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RAND

Safer Skies

Baggage Screening and Beyond

With Supporting Analyses

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National Security Research Division

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Preface

This paper is the result of an examination of plans for implementing explosive detection systems for checked baggage at all U.S. airports, and it contains suggested changes to the existing plans for implementation of the systems.

The work was funded by RAND’s independent research and development funds. It should be of interest to those concerned about whether the Federal Aviation Administration’s (FAA’s) plans (now part of the Aviation and Transportation Security Act) appropriately respond to the security threats against our air transportation system. It should also interest those who wish to better understand how to address the natural tension between unfettered access to our commercial aircraft and enhanced transportation security. The research and the writing of this paper were completed in March 2002, and hence it does not reflect subsequent developments in this field. Its publication serves to document RAND’s approach to this problem as well as its analytical findings.

This study was conducted by RAND as part of its continuing program of self-sponsored research. We acknowledge the support for such research provided by the independent research and development provisions of RAND's contracts for the operation of its Department of Defense federally funded research and development centers: Project AIR FORCE (sponsored by the U.S. Air Force), the Arroyo Center (sponsored by the U.S. Army), and the National Defense Research Institute (sponsored by the Office of the Secretary of Defense, the Joint Staff, the unified commands, and the defense agencies).

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On November 19, 2001, Congress passed the Aviation and Transportation Security Act.[1] The legislation highlights the importance of baggage screening as part of a comprehensive program to increase airport security. Specifically, it mandates that by December 31, 2002, 100 percent of checked baggage at all the nation's airports must be screened for explosives. RAND examined existing plans for implementing explosive detection systems (EDSs) for checked baggage at all airports in the United States and suggested changes that might be advisable.

An EDS is a very large scanning machine that uses magnetic resonance imaging (MRI) technology to generate three-dimensional images of the contents of individual bags.[2] EDS machines are expensive and take up a great deal of room. While our study was in progress, the newly created Transportation Security Administration (TSA) became interested in the possible use of explosive trace detection (ETD) machines, which "sniff" molecules that adhere to a swab run over the surface of a piece of baggage. ETD machines are less expensive and take up less room than EDS machines do, but they are less sensitive and less accurate in detecting explosive materials. To achieve detection rates comparable to those for EDS machines, samples must be taken from inside each bag. We also evaluated the use of ETD machines, applying the same methodology we applied to the EDS machines. Recently, it has been suggested that, while all bags will be scanned, only some of them will be (randomly) selected to be subject to the full ETD screening. While this selectivity may help increase safety while easing delays, it does not change our basic conclusions or recommendations.

The Importance of Getting It Right

In 2001, 710 million passengers traveled on civil airliners in the United States. For these passengers, baggage screening is a necessary part of an overall plan for airport and airline security. History has shown, however, that passengers want security without having to undergo substantial inconvenience. Since

[1]Public Law No. 107-71.

[2]MRI is the technology that generates CAT (computerized axial tomography) scanner images of the human body.

September 11, TV news programs have shown airline passengers who profess to be willing to endure any inconvenience in the name of security. But these programs have not shown the many people who have decided not to fly because of long and intrusive security procedures. Congress passed the Aviation and Transportation Security Act partly out of fear that the public would lose confidence in the safety of flight and thus would cease flying altogether. The remedy for that fear—baggage screening, together with enhanced passenger screening—should not make flying so onerous as to produce the same result.

An analysis of the cost of providing security without massively inconveniencing the flying public suggests that this cost is small compared with the losses commercial aviation will suffer if potential passengers elect not to fly. Some people, especially those who fly infrequently, will tolerate substantial delays at airports if they think that real security is the result. But those for whom time is valuable and who may have a reasonable alternative to commercial air travel are considerably less likely to fly in such circumstances. Substantial loss of these travelers would seriously harm the aviation industry—and the nation's economy. Thus the cost of "getting it right" in terms of balancing security needs against inconvenience would be more than compensated by the financial returns resulting from a stronger national economy.

