Optimization of an Airport Security Selectee Lane using Simulation

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MS Thesis Defense

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Introduction

- Aviation security system is critical
- 400 commercial airports and over 700 million passengers flying annually
- Various layers of defense
  - **passenger prescreening**
  - **passenger checkpoint screening**
  - intelligence inputs
  - checked baggage screening
  - air cargo screening
  - airport access control
  - airport perimeter security
  - in-flight security

- FAA - Federal Aviation Administration has been constantly implementing improvement measures
- 9/11 Attacks

- Research - effectiveness and efficiency of the aviation security system

Organization of the presentation

- Literature review – Selectee Lane
- Goals of the thesis
- Nie (2008) model
- Simulation Modeling
  - Framework
  - Modules
- Model Validation (Goal 1)
- Optimization approach using simulation (Goal 2)
- Trade-off between system performance parameters (Goal 3)
- Observations and Conclusions

Selectee lane

- Two lanes:
  - Normal
  - Selectee – which has enhanced scrutiny

- Selectee lane is not efficiently utilized because of the small number of passengers selected to go through it

- Passenger prescreening system (CAPPS*)
  - Classifies passengers into various risk classes
  - Current system assigns top *b* risk class passengers to selectee

**Computer-Aided Passenger Prescreening System*

Previous research – Nie (2008)

- Selectee lane queueing design model that leads to more efficient utilization of selectee lane resource
- Assumptions:
  - Passengers arrive via a time-homogeneous Poisson process
  - The queue reaches a steady state condition
- Model is used to generate an assignment matrix for arriving passengers
- Based on objective function that maximizes the passenger checkpoint screening system's probability of true alarm

