led to boom in air transport in 1950’s and 1960’s

– Containerized air cargo introduced in 1960’s


– Air traffic and aircraft size continue to grow, leading to new logistical and security concerns.
Dr. David Rapoport postulated that the modern world has seen four waves of terror: anarchists, anti-colonialists, new left and religious. We are now in the religious wave of terrorism.

The religious wave of terrorism started with overthrow of shah of Iran by a theocracy in 1979 and Russian war in Afghanistan started in same year.

Religious wave is primarily fundamentals Islamic terrorists, however Christians, Sikhs and cults such as Aum Shinrikyo in Japan are active.

Bombing is primary modus operandi, with many groups seeking to acquire weapons of mass destruction. Goal is massive damage against target group.

Terrorists are fanatical and creative, constantly seeking ways to exploit any weakness in defenses.
Government Response (1 of 2)

– Every act of terror generates a government response, often disproportionate to actual threat.
– US government is limited in actions by public opinion and rule of law.
– Passenger and baggage screening began in early 1970’s in response to hijackings. High profile aircraft bombings in 1980’s lead to increased security.
– September 11, 2001 attacks were game changing. US declared “war on terror”.
– Legislation formed department of homeland security and created initiatives such as “Aviation and Transportation Security Act”, “Intelligence Reform and Terrorism Prevention Act of 2004 “ and “Implementing Recommendations of the 9/11 Commission Act of 2007”
- Reactions to terrorism have been a learning process, and have caused hardship and confusion.

- Currently have a robust legal framework in place for fighting terrorism, however implementing that framework has been a challenge.

- Initiatives have been delayed because logistics and technology could not meet goals.

- Larger problem is terrorists are innovators, with governments reacting to new threat. Proactive defense is difficult.
Radiographic inspection (X-ray, gamma ray)
- Provides a detailed view of the contents. Dual energy machines provide an estimate of atomic number of contents.

Neutron based inspection
- Identify outline and composition of material in container. Can create secondary reactions in nuclear material. Expensive and hazardous, can damage cargo.

Passive radiation detectors
- Cost effective, fast, can be automated. More complex equipment can determine type of radioactive material. Can be defeated by shielding.

Sniffer dogs
- Cost effective robust and portable. Trained to detect one set of scents. Fatigues, requires breaks and constant retraining.
– Air sampling explosives detection system
  
  • Air is drawn from around or inside a bag or container and analyzed for explosives using gas chromatography, mass spectrometry or Ion mobility spectrometry. Very sensitive (parts per billion). Can be defeated by hermetically sealing explosive device. PETN has very low vapor pressure, making its detection difficult.

– Swab based explosives detection system
  
  • A swab is run across the surface of suspected of having explosives, then heated to release any trapped explosive particles. Gas is analyzed in the same manner as air sampling explosives detection system.
Review of Baggage Screening

- Screening stations must check 100s of bags per hour. Cost, throughput and detection rate are key metrics.

- Small size of baggage and need for low cost, high throughput screening promotes simple inspection strategies. Typical inspection strategy illustrated below:

  ![Diagram](attachment:image.png)

  - Simplicity of inspection strategy allows for complete evaluation of search space. Research focused on life cycle cost model.

  - Partitioning passengers and baggage into risk groups was active research area, however legal and political pressure prevents implementing such a system.
Review of Cargo Inspection

- Cargo containers are large metal boxes which could be holding almost anything. Inspection is much more complex than baggage screening.

- Cost and detection rate are key metric. Throughput, radiation exposure, etc are important but secondary considerations.

- Primary focus has been radiological contraband for nuclear weapon or dirty bomb.

- Almost all inspection strategies have been based on binary decision trees.

