Passenger Screening Strategies in Aviation Security: New Directions*

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BACKGROUND AND MOTIVATION

- The Transportation Security Administration (TSA) is revising the Computer-aided Passenger Prescreening System, called CAPPS II, to systematically differentiate between low and high risk passengers.
- The development and need for CAPPS II suggests that
  - Good strategies for dividing passengers into groups is useful.
  - Good screening strategies are needed for each such group.
- When can one assert that an aviation security strategy is "good"?

OBJECTIVES

- Maximize security for a given budget by determining which passengers should be subjected to which type of screening.
- Evaluate the effectiveness of different classes of screening.
- Explore effectiveness of heuristic solution approach.

DEFINITIONS

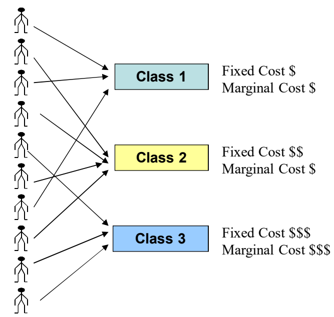
- A device is a process, consisting of personnel and/or aviation security technology, used to identify a threat to the system.
- A class is a specified subset of devices and procedures used to screen passengers/baggage prior to boarding an aircraft.
- The cost factors associated with a class include:
  - fixed costs (FC): purchase or overhead costs for using a class,
  - marginal cost (MC): direct cost for class to screen passengers/ baggage.
- Each passenger's risk level is quantified as an assessed threat (AT) value. This value is between zero and one, where values closer to one correspond to riskier passengers.

PERFORMANCE MEASURES

- The Security Level for the system or device is the *true alarm* P(A|T)
  - Alarm response for a threat item.
- False clear P(NA|T)
  - Clear response with a threat item
  - P(A|T) + P(NA|T) = 1.
- False alarm P(A|NT)
  - Alarm response with a non-threat item.
- These values are determined by
  - Types of technology deployed.
  - How technologies/information are used (procedural).

MULTILEVEL BUDGET ALLOCATION PROBLEM (MBAP)

- How should N passengers be assigned to M classes such that the overall security level is maximized, subject to a budget constraint?



SOLUTIONS

- What do solutions tell us?
  - How to assign passengers to classes.
  - Which specified classes to use / not to use.
  - System security level
    - Computed as the sum of the products of the individual security levels and risk levels of the classes.
    - The risk level of each class is a function of the set of passengers (and their assessed threat values) assigned to that class.
  - How the budget should be allocated for purchasing and maintaining equipment.
    - Devices associated with non-empty classes are purchased / maintained.

SCENARIO PARAMETERS

- Number of classes.
- Number of passengers.
- Two sets of assessed threat value distributions.
  - Passengers are indistinguishable (identical assessed threat values).
  - Passengers are distinguishable, with truncated exponential assessed threat values between 0 and 1 (i.e., 80% of passengers having an assessed threat value less than 0.2).

NUMBER OF PASSENGERS

- Data extracted from the Official Airline Guide (OAG)
  - Considers a set of domestic flights from a single airline carrier (UAL) at a major US airport (ORD).
- Assumptions
  - Passengers arrive uniformly between 30 and 90 minutes before their scheduled departure time.
  - Enplanement rate is 80%.
  - Use peak traffic volume.
    - Number of passengers: 1230, 3690, 6200

DEVICE DATA

Device Type	False Clear	Fixed Costs*	Marginal Cost ($)	Units/ hour
Explosive Detection System (EDS)	0.12	0.4167	1.00	125
Open Bag Trace (OT)	0.15	0.1199	0.83	28
Metal Detector (MD)	0.30	0.0051	0.28	90
Hand Wand Inspection (HW)	0.20	0.0009	1.25	20
X-ray Machine (XR)	0.20	0.0720	0.28	90
Detailed Hand Search (DHS)	0.20	0.0	1.25	20
Open Bag Trace with Detailed Hand Search (ODHS)	0.15	0.1199	1.29	18

