Feds with EDS: Searching for the Optimal Explosive Scanning System

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Summary

A May 2002 Transportation Security Administration (TSA) press release describes pilot testing of different baggage screening programs at three airports [Melendez 2002]. One airport used all Explosive Trace Detection (ETD) machines, one used all Explosive Detection System (EDS) machines, and a third airport used half and half. We show that these pilot tests were unnecessary.

We focus on maximization of productivity of the machines and of the amount of time they have to process the highest peak in checked bags. We show the importance of proper flight schedule planning and the ideal method for scheduling.

The implementation of the model's conclusions will save money in purchasing and installing machinery. Security will be paramount. Minimizing passenger inconvenience will be the secondary concern; but under our model, we eliminate, or at least minimize, expected delays.

By extending our model, we can also potentially find the optimal amount of time before takeoff when passengers should be required to arrive at the airport. To minimize cost, this time may need to be increased or decreased, depending on experimental data.

General Assumptions

- We assume all data as given on the problem statement.

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- Flight delays due to baggage inspection are unsatisfactory. However, a 15-minute delay is considered on time, according to FAA policy [Mead 2002].
- The percentage of planes that are cancelled before baggage is checked is negligible.
- There are no extreme unforeseen circumstances, e.g., striking workers that might affect baggage screening and flight departures.
- The number of passengers who check more than two bags is negligible.
- All airports have EDS or other scanning machines functional, so we do not need to rescan bags from connecting flights originating elsewhere.
- A system of bag queuing and prioritizing process is in place.
- Prioritizing negates the benefits of passengers arriving earlier than mandatory time.
- There is no significant delay in having to re-scan or hand-examine bags due to false positives.
- The throughput rate of bags per hour per EDS machine can be increased to 210 bags/h/machine by training the operators.
- We ignore the cost of repurchasing EDS or ETD machines due to defects and breakdowns. We also assume that performing scheduled maintenance on these machines reduces the chance of machine failure.
- We ignore potential lines at the airline check-in desk.

The Model

$$Q_{\text{EDS}} = \left\lceil \frac{\phi \displaystyle\sum_{i=1}^{8} (t_i n_i P_{\text{seats filled}_i})}{\Omega \ell (1 + \tau - \mu)} \right\rceil \tag{1}$$

where

Q_{EDS} = number of EDSs needed;

ℓ = throughput rate of each machine (bags/h/machine);

τ = minimum early passenger arrival time (h), i.e., how long before departure the airline closes bag check-in;

μ = travel time of one bag between EDS and the plane (h);

t_i = number of seats on flight of type i;

n_i = number of flights of type i during the peak hour;

$P_{\text{seats filled}_i}$ = estimated percentage of seats filled in flights of type i;

ϕ = summation shift constant, defined below;

Ω = percentage of time that the EDS is operational (given as 92%).

Derivation

We are dealing with a model of rates, such that B_{peak}, the number of bags in the peak hour, equals the rate of bags processed multiplied by the amount of time T. The rate of bags per hour depends on ℓ, the number of bags that one machine can process in one hour, times Q_{EDS}, the number of EDSs. We combine these equations and solve, getting

$$Q_{\text{EDS}} = \frac{B_{\text{peak}}}{\ell T}.$$

Since each EDS is operational only portion Ω of the time, we must discount the time by this constant, Ω, yielding

$$Q_{\text{EDS}} = \left\lceil \frac{B_{\text{peak}}}{\Omega \ell T} \right\rceil.$$

We add the ceiling brackets because the number of EDS must be whole. We now derive formulas for B_{peak} and T.

B_{peak}

The aggregate number B_{peak} of bags on one flight is the number of passengers times the average number of bags that each carries. The average number of bags per passenger, $\bar{b}$, is $b_1 + 2b_2$, where b_1 and b_2 are the proportions of passengers who check one bag and two bags, respectively.

The problem statement lists seating capacities of eight flight types, but the number of passengers per flight depends on the probability that those seats are filled, $P_{\text{seats filled}_i}$. By multiplying the number of bags on one flight, $\bar{b} t_i P_{\text{seats filled}_i}$, by the number of flights of the same type departing in the peak hour, n_i, we get the total number of bags on all flights of type i. By summing up all eight flight types, we arrive at

$$B_{\text{peak}} = \sum_{i=1}^{8} t_i P_{\text{seats filled}_i} \bar{b} n_i.$$

However, a couple of other factors need consideration.