RAND's Approach

Before September 11, the Federal Aviation Administration (FAA) planned to deploy EDS machines nationwide using a government-imposed, "top-down" approach whereby the federal government would provide EDS machines to individual airports. This initial plan, which was not coordinated with individual carriers or the airports where the equipment would be installed, called for deployment by 2013. After September 11, the FAA advanced that date to 2005 and prepared a deployment plan showing how the new timeline might be met. Federal legislation spurred by the terrorist attacks on September 11 then called for a further compression of the FAA's schedule, and machines for screening 100 percent of checked baggage were to be deployed by December 2002. Again, the approach was top-down and did not incorporate input from air carriers or local airports.

To determine the feasibility of this deployment schedule, we examined the FAA's analysis to better understand the calculations and assumptions that supported both the 2005 and the new deployment schedule. We also visited two major airports: Dulles International (Washington, D.C.) and Dallas–Fort Worth. At Dulles, we examined the process that airports and airlines would have to go through to meet the 2002 deployment deadline. At Dallas–Fort Worth, we discussed the possible EDS deployments with officials of a major national airline and a team of independent experts in the analysis and design of airport facilities. We then built a simple queuing model to test the assumptions and robustness of the FAA projections of the number of machines that would be needed to screen 100 percent of checked baggage at all airports.[3]

Problems with the Federal Legislation

Our analysis revealed that the FAA's 2005 deployment plan was not based on an adequate assessment of the consequences of fielding an effective baggage screening system of the sort envisioned by Congress. For example, the plan did not adequately account for the demands that peak loads place on the baggage handling system, nor did it account for the actual performance and reliability of machines already deployed. Moreover, it was not clear how the available EDS equipment would be allocated among the various airports or what metric was to be used to ensure that the national aviation transportation system was running effectively. Most important, however, the deployment plan did not consider the severe space constraints that airports would have to overcome if they were to field all the new EDS equipment needed to screen every bag.

We identified six main problems with the deployment schedule set out in the Aviation and Transportation Security Act:

1. A rudimentary queuing model showed that the FAA estimate of the number of EDS machines needed to screen 100 percent of checked baggage for the major airports was too low by a factor of about 2.5.
2. The allocation of EDS equipment to the nation's airports has not been tested against a model of the national transportation system to ensure that bottlenecks will not develop during the implementation period or that the requirements of the hub system can be met.
3. Most disturbing, a top-down analytic approach is inappropriate for conducting a thorough analysis of the requirements for solving the

[3] See Appendix A for a quantitative assessment of potential delays in baggage handling and their sensitivity to the number of machines deployed, level of demand, machine reliability, and other factors.

problems of airport baggage screening. A more appropriate approach—one that has been used by a number of airports in planning the design of new terminals—is a stochastic simulation incorporating a realistic and detailed representation of the movement of passengers and baggage through the airport.[4] Indeed, simulations already exist for 24 of the 25 largest airports. The stochastic simulations we examined, which were provided by the TransSolutions Corporation, showed how critical each airport's design is to the number and placement of EDS machines at that airport. Each of the 453 commercial airports in the United States presents a unique challenge to baggage system designers.

4. Although the FAA did initiate a "go-team" to determine what could be done to increase the number of approved EDS machines, the deployment plan does not take into account the ability of industry to produce FAA-certified machines.
5. The FAA's "top-down" approach does not adequately consider local constraints, such as the size of the airport terminal. It is space constraints, not machine availability, that is the proverbial long pole in the tent. Until suitable airport facilities are constructed, many of the EDS machines now being acquired at a highly accelerated rate cannot be installed.
6. The shortcomings of deploying EDS machines also hold for ETD machines. While the latter are much smaller than EDS machines, they are also less reliable in detecting bombs. Tests show that for ETD machines to achieve results that even roughly approximate those provided by EDS machines, trace samples must be taken from inside each bag. The process of opening every bag and taking multiple samples from each also requires additional airport floor space—space that might not be available at some airports without additional construction. Use of the ETD machine would likely also increase processing times. In sum, ETD machines will not likely provide an easy answer.