- Inspection strategies too complex for brute force search. Evolutionary algorithms or dynamic programming used.
• My research addresses the following open issues in optimizing the inspection process:
  – How can genetic algorithms be employed to optimize the inspection process for cargo containers, baggage and passengers?
  – How can the inspection process be optimized to detect two different types of contraband?
  – Are there alternative approaches to traditional binary decision tree based inspection strategies that might provide better performance?
• Initial research involved using a genetic algorithm to optimize cargo container inspection for radiological contraband

• Inspection process was modeled as a binary decision tree
Inspection Optimization via GA (2 of 2)

- Optimizer used three nested GA

- Optimizer located inspection strategies with lower costs than previously published work
• optimize cargo container inspection process for detecting and classifying two types of contraband (explosives and radioactive materials)

• Extend sensor model and classifiers to encompass two contraband types

• Radiation detectors and ETD only detect one type of contraband, ignoring the other type

**Container Types**

- \(\emptyset\) = container not holding any contraband
- \(A\) = container holding explosives (contraband A)
- \(B\) = container holding radioactive material (contraband B)
- \(A+B\) = container holding both contraband A and B

**Classification Types**

- \(\checkmark\) = container properly classified
- \(\times\) = container incorrectly classified
- \(?\) = container classification unknown
• X-ray and neutron inspection systems can detect both types of contraband, although at different sensitivities

• It is assumed that one type of contraband does not interfere with detection of the other type.
Dual Contraband Inspection (3 of 3)

- Decision trees located for dual contraband were much more complicated than the trees for single type of contraband.
• Decision tree based inspection strategies have a number of limitations
  – Binary decision trees do not capture all the possible actions
  – It is difficult to incorporate outside knowledge, such as overall threat level or the country of origin into a decision tree based inspection strategy
  – Decision tree based inspection strategies are inefficient in that the information gathered at an inspection station is used to make a binary decision. Much of the information is lost after the decision is made

• Is there a better way?
• Humans are (fairly) good at making choices about the disposition of an object or situation often using noisy or conflicting data (is this food safe to eat? is this a dangerous situation)

• Humans (generally) do not use a decision tree for making their choices. Instead they form beliefs and make choices based on those beliefs.

• Simple belief based inspection model:
  - Abstract belief to a scalar value
  1. Start with a bias based on outside knowledge
  2. Take action based on belief
     a. Inspect using a sensor (if available)
     b. Let object pass inspection
     c. Manually inspect object
  3. If “inspect with a sensor”, update belief and go to step 2
• How do we calculate belief based on sensor reading?

• Define $H_0$ as area under upper tail of noise distribution and $H_1$ as area under lower tail of signal distribution. Let $\Delta b$ be change in belief from sensor reading. Also define two weighting factors $W_a$ and $W_b$.

\[
\Delta b = W_a \left( \frac{W_b H_1 - H_0}{H_0 + H_1} \right)
\]
• Level of belief changes based on results of each inspection. Let $b$ be level of belief prior to inspection and $b'$ level of belief after inspection.

$$b' = b + \Delta b$$

• Classifiers can be defined based on level of belief
In two examples taken from open literature, belief based inspection performed better than decision tree inspection.

Baggage screening example

![Binary tree topology](image1) ![Ternary/belief topology](image2)

Belief Based Inspection (5 of 6)
Belief Based Inspection (6 of 6)

- Passenger screening example

![Binary tree topology vs. ternary/belief topology](image)

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<th>Detection Rate (%)</th>
<th>Cost ($)</th>
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<td>75</td>
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<td>95</td>
<td>0.80</td>
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• Results – used to provide evidence about the effectiveness of the methods presented.
  – A description of an example must be given followed by the results or findings obtained from the proposed method.
  – If the research builds upon previous work, the results or findings obtained should be compared with these other methods.
Conclusions/Future Research

• Evolutionary algorithms can locate better solutions than other methods presented in open literature
  – Web based computing makes EA optimization fast and cost effective.

• Belief based inspection strategies provide better solutions than decision tree based inspection strategies.
  – New area of research plenty of work left to do.
  – Not just for contraband inspection, can perhaps be applied to any field where decision trees are used.
  – Is this a game changer?
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<td>Optimization of container inspection strategy via a genetic algorithm</td>
<td>Annals of Operations Research</td>
<td>Published February 2010</td>
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<tr>
<td>Belief based Optimization of Inspection Strategies</td>
<td>IIE Transactions</td>
<td>May 2012</td>
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