Flight cancellations. The problem statement says that 2% of flights are cancelled daily. However, in our flying experiences, a flight is generally not cancelled until after the bags have been checked and the passengers are waiting at the gate or perhaps already on the flight. When forced to, airlines tend to delay flights as long as possible, canceling only after all other options have been exhausted. Thus, we assume that the cancellation of flights does not affect the number of checked bags to be scanned.

Connecting passengers. Since airports must scan all bags, and since typically the EDS machines are in the passenger check-in area, we assume that bags of connecting passengers do not need to be rescanned, in agreement with current FAA policy. We define the percentage of non-connecting passengers, i.e., those originating in our airport, as P_{orig}.

Including these factors, we get

$$B_{\text{peak}} = \sum_{i=1}^{8} t_i P_{\text{orig}} P_{\text{seats filled}_i} \bar{b} n_i.$$

Defining the summation shift constant $\phi = \bar{b} P_{\text{orig}}$, we have

$$B_{\text{peak}} = \phi \sum_{i=1}^{8} t_i P_{\text{seats filled}_i} n_i.$$

Substituting this into the formula for Q_{EDS}, we get

$$Q_{\text{EDS}} = \left\lceil \frac{\phi \sum_{i=1}^{8} (t_i n_i P_{\text{seats filled}_i})}{\Omega \ell T} \right\rceil,$$

with T yet to be shown to be $(1 + \tau - \mu)$.

The Cost Function Caveat

The ultimate goal is to minimize cost. This model's cost function (in thousands of dollars) for airport A is $Q_{\text{EDS}}(1100+\omega)$, and for airport B, $Q_{\text{EDS}}(1080+\omega)$, where ω is the operating cost per machine, and 1100 and 1080 are the costs to purchase and install the machines at each airport, according to data in the problem statement. To minimize cost, we minimize Q_{EDS}, either by reducing B_{peak}, increasing ℓ, or increasing T.

Minimizing B_{peak} would involve having passengers check fewer bags or else reducing the number of passengers flying during peak hour, via either flight cancellation or rescheduling to non-peak times. Flight cancellation would involve lower airline revenue and fewer choices of flights for consumers and is clearly undesirable. Rescheduling to non-peak times seemingly would be desirable; but surely the airlines and airports have already tackled this issue in the past, so further progress in rescheduling cannot be expected. Finally, requiring passengers to check fewer bags (which the threat of longer wait times might indirectly accomplish) would be unpopular; furthermore, merely suggesting passengers bring less checked luggage cannot be relied upon.

Maximizing ℓ, the number of bags per hour that each machine can process. We assume that the range between 160 and 210 depends on the competence of the operator. Thus, by instituting a more comprehensive and extensive training regimen, we can hope to increase ℓ. We also assume that the savings due to needing fewer machines outweigh the costs of increased training. Acknowledging that other factors could limit the machine's output, we estimate ℓ to be a modest 190 bags/hour/machine.

Maximizing T. All airlines have a time τ before departure after which a passenger may not check in and board. Taking into account data supplied in the problem statement, we have $\tau = 45$ min. By then, all bags will be present, so EDS operators can be guaranteed $\tau - \mu$ min to process bags for a flight, where μ is the time to load the bags onto the plane. As we have no data, we arbitrarily set $\mu = 6$ min, so EDS operators have at least 39 min (0.65 h) to process the bags. Our task is to maximize this amount of time.

If the peak hour were the only hour in which flights departed, EDS processing for peak hour can begin 45 min before the first flight, and the last bag of the last flight must finish being processed 6 min before the end of the hour. Thus, we have at most 1 h 39 min to process all of the bags. Therefore, the total time is $T = 1 + \tau - \mu$.

To use this maximum time interval best, we need a steady supply of bags coming in, to allow the machines to operate at maximum output for the entire time interval. As we will show, we can come close to a constant flow.

We now revoke the assumption that the peak hour is the only hour of flights. The bags in the hours immediately before and after peak, by definition fewer than B_{peak}, can be processed in less time than needed to process B_{peak}. When the peak hour's first bags arrive 45 min before the peak hour begins, we cannot yet assume that the EDSs will be available to process them, because flights departing during the hour before peak will have bags that still need to be processed. Similarly, we cannot assume that the EDSs can process our peak hour's bags all the way up to the last moment, since the bags of the next hour's first flight will likely require more than a few minutes to process. So, we should expect encroachments on the 1.65-hour maximum time interval. However, both the highest morning and evening peak hours are sufficiently greater in volume than the neighboring hours [Bureau of Transportation

Statistics n.d.], so we can operate at maximum time, 1.65 hours, without fear of other periods' effects. So, we define $T = (1 + \tau - \mu)$ and arrive at **(1)**.