* Fixed costs normalized per passenger per unit time

CLASSES

- A class is a set of devices along with a procedure designating how passengers are screened.
  - All passengers are screened by all devices associated with the class they are assigned to.
- The security level for each class is measured by the overall true alarm of that class.
  - Function of false clear for the devices.
  - Assume that each passenger has one checked bag and one carry-on bag.
  - Assume that a threat is equally likely to be detected in a checked bag, in a carry-on bag, or directly on the passenger.
  - A threat is detected if *any device gives an alarm response*. For example, if a bomb is in a checked bag, the threat is detected if any of the checked baggage screening devices give an alarm response.
- Number of classes: 3, 5, 8.

THREE SPECIFIED CLASSES

Class	Devices			FC	FC	FC	MC	Security
	Checked	Passenger	Carry-on	N=1230	N=3690	N=6200	($)	Level
1	EDS	MD	XR	67.49	202.47	340.19	1.56	0.793
2	EDS	MD, HW	XR, ODHS	67.62	202.85	340.83	2.81	0.927
3	EDS, OT	MD, HW	XR, ODHS	93.10	279.30	469.29	4.93	0.964

FIVE SPECIFIED CLASSES

Class	Devices			FC	FC	FC	MC	Security
	Checked	Passenger	Carry-on	N=1230	N=3690	N=6200	($)	Level
1		MD	XR	18.48	56.94	95.68	0.56	0.500
2	EDS	MD	XR	121.48	364.44	612.35	1.56	0.793
3	EDS	MD	XR, DHS	121.48	364.44	612.35	2.81	0.847
4	OT	MD, HW	XR, DHS	48.70	146.10	245.47	2.64	0.917
5	EDS, OT	MD, HW	XR, ODHS	167.58	502.74	844.72	4.93	0.964

EIGHT SPECIFIED CLASSES

Class	Devices			FC	FC	FC	MC	Security
	Checked	Passenger	Carry-on	N=1230	N=3690	N=6200	($)	Level
1		MD	XR	23.73	71.18	119.60	0.56	0.500
2		MD, HW	XR	24.01	72.03	121.03	1.81	0.580
3	EDS	MD	XR	151.85	455.56	765.43	1.56	0.793
4	EDS	MD	XR, DHS	151.85	455.56	765.43	2.81	0.847
5	EDS	MD	XR, ODHS	152.14	456.41	766.87	2.81	0.873
6	OT	MD, HW	XR, DHS	60.87	182.62	306.84	3.89	0.917
7	OT	MD, HW	XR, ODHS	81.35	244.05	410.06	3.93	0.920
8	EDS, OT	MD, HW	XR, ODHS	209.48	628.43	1055.90	4.93	0.964

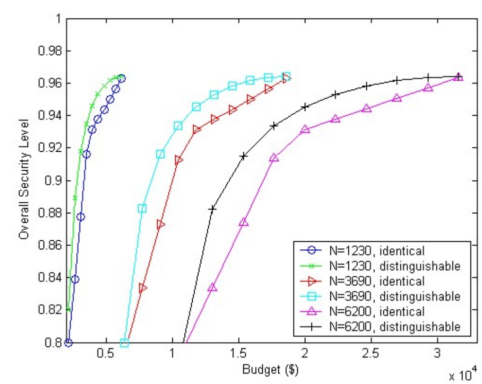
DESIGN OF SCENARIOS

- A total of 180 scenarios are considered:
  - 18 sets of scenarios
    - 3 sets of classes (3, 5, 8)
    - 3 sets of passengers (1230, 3690, 6200)
    - 2 assessed threat value distributions
  - For each set, a range of 10 budgets are considered
    - $800 (5 classes, N=1230) to $31,500 (8 classes, N=6200)
  - Total number of scenarios = 2*3*3*10 = 180.
- Computing Information
  - Run on Pentium III 550 MHz processor with 1048 MB of RAM.
  - Time measured in CPU seconds.