Goals

- To conclusively evaluate the effectiveness Nie's model

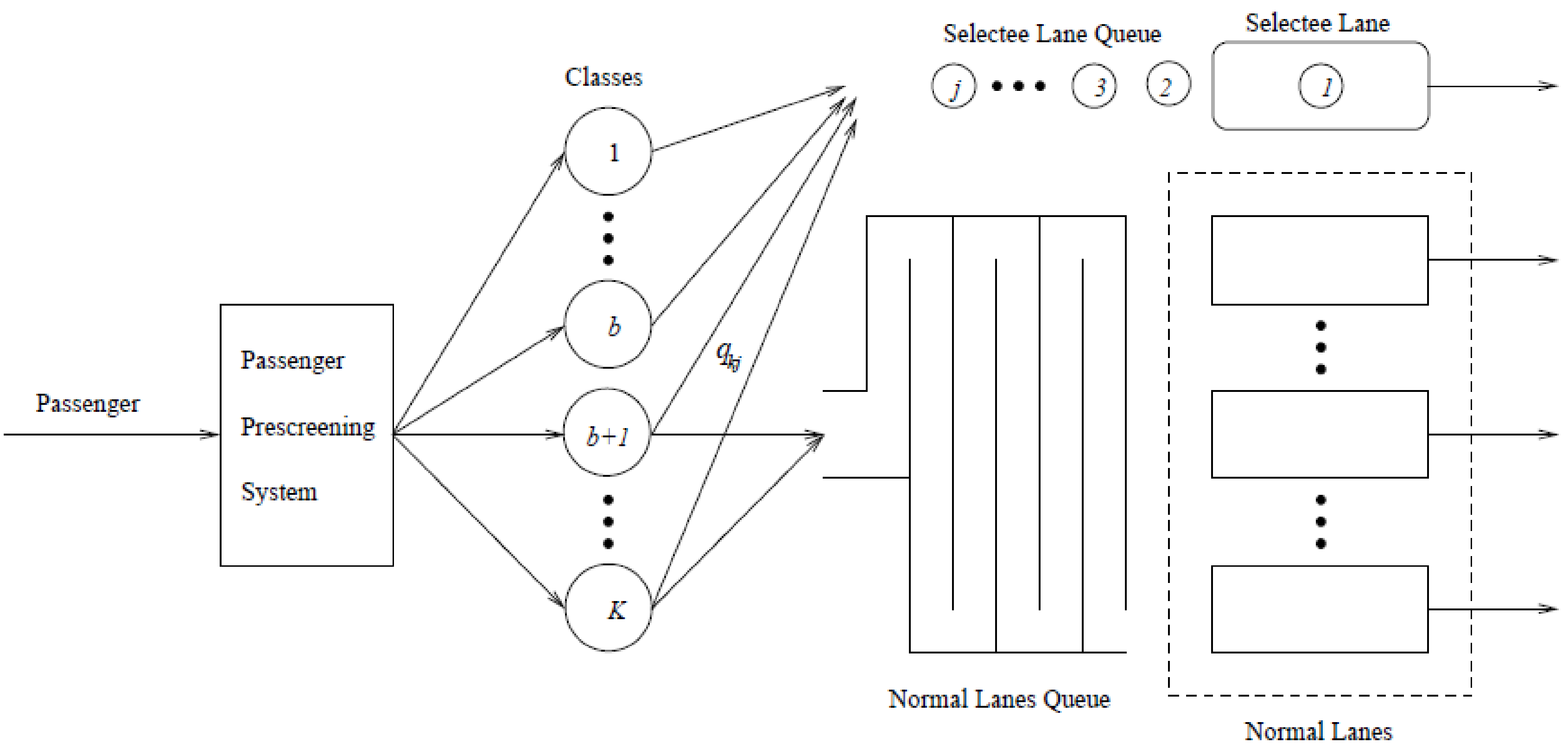
- To improve upon the assignment matrix

- To examine the tradeoff between the objectives of maximizing the **probability of true alarm *Pr* (TA)** and minimizing the **expected Time in System**

Selectee lane queueing design model (Nie, 2008)

- Parameters
  - K : number of risk classes (k – variable)
  - b : top risk classes that are assigned to selectee
  - $K - b$: remaining risk classes
  - α_k = Pr(a passenger carries a threat | he belongs to class k) thus $\alpha_1 > \ldots > \alpha_K$.
  - C : Capacity threshold (j – variable)
  - For $k \geq b + 1$ and $j \leq C - 1$, q_{kj} is a binary decision variable | $q_{kj} = 1$: assign selectee ; $q_{kj} = 0$: assign normal

Selectee lane queueing design model (Nie, 2008)



Selectee lane queueing design model (Nie, 2008)

- Other assumptions:
  - Screening time for one passenger in the selectee lane is random and exponentially distributed with rate μ
  - Normal lane is assumed to have infinite capacity
  - Selectee lane queueing system is modeled as a continuous-time Markov Chain with transition rates λ_j and μ
  - $\theta_S > \theta_{NS}$: Conditional probability of alarm given selectee or non-selectee

Selectee lane queueing design model (Nie, 2008)

Four possible outcomes:

- True Alarm (TA) – system gives an alarm and a threat exists;
- False Alarm (FA) – system gives an alarm but a threat does not exist;
- True Clear (TC) – system gives a clear signal and a threat does not exist;
- False Clear (FC) – system gives a clear signal but a threat exists.

Selectee lane queueing design model (Nie, 2008)

- Expression for *Pr* (TA) is developed and the problem is formulated as the following nonlinear binary integer program:

$$\text{Max } Pr\ (\text{TA})$$

$$\text{s.t. } q_{kj} \quad \{0, 1\},\ k = b + 1, \ldots , K,\ j = 0, \ldots , C - 1.$$

- For small-size problems, the optimal solution can be obtained via total enumeration, but for large-size problems, heuristic methods are proposed.

Output of the model (Nie, 2008)