Solving for the Optimal $Q_{\textbf{EDS}}$

Calculating $B_{\textbf{peak}}$

We examine each component of the equation

$$B_{\text{peak}} = \sum_{i=1}^{8} t_i n_i P_{\text{seats filled}_i} \bar{b} P_{\text{orig}}.$$

The problem statement tells us that 20% of passengers check no bags, 20% check just one bag, and 60% check two bags. So, the average number of bags per passenger is $\bar{b} = 1.4$.

Using the given proportions of seats filled for the various types of flights plus data from the T-100 Domestic Segment table in the Large Air Carriers database from the Intermodal Transportation Database [Bureau of Transportation Statistics n.d.], we calculate the averages for each flight type i:

$$P_{\text{seats filled}_i} = \begin{cases} .8679, & 1 \le i \le 3; \\ .8194, & 4 \le i \le 7; \\ .7705, & i = 8. \end{cases}$$

On average, 15% of passengers are from connecting flights, so $P_{\text{orig}} = .85$.

Our equation has now become

$$B_{\text{peak}} = (.85)(1.4) \sum_{i=1}^{8} t_i n_i P_{\text{seats filled}_i} = 1.19 \sum_{i=1}^{8} t_i n_i P_{\text{seats filled}_i}.$$

Substituting in the values for airports A and B for t_i and n_i (from the Technical Information Sheet) and our values for $P_{\text{seats filled}_i}$, we get

$$B_{\text{peak at A}} = 5286 \text{ bags}, \qquad B_{\text{peak at B}} = 5683 \text{ bags}.$$

Calculating $Q_{\textbf{EDS}}$

An EDS is operational $\Omega = 92\%$ of the time. We use $\ell = 190$ as an average value for the rate of bags per machine per hour. We have $\tau = 0.75$ h and $\mu = 0.1$ h. Using these values and the respective values of B_{peak} for each airport, we arrive at

$$Q_{\text{EDS for A}} = 19, \qquad Q_{\text{EDS for B}} = 20.$$

Exploring ϕ

During holidays, passengers are more likely to carry more bags. We examine the extreme of each passenger carrying two bags, which alters ϕ to 1.7. **Table 1** shows the effect on delays for airport A; results for airport B are similar.

Table 1.
Delays (in min) for airport A, for various machine speeds ℓ, values of ϕ, and proportions of seats filled. The value $\phi = 1.7$ corresponds to each passenger checking two bags.

ℓ	$\phi = 1.19$			$\phi = 1.7$		
	max	est.	min	max	est.	min
160	39	14	0	98	63	21
190	17	0	0	67	37	2
210	6	0	0	51	24	0

As expected, delays are greater when each passenger checks two bags. In addition, there will probably be more seats filled during this time period. However, since these busiest times of the year occur so rarely, we believe it is not worth buying extra machines to handle this overload. A possible solution to increased baggage is to turn to more temporary solutions, such as renting other portable screening devices or hiring extra workers or K-9 dogs.

In the worst-case scenario, on the busiest day of the year in airport A or B, when every flight in the peak hour is full, and the EDS is operating at its highest rate ($\ell = 210$), there will be only about 50 min of delay. We believe this is acceptable.

Scheduling Algorithm

We developed the following algorithm to schedule the departure of different flight types within the peak hour so that the number of passengers, and, consequently, the number of bags, is evenly distributed.

1. Obtain data on the number of flights and seats on each flight.

2. Modify the seat data to represent the average number of people on each flight. To do this, multiply by the estimated percentage of seats filled for the type of the given flight.

3. Calculate total number of people on all flights during the peak hour.

4. Determine the desired number of time intervals during the peak hour. We chose 6 as an appropriate number.

5. Determine the average number of people to fly during each time interval. Allocate that number of spaces for each interval, i.e. total number of people divided by 6.