We concluded that the deployment plan proposed in the Aviation and Transportation Security Act for EDS machines, particularly because of its top-down orientation, was not workable and that replacing EDS with ETD machines will not eliminate the problem. However, a number of steps can be taken to improve system performance. These improvements will not achieve the congressional mandate for 2002, but they will go a long way toward

[4]See Appendix B for a general description of the properties and capabilities of a detailed simulation model.

providing increased levels of airport security through a more effective program of baggage screening.

An Alternative Approach

As an alternative to the top-down approach of the Department of Transportation's (DOT's) deployment plan, we propose a bottom-up approach that will empower airports and airlines to work together to solve what is essentially a local problem. Moreover, we recommend that the problem-solving teams follow the example of the Dallas–Fort Worth Airport in using the most appropriate stochastic simulation models to provide the best possible forecasts and projections. With such an approach, the federal government will play a different but no less important role. That role will be to organize, coordinate, and ensure the quality of a bottom-up system that fully enfranchises local airports and airlines in developing baggage-screening solutions that can work in the field. The government should

- Establish the standards for machine and system performance.
- Participate in local partnerships that are designing local solutions.
- Integrate the local plans into a national architecture.
- Evaluate the effectiveness of each airport's security systems.
- Set parameters now for the longer term so that airports will be able to incorporate the new requirements into their modernization/expansion programs, many of which are now on hold.
- Test proposed options against a model of the national transportation system to ensure that bottlenecks do not develop during the implementation period and that the requirements of a hub system can be met.

A bottom-up approach should be implemented immediately, giving the local partnerships a period of perhaps 60 days to report to the DOT concerning their requirements for government-funded EDS machines and to provide an estimate of the facility modifications needed to incorporate EDS into the airport infrastructure.

With this approach, the DOT will still have the responsibility for determining the timeline for airports to receive EDS equipment consistent with the plans submitted by the partnerships. To do so, the DOT will need to model and develop metrics to address the overall performance of the civil aviation system, particularly the impact that new security procedures have on the functionality of hub airports and, ultimately, on the performance of the entire air transportation system as a vital element in the nation's economy.

Profiling: A Strategy for Reducing the Problem to a Manageable Level[5]

Even if the best planning tools are available, a bottom-up approach is used, all the airports and airlines work productively with the DOT, and maximum production of new EDS equipment is achieved—even then, the 2002 congressional deadline for the fielding of EDS machines almost certainly cannot be met. What is needed is an interim measure, a way of ensuring that the existing baggage scanning capacity focuses on those bags most likely to pose a threat. This can be done by adopting baggage handling procedures that have been proven around the world to increase aviation security without overburdening the traveling public.

One of the most effective of these procedures would be expanded use of the Computer Assisted Passenger Profiling System (CAPPS). For example, airport security could use a so-called "trusted traveler" program to focus on identifying the bags least likely to pose a threat. This approach is consistent with generally accepted standards of nondiscriminatory profiling used by civil aviation authorities throughout the world. The procedure would be based not on gender, race, or national origin, but rather on "selecting" passengers about whom a great deal is known and who exhibit behaviors that keep them off any likely-threat list. U.S. citizens who have detailed background investigations on record with the government would be obvious trusted traveler candidates. Numerous other indicators exist as well, many of which could be used successfully in a nondiscriminatory manner.

Such expanded use of CAPPS in no way alters the desirability or utility of using CAPPS to positively identify likely threats. Civil aviation authorities should have up-to-date access to the entire range of information that can be provided by law enforcement and intelligence organizations about people who are on "watch lists," have overstayed their visas, or have drawn attention to themselves for other reasons. Similar systems are used in Israel, which is generally believed to have the world's most secure civil aviation system. While it would be impractical to try to import Israel's successful system on a wholesale basis—the scale and logistics of Israeli and U.S.