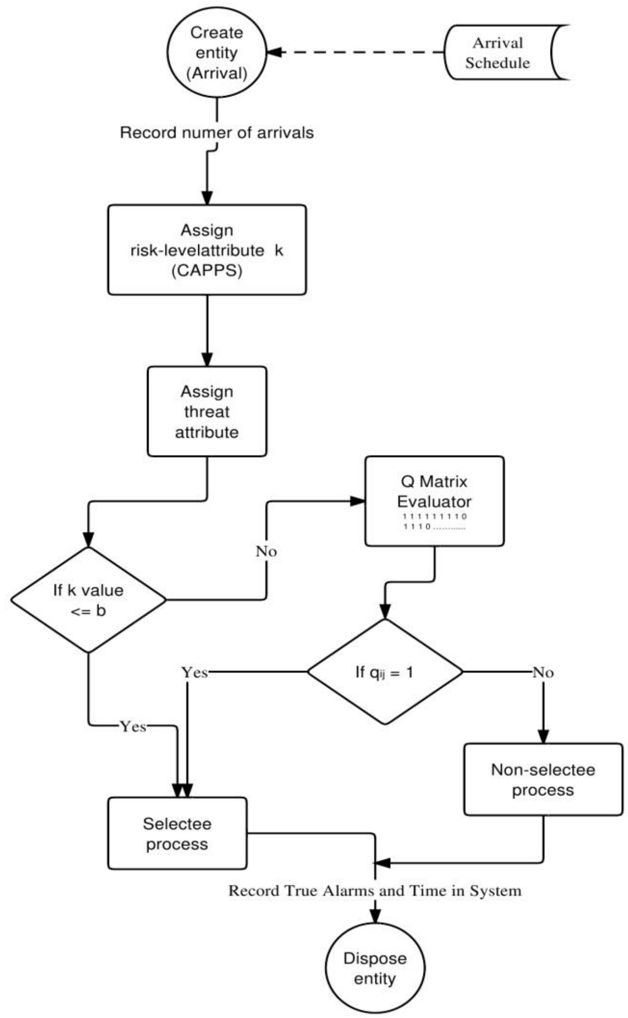
Q

$q_{1,0}$	$q_{1,1}$	$q_{1,2}$	$q_{1,3}$	$q_{1,4}$	$q_{1,5}$	$q_{1,6}$	$q_{1,7}$	$q_{1,8}$	$q_{1,9}$	$q_{1,10}$	$q_{1,11}$
$q_{2,0}$	$q_{2,1}$	$q_{2,2}$	$q_{2,3}$	$q_{2,4}$	$q_{2,5}$	$q_{2,6}$	$q_{2,7}$	$q_{2,8}$	$q_{2,9}$	$q_{2,10}$	$q_{2,11}$
$q_{3,0}$	$q_{3,1}$	$q_{3,2}$	$q_{3,3}$	$q_{3,4}$	$q_{3,5}$	$q_{3,6}$	$q_{3,7}$	$q_{3,8}$	$q_{3,9}$	$q_{3,10}$	$q_{3,11}$