6. Do the following n times (where n = total number of flights):
   (a) Find the flight with the most people on it.
   (b) Starting at the first interval, and searching sequentially through to the last, find the time interval with the most number of spaces still available.
   (c) Assign said flight to this time interval.
   (d) Subtract the number of available spaces by the number of people on said flight.
7. Make sure there is a flight at :00 and one at :59 to ensure the efficiency of our model, so as to maximize the time interval available for processing and allow the use of machines at full capacity. To do this:
   (a) For the first 30 minutes, start at the beginning of the time interval and evenly distribute the interval's assigned flights in order of decreasing flight capacity and increasing time.
   (b) For the second half hour, start at the end of the time interval (:39, for instance) and evenly distribute the interval's assigned flights in order of decreasing flight capacity and decreasing time.

Essentially, we are evenly distributing the flights scheduled in this peak hour among six 10-minute intervals. The flights were modified to represent the average number of passengers per flight, rather than the number of seats per flight, since the former has more impact on the number of bags scanned than the latter. The manner in which the flights are distributed among those intervals is analogous to filling a jar with different-sized rocks. Begin by adding the largest rocks, then smaller rocks, then pebbles, then sand, and finally water. With each additional step, you are filling in gaps. If you start with water and fill up the jar, then there is no room left for anything else. Thus, we start with the larger capacity flights and move our way down.

We wrote a computer program in C++ to implements the algorithm. [EDITOR'S NOTE: We omit the program code.]

Figure 1 shows the number of bags still left for the EDS to process at airport A after each minute in airport A, as a function of time, according to our algorithm. For airport B, the results are similar.

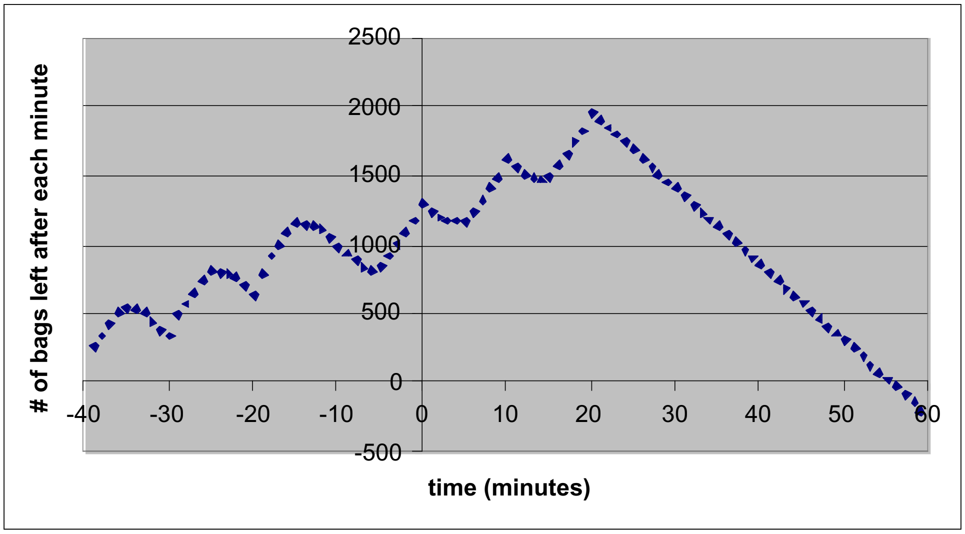

Figure 1. Bags left to process at airport A, as a function of time, according to the flight-distribution algorithm.

Cost Analysis of EDS and ETD

$$C(\alpha, \omega, Z) = B_{\text{peak}} \left(\frac{\alpha(1000 + c_i + \omega Z)}{\Omega_{\text{EDS}} \ell_{\text{EDS}} (1 + \tau - \mu)} + \frac{(1.2 - \alpha)(45 + 10\omega Z)}{\Omega_{\text{ETD}} \ell_{\text{ETD}} (1 + \tau - \mu)} \right)$$

where

C = total cost of recommended system;

$B_{\textbf{peak}}$ = total number of bags during the peak hour;

α = percentage of B_{peak} that the EDS will screen;

ω = hourly operational cost of EDS; cost of ETD machine is 10 times this amount;

Z = years

c_i = installation cost of EDS, dependent on airport (thousands of dollars);

ℓ = throughput rate of each machine (bags/h/machine);

Ω = percent of time that the machines are operational;

τ = minimum early passenger arrival time (h);

μ = travel time of one bag between EDS and the plane (h);

1000, 45 = cost of EDS and ETD machines, respectively (thousands of dollars).

We also assume that the installation cost of the ETDs is negligible.