[5] See Appendix C for further discussion of passenger profiling.

operations are vastly different—the concept is sound: focus security efforts on those who arouse suspicion.

Conclusion

We propose an approach that is based on developing security solutions that are appropriate to individual locations while ensuring that national interests are safeguarded. Such a bottom-up approach not only empowers airports and airlines by involving them in new partnerships with one another and with the federal government, but also constitutes a systemwide effort that uses the best analytic tools available to provide the most reliable forecasts and projections. These are the keystones to an effective program. Baggage screening is an important component of a full spectrum of security measures that can be brought to bear immediately. The common goal should be a fully functioning air transportation system that provides passengers with safe, efficient, and convenient means of carrying out the nation's business.

Appendix

A. Analysis of Deployment Requirements for Baggage Scanning Equipment

Introduction

Even prior to September 11, 2001, the Federal Aviation Administration (FAA) had a plan to field explosive detection system (EDS) equipment to every commercial airport in the United States. At that time, primarily because of funding limitations, deployment completion was scheduled for 2013. After September 11, it was clear to the FAA that the deployment schedule had to be shortened. Assuming adequate funding and trying to account for limitations on manufacturing capacity for certified EDS machines, the FAA then tentatively set 2005 as a target date. However, Congress mandated an earlier date, December 31, 2002. RAND undertook a review of whether the FAA's plan for the 2005 target date could be implemented within the new time frame.

This appendix takes the need for the highest level of security at U.S. airports as a given. Since this need translates to having to scan all or most of the baggage that passengers bring to the airport, we have taken two views in seeking an answer to Admiral Busick's query. One view, the one we stress in this paper, is that of the organization that has to buy, deploy, and operate the equipment. The other is that of the flying public. The buyer of the equipment is concerned with its total scan rates, its size and cost, and the facility space needed for its deployment and operation. The airline passenger is worried about security, but is also worried about whether he and his baggage are going to get onto the aircraft before it departs.[1] If the lines in which he and his baggage must wait are too long, he may judge that his concerns about the safety of flying and about the loss of time associated with waiting at the airport outweigh the benefit of flying. He may then opt to use other forms of transportation or not to travel at all.

The choices of the potential passenger will directly affect the economic vitality of the airlines and will indirectly affect the growth of the U.S. economy. His

[1]For convenience, we have labeled all passengers as men. Of course, approximately half are actually women.

viewpoint is thus important. However, it is also the more challenging of the two viewpoints and the one given less attention is in this paper.

Our work originally focused on EDS machines, as called for in the FAA plan and implied in the congressional bill. However, subsequent interest in the use of explosive trace detection (ETD) machines, which can detect very small amounts of explosive material by chemical means, led us to include their performance as well.

Assessing Plans for Explosive Detection System Machines

We were asked to independently assess how many EDS machines would have to be deployed to achieve two objectives: 100 percent scanning of all checked baggage, and performance of that scanning within timelines that would not bring airport throughput to a halt. An EDS machine uses the same magnetic resonance imagery (MRI) technology commonly found in the medical profession. It can rapidly image a bag and its contents, measure selected properties of those contents (e.g., density and shape), and advise a human operator as to whether the contents are consistent with a bomb. EDS machines are in operation at many of the large airports around the world; approximately 150 were in operation at U.S. airports at the end of 2001. The FAA estimated that approximately 2,000 EDS machines would be required to meet the objectives just stated. Our primary research objective was to test whether this estimate was reasonable for planning purposes.[2]

After review of the FAA's estimates, we identified four factors that could be cause for concern:

- The estimated buy size of 2,000 EDS machines was derived using current traffic levels. Based on our understanding of the need at many airports for additional space for baggage scanning operations, and considering the likely time that will be needed for new airport construction, we believe that it is sensible to plan against a future demand. Our assessment considers two demand levels, one consistent with recent levels of airport operations and one consistent with traffic levels forecast for calendar year 2010.[3]

[2]During our first conversation with Admiral Busick, he provided us with these estimates and helped arrange for us to visit the contractor that had generated them.