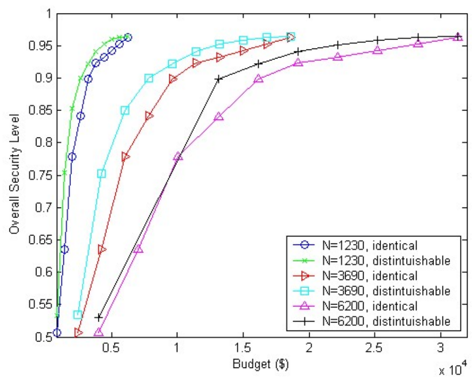
OPTIMAL SOLUTIONS

- All scenarios were formulated as integer programming models and solved using commercial software (CPLEX).
  - Time limit of 170,000 CPU seconds (~2 days).
  - All sixty 3-class scenarios were solved to optimality.
  - Two of sixty 5-class scenarios did not finish.
  - Ten of sixty 8-class scenarios did not finish.

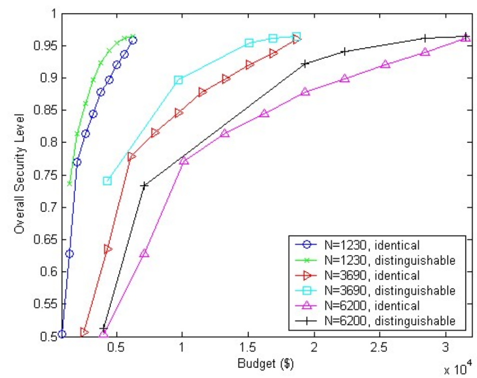
OPTIMAL VALUES FOR THREE CLASS SCENARIOS



OPTIMAL VALUES FOR FIVE CLASS SCENARIOS



OPTIMAL VALUES FOR EIGHT CLASS SCENARIOS



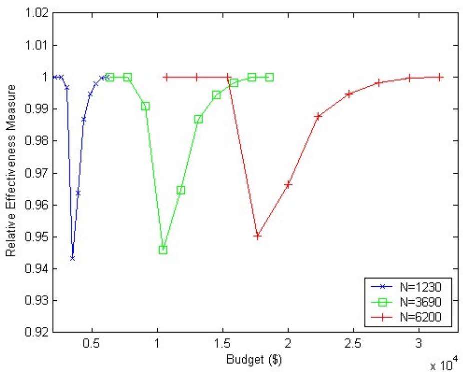
ALGORITHM OBSERVATIONS

- Solving integer programming models provide optimal solutions, but this is inefficient for problems with many passengers and/or classes.
- Can a Greedy heuristic quickly find near-optimal solutions?

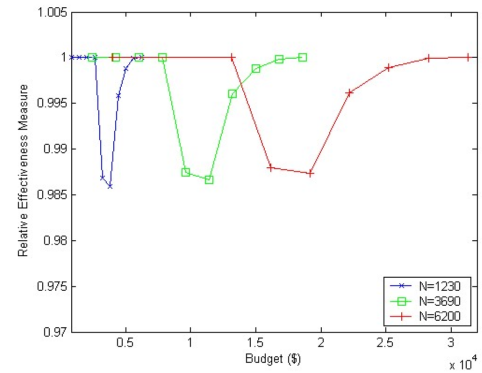
EFFECTIVENESS OF GREEDY HEURISTIC

- Greedy heuristic executes in less than 2 CPU seconds.
- Relative Effectiveness Measure (ρ)
  - Measures quality of solutions obtained by heuristic
  - $\rho = \dfrac{\text{Heuristic Value} - \text{Lowest Feasible Value}}{\text{Optimal Value} - \text{Lowest Feasible Value}}$
  - If ρ = 1: heuristic found optimal solution.
  - If ρ = 0: heuristic found worst possible solution.
- When passengers are identical, ρ = 1 for all scenarios
  - These cases are omitted from the following figures.