Deriving the Model

By requiring that 20% of all bags be screened through both an EDS and an ETD machine, the effective number of bags to screen increases by 20%. The number of bags that go through the EDS, B_{EDS}, plus the number of bags that go through the ETD machine screening, B_{ETD} , must equal this effective number of bags. Therefore,

$$B_{\text{eff}} = 1.2B_{\text{peak}} = B_{\text{EDS}} + B_{\text{ETD}}.$$

The time to screen all these bags remains the same as in our previous model, and therefore τ and μ have the same values as given earlier. Likewise, the equation to determine the number of EDSs remains the same, and the number of ETD machines can be determined using the same equation with parameters for ETDs substituted.

Cost

The initial cost per machine equals the machine cost plus installation cost. EDSs are given as costing \$1 million, while ETD machines are only \$45K. Luckily, ETD machines are usually fairly small and portable, so their installation costs are assumed to be negligible. However, the installation cost of EDSs, c_i, is substantial: \$100K for airport A and \$80K for airport B. The annual variable cost of operating the machinery is ω for an EDS, 10ω for an ETD. We adopt a horizon of Z years.

The total cost C is the fixed cost plus the variable cost of each machine over the time horizon. All costs in the following equations are in thousands of dollars.

$$C(\omega, Z) = Q_{\text{EDS}}(1000 + c_i + \omega Z) + Q_{\text{ETD}}(45 + 10\omega Z).$$

Substituting, we get:

$$C(\omega, Z) = \frac{B_{\text{EDS}}(1000 + c_i + \omega Z)}{\Omega_{\text{EDS}}\ell_{\text{EDS}}(1 + \tau - \mu)} + \frac{B_{\text{ETD}}(45 + c_i + 10\omega Z)}{\Omega_{\text{ETD}}\ell_{\text{ETD}}(1 + \tau - \mu)}.$$

However, the number of bags going through each EDS is related to the number of bags going through each ETD machine. In addition, the number of bags going through each EDS is between 20% and 100% of the total number of peak-hour bags. We represent this relationship by the coefficient α, with $0.2 \le \alpha \le 1$.

$$B_{\text{EDS}} = \alpha B_{\text{peak}}.$$

Substituting into the cost equation, we are left with

$$C(\alpha, \omega, Z) = B_{\text{peak}} \left(\frac{\alpha(1000 + c_i + \omega Z)}{\Omega_{\text{EDS}}\ell_{\text{EDS}}(1 + \tau - \mu)} + \frac{(1.2 - \alpha)(45 + 10\omega Z)}{\Omega_{\text{ETD}}\ell_{\text{ETD}}(1 + \tau - \mu)} \right).$$

Using Maple, we plot C as a function of α and keep ω constant at an arbitrary \$50K. We can see in **Figure 2** that after various number of years, the cost of the machine can significantly depend on the number of bags that go through each machine, which depends on α.

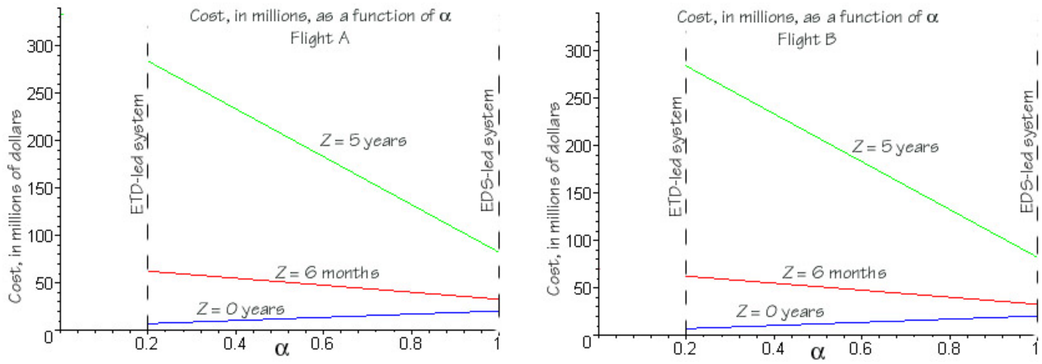

Figure 2. Costs over various time horizons for airports A and B.

For any α, the function C is linear in Z. Except for the particular Z value that makes the slope 0, only 0.2 and 1—the extreme values for α—can yield minimum values for C. This means that there are two significant cases to study:

- the EDS-led system, in which EDSs are the first tier of baggage scanning, processing 100% of the bags, and ETD machines are the fail-safe, scanning 20% of the bags; or else, vice versa,
- the ETD-led system, in which ETD machines process 100% and the EDSs scan 20%.