[3]The combined impact of the September 11 attacks and the economic slowdown of 2001 has altered the FAA forecast of future passenger demand. This paper's analyses use the old date. New FAA forecasts predict that the 2010 demand we used will not occur until 2012.

- The criterion used in the FAA sizing of the EDS buy was "no delay greater than one hour" over the course of the day. There is consensus among airport managers that 1 hour is too long. Delays of this magnitude, if they occur over extended portions of the day or apply to a substantial fraction of the bags, will seriously impede passenger and baggage throughput at the airport and will eventually reduce passenger willingness to fly.
- The FAA's criterion offered no margin for dealing with the numerous uncertainties associated with achievable scan rates, false positive detections, variable passenger demand, equipment reliabilities, and so forth. These uncertainties are likely to exacerbate delays, causing substantially higher peak-hour delays as well as an overall rise in non-peak delays.
- Airport facilities, airline incentives, and other factors limit an airport's ability to concentrate the machines for maximum utility.

Because of the project's scope, we were only able to examine operations at a single large hub airport, Dallas–Fort Worth (DFW). From that analysis we reached general observations about what might happen at all large airports.

Early in the study we visited the contractor that had provided the FAA with initial estimates of how many EDS machines would be needed at U.S. airports to complete the FAA's program. The contractor shared its methodology and resulting calculations with us.[4] The contractor also concurred with our view that if additional time and resources became available, a stochastic simulation of airport-passenger-bag management should be undertaken to properly size EDS deployments at major U.S. commercial airports. However, neither the contractor nor we have had the time or resources to undertake such a simulation. The contractor's calculations and the analysis presented in this appendix should be viewed as a rough first approximation. We replicated the contractor's single point estimate and extended it by performing a series of sensitivity analyses designed to test the robustness of our estimates.[5] We show outcomes as a

[4]We believe that the estimates provided to the FAA were competently done. The contractor deserves high marks for what it was able to accomplish in a relatively short time.

[5]The FAA's estimates were based on the following:

(a) The demand for baggage scanning was derived from the timing of aircraft departures, as taken from a recent Official Airline Guide (OAG). A common load factor was assumed (70 percent), and the check-in baggage total for each aircraft was taken from estimates of average check-in bags per passenger.

(b) Demand was derived for individual airlines unless an airline did not have enough demand to warrant its own machine. It was judged reasonable for airlines with only a few departure flights a day from a particular airport to "share" a machine with another airline that also had a small number of flights from that airport.

(c) A concept of operations for the machines was assumed for each airport. For large airports, a two-tiered approach was assumed: the first tier reached judgments about whether the bag might have something dangerous within it, and the second tier looked function of equipment reliability, passenger arrival characteristics (what we call the "spread"), false positive detection rates, and aircraft load factors. We show how increasing the number of deployed machines can compensate for the negative effects of these factors.

Note, however, that our sensitivity analysis cannot replace a realistic simulation of total airport throughput. The design of airport security needs to ensure that passengers and their bags reach their aircraft in a manner that is not so inconvenient that the flying public chooses to forgo flying. The Congress passed the Aviation and Transportation Security Act partly in response to its fear that the flying public would lose confidence in the safety of flight and thus cease flying. The cure for that fear should not unintentionally yield the same result. If buying more machines is the way to provide efficient airport flow, then more machines should be bought.[6]

Before turning to the results of our analysis, it is also worth noting that most busy airports have multiple queues, some that can reinforce and extend the delays associated with getting bags scanned, and others that lessen the perceived impact of scanning delays.[7] The lines at check-in counters and at the screening stations for passenger carry-on baggage are often substantial, the latter more so now, since September 11. The perceived requirement that passengers must arrive at the airport at least 2 hours before departure time (common at some airports at the time of this writing) is, we believe, a deterrent to travelers. If baggage screening by itself produces a queue, it will be an entirely new queue. How these queues interrelate is part of the overall problem, beyond our analysis,

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more closely to resolve whether the bag needed to be pulled and openly searched. We used this concept as our base case.