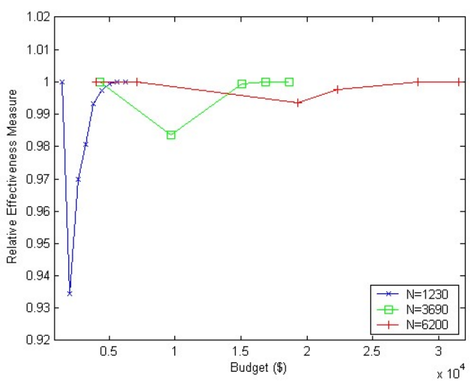
GREEDY HEURISTIC VALUES FOR THREE CLASS SCENARIOS



GREEDY HEURISTIC VALUES FOR FIVE CLASS SCENARIOS



GREEDY HEURISTIC VALUES FOR EIGHT CLASS SCENARIOS



COMPUTATION TIME RANGE

Passenger Type	Number of Classes	Range (s) N = 1230	Range (s) N = 3690	Range (s) N = 6200
Identical Passengers	3, optimality	[0.97, 1.3]	[0.97, 1.1]	[0.98 1.0]
	3, heuristic	[0.031, 0.047]	[0.079, 0.11]	[0.093, 0.19]
	5, optimality	[1.17, 1.18]	[1.17, 1.18]	[1.17, 1.18]
	5, heuristic	[0.078, 0.27]	[0.17, 0.77]	[0.11, 0.48]
	8, optimality	[1.17, 1.18]	[1.17, 1.18]	[1.17, 1.18]
	8, heuristic	[0.078, 0.27]	[0.17, 0.77]	[0.20, 1.2]
Distinguishable Passengers	3, optimality	[1.95, 18.9]	[8.4, 10.6]	[31.2, 226.5]
	3, heuristic	[0.031, 0.047]	[0.062, 0.11]	[0.093, 0.19]
	5, optimality	[6.1, 86200]	[14.9, 157700]	[35.7, 78600]
	5, heuristic	[0.031, 0.11]	[0.078, 0.28]	[0.094, 0.48]
	8, optimality	[7.4, 114600]	[35.6, 128000]	[57.9, 14400]
	8, heuristic	[0.062, 0.26]	[0.19, 0.76]	[0.20, 1.3]

- **Time measured in CPU seconds**
- **Considers only scenarios that were solved to optimality**

RESULTS

- Given two scenarios with the same number of passengers, the same number of classes, and the same budget allocation, those scenarios assuming *indistinguishable passengers* (i.e., the same assessed threat values) always have lower system security levels than those scenarios assuming *distinguishable passengers* (i.e., different assessed threat values) .
- Cost per person (for optimal solutions)
  - Ranges for overall security level of 90%
    - [$2.64, $3.64] for identical passengers
    - [$2.12, $2.78] for distinguishable passengers
  - Ranges for overall security level of 95%
    - [$4.31, $4.84] for identical passengers
    - [$3.44, $4.04] for distinguishable passengers

RESULTS

- When the passengers are indistinguishable, the Greedy heuristic always solves the MBAP to optimality.
  - Optimal solutions were obtained in under 2 CPU seconds.
  - The optimal passenger assignment used only two classes.
- When passengers were distinguishable (by assessed threat values)
  - Optimal solutions were obtained in between 2 CPU seconds and several CPU days!
  - The optimal solution never used more than three classes.
  - The Greedy heuristic's relative effectiveness measure was always greater than 0.935.

IMPLICATIONS OF RESULTS

- Differentiating Passengers Improves Security
  - Scenarios with distinguishable passengers always have higher security levels than scenarios with indistinguishable passengers, given the same budget level.
  - Practical Implications
    - The accuracy of CAPPS II in assessing passenger threat levels is a critical factor.
- Only a Few Classes are Needed
  - Optimal solutions never used more than 3 classes.
  - Practical Implications
    - Fewer devices to cross-train screeners to operate.
    - Fewer flow paths through the system reduces likelihood passenger taking wrong path (Intentionally or accidentally).
    - Less space needed for more devices.
- Work in Progress
  - Passengers arriving dynamically.
  - An alternative model, where classes are defined in terms of (already purchased) devices and their associated capacities.

QUESTIONS?