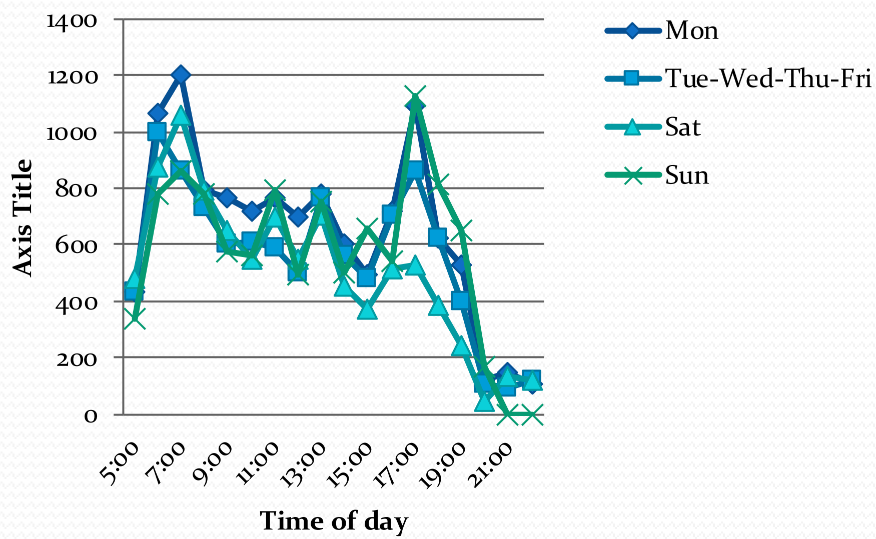
Development of simulation model

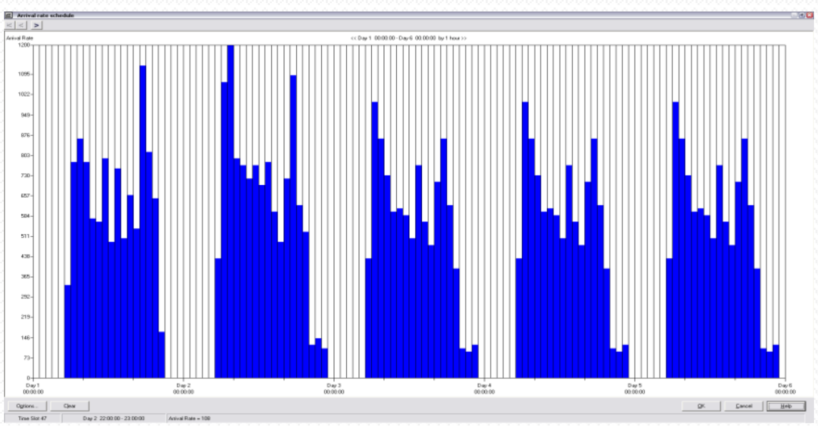
- The simulation model was developed based on realistic assumptions
- Parameter settings corresponding to mid-sized airport were used:
  - Number of risk levels, $K = 5$
  - Top risk levels, b = 2
  - Capacity threshold, C = 12
- The Q matrix is the input variable
  - Dimensions C x (k – b)

Development of simulation model



Passenger Arrival





Time	Mon	Tue-Wed-Thu-Fri	Sat	Sun
0:00	0	0	0	0
1:00	0	0	0	0
2:00	0	0	0	0
3:00	0	0	0	0
4:00	0	0	0	0
5:00	432	432	480	336
6:00	1068	996	876	780
7:00	1200	864	1056	864
8:00	792	732	792	780
9:00	768	600	648	576
10:00	720	612	552	564
11:00	768	588	696	792
12:00	696	504	552	492
13:00	780	768	708	756
14:00	600	564	456	504
15:00	492	480	372	660
16:00	720	708	516	540
17:00	1092	864	528	1128
18:00	624	624	384	816
19:00	528	396	240	648
20:00	120	108	48	168
21:00	144	96	132	0
22:00	108	120	120	0
23:00	0	0	0	0

Passenger arrivals

- NSExpo function is used
  - The distribution is used in situations where arrivals follow a Poisson process; however, the arrival rate varies over time in accordance with the defined schedule.
- Schedule is derived from Paul *et al*. (2007)

Assigning risk level attribute

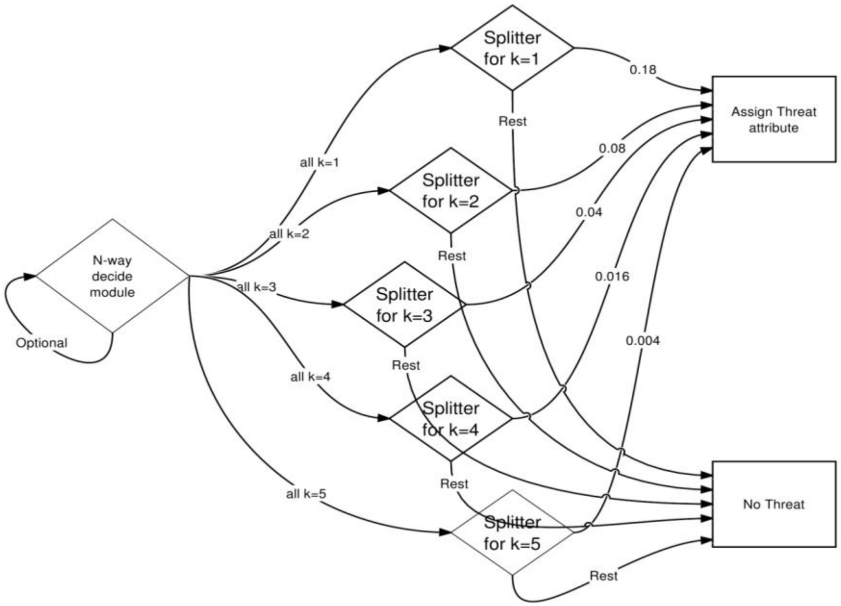
- This module represents the CAPPS
- Used to assign a risk level value of *k* from 1 to 5
- Assigned based on Discrete Probability Distribution using function DISC
- Operand array of values:

  (0.016666667,1, 0.083333333,2, 0.25,3, 0.5,4, 1,5) contains probability-value pairs

Risk level k	Average number of Arrivals	Cumulative probability
1	20	0.016666667
2	80	0.083333333
3	200	0.25
4	300	0.5
5	600	1

Assigning threat attribute

- The probability that a passenger carries a threat is approximately 0.021 for each possible K - by the Bureau of Transportation Statistics.