(d) The EDS scanning rates used were based on real experience gained by fielded equipment. We used similar rates.

(e) The prime criterion for sizing the total buy was keeping the longest delay experienced by any airline under 1 hour.

Our primary concerns with the current estimate of 2,000 are (1) we think the 1-hour sizing criterion is too long; (2) there was a general lack of sensitivity analysis related to equipment malfunctioning, etc.; (3) the average load factors probably understate peak-hour traffic experience and obviously underestimate conditions during high-volume traffic days (e.g., the day before Thanksgiving); (4) no future traffic levels were used.

[6]Other analysis suggests that limiting the growth of aviation would cost the nation tens of billions of dollars annually in the near term, and hundreds of billions in subsequent decades. If buying more EDS machines can remove hindrances to flying, the cost would be more than compensated by the return to the nation's economy.

[7]One of the pivotal reasons for using a realistic large-scale simulation of airport throughout is the need to better understand how these various queues interact. For example, a long queue at the baggage check-in counter may be caused by having only enough clerks to accept bags at a rate consistent with the scanning capabilities of the machines. Thus, queues that would normally be attributed to the limitation of EDS machines might be attributed to there being too few clerks handling the check-in process. Obviously, these check-in queues would add directly to queues associated with passenger screening, while bag scanning delays would not.

and another reason for a stochastic simulation of an airport-passenger-bag management system.

Assumptions and Assessment Process

Generalizations drawn from an analysis of the equipment needs of a single large airport may not be appropriate for all commercial airports. Small airports differ from large airports in terms of requirements and geometries. At many small airports, one EDS machine may suffice. However, to provide a backup capability to handle machine outages, a small airport might need two machines rather than one, or access to personnel that can handle the job by hand-searching the bags. However the capability is supplied, these airports accommodate only a small fraction of the total passengers, lessening their impact on total equipment needs for all airports.[8] Overall traffic behavior and baggage demand levels suitably scaled do not differ much among large airports having substantial hubbing activity, with the exception of origin-destination (O/D) traffic levels. The fraction of O/D passengers, compared to the fraction of connecting passengers, varies at the major hubs, being low at some—Atlanta Hartsfield International—and higher at others—Chicago O'Hare International. Over the course of the day, Dallas–Fort Worth (DFW), our selected hub airport, is somewhat lower (~36 percent O/D traffic, according to 1996 data). However, O/D traffic is generally higher during peak traffic hours, when business travelers tend to dominate the manifest. We assumed an O/D traffic level of 50 percent as a norm in our calculations, approximately matching the industry average at large hubs. This norm was also used in the FAA estimates.

We also assumed that only check-in baggage from O/D passengers is scanned. This implies that bags being transferred from one aircraft to another have already been scanned at the airport where the baggage was first loaded onto an aircraft. As it is uncertain when small feeder airports will get their share of the EDS machines, this assumption is optimistic for hub operations.[9]

We used a computerized 1998 OAG schedule for flight departures at DFW to estimate the number of bags that will need to be scanned in the "near term." This computerized OAG also provided a schedule for aircraft traffic projected at DFW

[8]Small airports need baggage scanning equipment regardless of their size. The number of machines needed will be disproportionately large because of the sensitivity of overall performance to uncertainties. However, the total number will still be small compared with the buy requirements at the 30 largest U.S. airports.