We show later that the case of α between these two extremes is undesirable.

Installing an ETD-led system (i.e., $\alpha = 0.2$) would be cost-effective only for a very short time horizon of a few months. This makes sense since the installation cost of an all-EDS system is very expensive, while the total of the high variable cost of operating the ETD machines is low over a short duration. However, after a few months, it is optimal to have $\alpha = 1$, or an EDS-led system, since this has minimum cost in the long run. The graphs assume that the cost of operation of the EDS is $\omega = \$50$K per year, which may or may not be realistic. A different value of ω will affect the slopes of the hs, thereby affecting when $\alpha = 1$ becomes optimal. Therefore, by finding where the derivative of the cost function is zero, we can find the critical turning point for our model at any ω, such that after this time, an EDS-led system would be more desirable. We have

$$\frac{\partial}{\partial\alpha}C(\alpha,\omega,Z) = B_{\text{peak}}\left(\frac{1000 + c_i + \omega Z}{\Omega_{\text{EDS}}\ell_{\text{EDS}}(1+\tau-\mu)} - \frac{45 + 10\omega Z}{\Omega_{\text{ETD}}\ell_{\text{ETD}}(1+\tau-\mu)}\right).$$

Setting this expression equal to 0 and solving for Z, we find

$$Z(\omega) = \frac{1}{\omega}\left(\frac{45\Omega_{\text{EDS}}\ell_{\text{EDS}} - (1000 + c_i)\Omega_{\text{ETD}}\ell_{\text{ETD}}}{\Omega_{\text{ETD}}\ell_{\text{ETD}} - 10\Omega_{\text{EDS}}\ell_{\text{EDS}}}\right).$$

Notice that Z is inversely related to ω. Also, B_{peak} and $(1+\tau-\mu)$ cancel out, thereby not influencing the critical cutoff time. Therefore, the only difference between airports A and B is the installation cost, which is unnoticeable when plotted. Therefore, just for airport A, we plot Z as a function of ω in **Figure 3**.

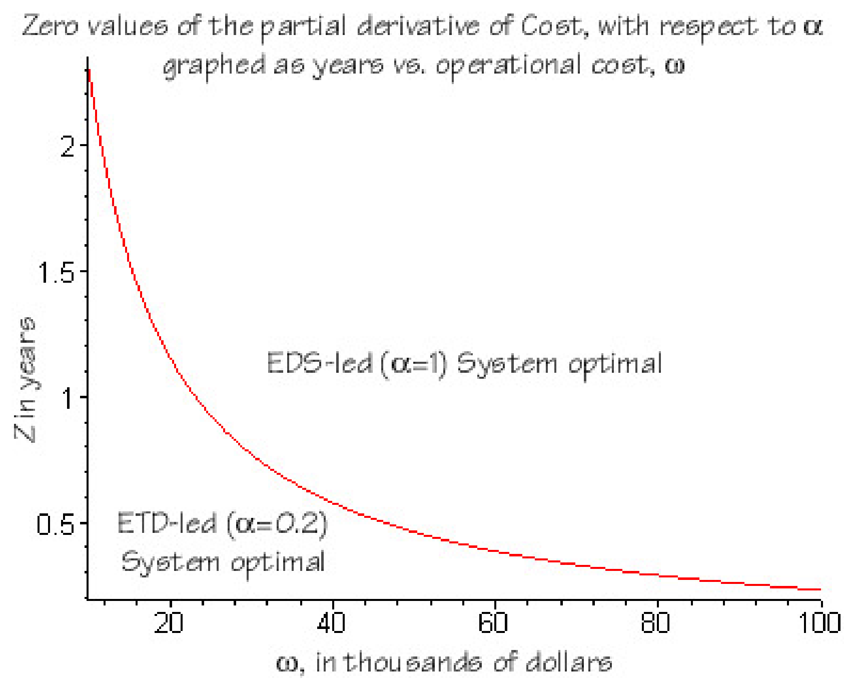

Figure 3. Time to equal cumulative cost as a function of annual operation cost of an EDS.