Risk level k	Probability
1	0.18
2	0.08
3	0.04
4	0.016
5	0.004

Allocation to Selectee or Non Selectee lane

- Top *b* class passengers are diverted to selectee using decision module
- Rest of the classes *K-b* are sent to Q assignment matrix evaluator that is 2-way by-condition module

Initial Values

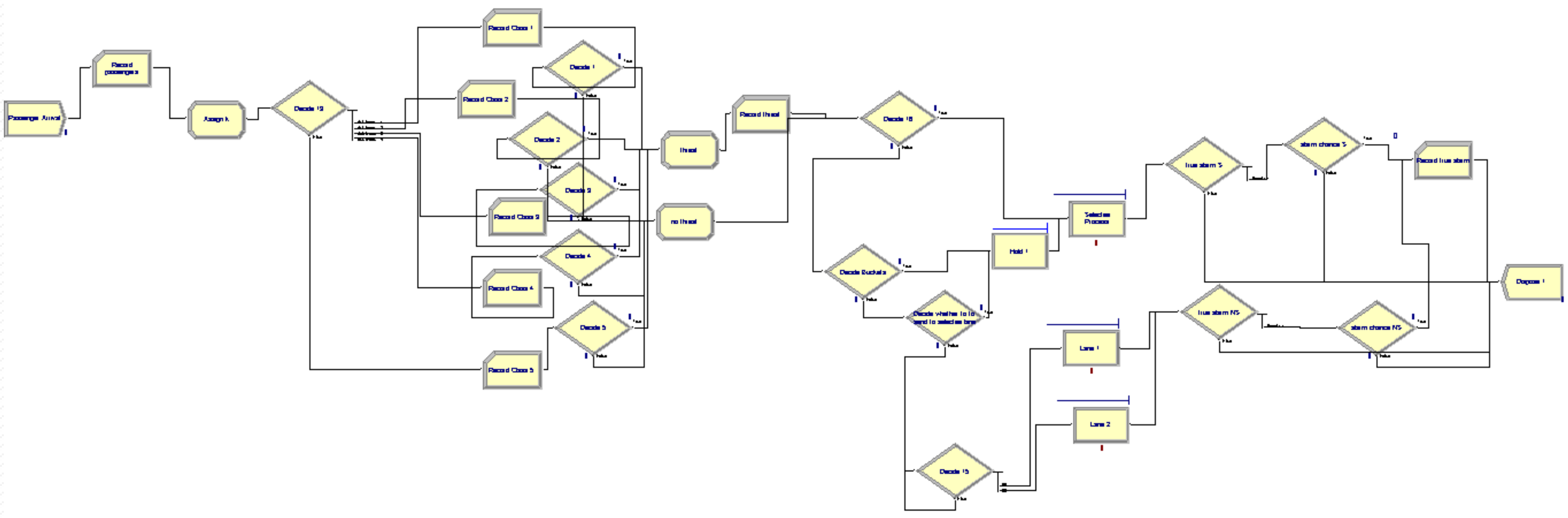
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	0	0
5	1	0	0	0	0	0	0	0	0	0	0	0

Alarm trigger

- The alarms from different resources are triggered with a conditional probability
  - 0.99 - selectee
  - 0.8 – non-selectee

- This is done using decide modules

Simulation modules



Recorded stats and runs

- Number of passenger arrivals
- Total true alarm triggers
- Time in system

- Stopping criteria: 5000 TAs
- Replications: 25

Goal 1

- To conclusively evaluate the effectiveness Nie's model
  - Selectee lane queuing design model heuristic is run using cpp program in Nie (2008); parameter settings are same as used in our simulation
  - Simulation model is then run using the parameter setting and Q matrix from Nie's model output
  - Values of True alarm probability obtained from both are compared
  - The corresponding probability of true alarm is 0.02027. If we run the simulation for the heuristic solution, the resulting probability of true alarm is 0.02022.

Goal 2

- To improve upon the assignment matrix
  - The solution obtained from Nie's model is assumed to be a good starting solution
  - Neighborhood change technique is used to generate multiple solutions and local search is conducted using simulation
  - This is carried out in 2 iterations
    - Iteration 1: 11 additional matrices are obtained from 1 starting matrix
    - Iteration 2: 18 additional matrices are obtained from top 3 performing solutions from Iteration 1 w.r.t. Pr(TA)

Properties of the Q matrix

- Elements are always binary numbers (0, 1)
- For a given row, 1s are clustered to the left and 0s to the right.
- The terminal 1s element for successive rows either ends at the same or lesser column than the row above it.
- Element $q_{k,0} = 1$ always; because passenger from any risk class k should be assigned to a selectee lane when there are 0 passengers in the selectee queue.