For (ω, Z) combinations below the curve, an ETD-led system is more cost-efficient; however, the operational cost of each machine will be high enough to make an EDS-led system cheaper in less than one year. Given not only a life expectancy of EDSs around 10 years but also bureaucratic inertia, we cannot expect the EDS-ETD system baggage inspection system to be replaced soon enough so that an ETD-led system will minimize costs. An EDS-led system is more desirable

Even though ETD machines become quite expensive after a short amount of time because of high operational cost, the low fixed cost might come in handy during the peak hours of peak times of the year. It would not be cost-efficient to buy extra EDSs just to handle these periods, but airports could buy extra ETD machines and store them until needed.

Determining Q_{EDS} and Q_{ETD}

We have determined that 100% of the bags should go through an EDS. We can calculate the total number of machines to buy by plugging the numbers into our initial equations:

$$Q_{\text{EDS}} = \frac{\alpha B_{\text{peak}}}{\Omega_{\text{EDS}}\ell_{\text{EDS}}(1+\tau-\mu)}, \qquad Q_{\text{ETD}} = \frac{(1.2-\alpha)B_{\text{peak}}}{\Omega_{\text{ETD}}\ell_{\text{ETD}}(1+\tau-\mu)}.$$

We estimate $\ell_{\text{ETD}} = 47$ bags/hour/machine, the average throughput rate of the ETD machines at the Winter Olympics in 2002 [Butler and Poole 2002]. The other constants have the same values as we used in our earlier model:

$$\begin{aligned} B_{\text{peak at A}} &= 5286, & B_{\text{peak at B}} &= 5683 \\ \ell_{\text{EDS}} &= 190, & \ell_{\text{ETD}} &= 47 \\ \Omega_{\text{EDS}} &= .92, & \Omega_{\text{ETD}} &= .98 \\ \tau &= .75, & \mu &= 0.1 \end{aligned}$$

Using these values, we find

$$\begin{aligned} Q_{\text{EDS}\,A} &= \lceil 18.33 \rceil = 19, & Q_{\text{EDS}\,B} &= \lceil 19.70 \rceil = 20; \\ Q_{\text{ETD}\,A} &= \lceil 13.91 \rceil = 14, & Q_{\text{ETD}\,B} &= \lceil 14.96 \rceil = 15. \end{aligned}$$

As expected, the EDS values for both airports are unchanged from our previous results, when we had not yet considered the ETD machines.

Recommendations for the Future

Although an EDS-led system, with merely enough ETD machines to cover 20% of the bags, is optimal based on our calculations, it might not be the absolute best solution. An important consideration is whether or not new technology might replace the machines before the critical cutoff time. For example, if current technology trends show that a better baggage screening system will be ready in less than a year, it might be worth taking the risk and buying an ETD-led system. Then, within the year, buy the better machines, with lower operational costs, that can replace the ETD machines. However, not only would this save very little, but this is quite a risk to take since your operational cost for the ETD machines will hurt the airport terribly if better technology does not come out in time. Therefore, our model shows that unless current trends show an immediate market introduction of new and advanced technology,

the best solution is to have all bags screened by EDSs and only 20% screened by ETDs

Down the road, however, we may need to re-evaluate the system.

Other variables that we should weigh heavily are the false positive rate, the false negative rate, and the human reliability factor. The false positive rate and the false negative rate should both be kept as low as possible, but it is more important that the false negative rate be extremely close to 0, as this affects the accuracy of the machine, while the false positive rate merely affects the efficiency of the machine. Increased precision would not only increase the safety of our air traffic system but also reduce the number of secondary, fail-safe screening devices, thus saving money. Currently, EDSs are widely reported to have between 22% and 30% false positive rates, which is ridiculously high.

New technology seems to be decreasing significantly this inefficiency, which will result in less required re-screenings and human intervention. A machine with high false negatives used as a first-tier scanner (as in the EDS in the EDS-led system) is very dangerous, and to counter the threat of explosives slipping through, costly random screening of negatives with a second device will be needed, though still not eliminating the said threat.

Conclusion: Strengths and Weaknesses

The main strength of our model is that the number of EDS machines it projects will work well even if some assumed constants and probabilities shift. More accurate statistical data, as should be available to airport administrators, would yield a more accurate optimal number of machines needed. The delays caused by fluctuations in assumptions are, under most every case, within acceptable ranges for delay, i.e., delays for other reasons happening at the same time. If this model is implemented, it should be stressed that the system is designed so that no extra delays should be expected. If this argument is sold to the people convincingly enough, instances of delay should not make passengers more likely to blame the EDS system over other causes for delay, such as waiting for connecting passengers, bad weather, or mechanical difficulties. Extreme circumstances, such as holiday travel days, normally force delays; any delay in the EDS system on such a day, if not compensated with temporary ETD machines, would run parallel to—not in addition to—delays already occurring. Besides, air travelers will be willing to wait a few extra minutes occasionally if it gives them a sense of security that many lacked following September 11.

One weakness of our model is that we did not go into different methods for implementing the prioritization and queuing regime for bags entering the explosives scanners. We considered several options. The tags placed on the bags at the check-in desk could list departure time, thus allowing easy sorting. This, however, does not allow for changes in departure time due to delays. A departure-listing screen, like those posted throughout the airports for passengers, could be displayed by the EDS machines. This list will be very long at a large airport, though, and would require EDS operators to recheck the display frequently.

Another weakness is that we ignored the placement of the EDS machines. Most EDSs are placed in the airport lobby near the check-in area. In a large airport, this could mean that the machines are spread out over a large area. So, the EDS machines could not work together like one unit, as our model implicitly assumes. This would mean a loss of efficiency: machines at one end of the airport could run out of bags while those at the other end could have too many. This problem could be remedied in the flight scheduling process, factoring in airline check-in desk placement in the even distribution of bags over the hour. The scope of that undertaking is far outside what we can accomplish here, though it ultimately deserves consideration.

References

Bureau of Transportation Statistics. n.d. Intermodal Transportation Database. http://transtats.bts.gov/DL_SelectFields.asp?Table_ID=236 and Table_ID=259. Accessed 10 February 2003.

Butler, Viggo, and Robert W. Poole, Jr. 2002. Rethinking checked baggage screening. July 2002. Los Angeles, CA: Reason Public Policy Institute. http://www.rppi.org/baggagescreening.html . Accessed 10 February 2003.

Gozani, Tsahi. 2002. Hearing on role of military research and development programs in homeland security. 12 Mar 2002. United States House of Representatives, Committee on Armed Services, Subcommittee on Military Research and Development. http://www-hoover.stanford.edu/research/conferences/nsf02/gozani2.pdf . Accessed 10 February 2003.

International Security Systems (subsidiary of Analogic Corporation). n.d. The EXACT: EXplosive Assessment Computed Tomography, features and specifications. http://www.analogic.com/Images/EXACT.pdf . Accessed 10 February 2003.

Johnson, Alex. 2002. Full bag scanning may be years away. 26 March 2002. MSNBC. http://www.msnbc.com/news/726695.asp?cp1=1 . Accessed 10 February 2003.

L.E.K. Consulting. 2000. Report on aviation congestion issues. Traffic Capacity Forum. Auckland (New Zealand): 16 Mar 2000. http://www.comcom.govt.nz/price/Airfield/isubs_27_04_01/Wellington/Appendix_6(c).pdf . Accessed 10 February 2003.

Mead, Kenneth M. 2002. Challenges facing TSA in implementing the Aviation and Transportation Security Act. United States House of Representatives, Committee on Transportation and Infrastructure, Subcommittee on Aviation. 23 Jan 2002. http://www.tsa.dot.gov/interweb/assetlibrary/Challenges_Facing_TSA_in_Implementing_the_Aviation_and_Transportation_Security_Act.pdf . Accessed 10 February 2003.

Melendez , Nico. 2002. Under Secretary Magaw announces explosive detection pilot programs to enhance aviation security. 20 May 2002. Transportation Security Administration. http://www.tsa.gov/public/display?content=84 . Accessed 10 February 2003.

Sharkey, Joe. 2002 The lull before the storm for the nation's airports. *New York Times* (19 November 2002). http://www.nytimes.com/ref/open/biztravel/19ROAD-OPEN.html . Accessed 10 February 2003.

Stoller, Gary. 2002. Flight check-in times vary among airlines, airports. *USA Today* (27 May 2002). http://www.usatoday.com/money/biztravel/2002-05-28-checkin.htm . Accessed 10 February 2003.

Successful baggage screening relies on human factors. 2002. *California Aviation* (27 March 2002). `http://archives.californiaaviation.org/airport/msg20658.html` . Accessed 10 February 2003.

Zoellner, Tom. 2002. Airport bomb scanning tab high. *Arizona Republic* (24 April 2002). `http://www.arizonarepublic.com/special42/articles/0424bombscan24.html` . Accessed 10 February 2003.