Neighborhood change technique

1

1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	0	0
1	0	0	0	0	0	0	0	0	0	0	0

2

1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	0
1	0	0	0	0	0	0	0	0	0	0	0

Iterations

Solution	Time (Sec)	*Pr* (TA)
Base (No Q Matrix)	53.91	0.01938
1	79.47	0.02022
2	81.00	0.02014
3	84.48	0.02019
4	81.61	**0.02023**
5	76.82	0.02022
6	80.07	**0.02025**
7	81.68	0.02004
8	83.47	0.02013
9	79.87	0.02020
10	81.01	0.02020
11	76.03	**0.02028**
12	77.86	0.02016

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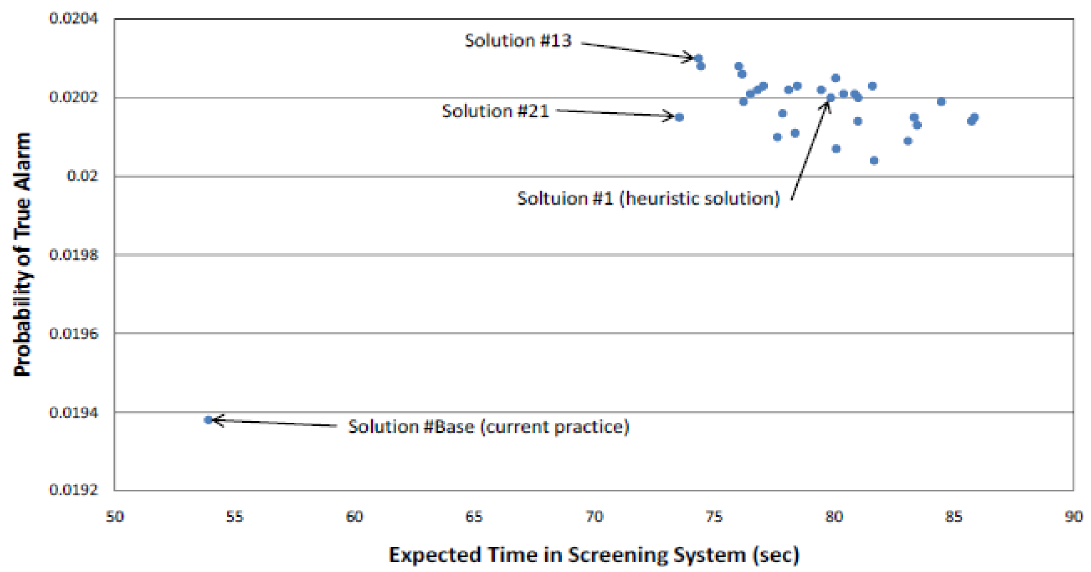
8	83.47	0.02013
9	79.87	0.02020
10	81.01	0.02020
11	76.03	0.02028
12	77.86	0.02016
13	74.35	0.02030
14	76.23	0.02019
15	74.45	0.02028
16	76.17	0.02026
17	76.52	0.02021
18	77.64	0.02010
19	78.38	0.02011
20	80.09	0.02007
21	73.55	0.02015
22	77.06	0.02023
23	83.35	0.02015
24	85.86	0.02015
25	80.87	0.02021
26	83.09	0.02009
27	85.74	0.02014
28	80.40	0.02021
29	78.47	0.02023
30	78.11	0.02022

Goal 3

- To examine the tradeoff between the objectives of maximizing the Pr (TA) and minimizing the expected Time in System



Results

- First, the simulation confirms that the Q matrix which is derived in the selectee lane queuing model does yield a significant improvement in true alarm probability.
- Second, through a neighborhood search technique around this Q matrix (evaluating each neighbor using simulation replications) we are able to significantly improve further upon the initial Q matrix.
- Third, we can also output through the simulation the average time in system for a passenger, and subsequently plot the average time in system versus true alarm probability for a variety of solutions. This yields a small set of non-dominated solutions.

Thank you