[9]Having to scan all transiting bags would be a disaster for airport hubbing operations. It would force significantly longer ground stops, lowering airline fleet utilization and aircraft bank integrity at the affected airports.

in the year 2010, which we used for our longer-term assessment.[10] Whether this growth is realistic after the September 11 events is obviously subject to question. Nevertheless, we believe it is prudent to assume that, security issues notwithstanding, the U.S. economy will resume a reasonable growth rate. Given that the transportation sector of the economy is judged to be a strong factor in that growth, we believe the government should recognize that designing the baggage scanning system so as not to impede that growth is an important public policy goal.[11]

Another reason for using the futuristic airline demand is the long lead time for airport facility planning and construction. Limited airport space is a critical issue. Most large airports will require either new facility construction or the invention of innovative ways to dramatically modify the space that already exists. The identification of what needs to be done at each airport must consider demand growth well beyond the date of initial machine deployments if the risk of being short of space immediately thereafter is to be avoided. By focusing on 2010, we can estimate the amount of equipment space that will have to be provided at the large hub airports within the current decade.[12]

Following the approach used in the FAA's analysis, we assumed a three-step detection process: a high- and a low-speed EDS as the first two steps and, when indicated, a manual open-bag inspection as the third step.[13] These three steps proceed as follows:

- *Initial inspection by high-speed EDS machines*. These machines rapidly scan the bag, searching for objects whose density matches that of a known explosive material. If no such objects are found, the bag is judged "safe." Baggage scan rates of 350 bags per hour (or approximately one bag every 10 seconds) have been achieved in these conditions.[14] Test data suggest that approximately 25 percent of the bags will have objects (not necessarily bombs) that match the sought density and thus cannot be judged "safe"

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[10]This computerized OAG was constructed a few years ago to generate nationwide traffic profiles that could be used in large-scale simulations of the national airspace system (NAS). The 2010 traffic schedule is based on a computer program that looks at demand at all U.S. airports and apportions flights on a demographic basis to airport-pairs. In general, the computer seeks "open" slots for the scheduling of arrival and departure times, avoiding congestion as best it can. Whether this is a sensible assumption for future airline schedules is a topic for a later day.

[11]Comments by Secretary Mineta on setting a goal of no security-related delays greater than 10 minutes clearly relate to this point.

[12]It is worth noting that any major new construction at an airport will take nearly a decade to complete if current planning and construction timelines are assumed. If this is the case, planning needs to begin today if a 2010 date for full operation is to be met.

[13]No analysis on delays has been provided for the manual inspection part of this process.

[14]We have been told that this is consistent with the operational performance of the CTX9000, one of the EDS machine types currently in production.

without a more in-depth examination of their contents.[15] This is the phenomenon usually referred to as a *false positive*.[16] Any "unresolved" bag is passed on to step two; all other bags go directly to the airline's baggage assembly area.[17] We use the term *tier 1* as a descriptor of this step.

- *Follow-up inspection of unresolved bags by slower-speed EDS machines*. To further identify an object having the threatening density, another EDS machine provides a set of images to the machine operator who can manipulate the images and get a feeling for the object's size, shape, and density.[18] Based on this more thorough inspection of the bag, the operator reaches a judgment about whether the bag has a bomb in it. The time required for this inspection is dictated by operator skill and experience. Based on field data, we have set this rate at one bag per minute.[19] There is, naturally, a wide dispersion about this number. We have assumed that all but a small fraction of the bags (less than 1 percent) are resolved as safe and sent to the airline's baggage assembly area. Those still not resolved must be hand searched to determine whether they are "safe."[20] We use the term *tier 2* as a descriptor of this step.

  Manual open-bag inspection. This third step does not impact our analysis. No time was added to the delays to represent it.[21] So the assumption of a less than 1 percent rejection factor in tier 2 has no bearing on our results.

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[15]This assumption also matches current operating experience. There is a close coupling between the machine's average scan time and its ability to discern whether a bag is "safe." For this analysis, we made no attempt to "optimize" this parameter and lack the data to do so.

[16]We do not know the actual probability of failing to detect a real bomb. But recognizing that the attempt to put a bomb onto a U.S. aircraft is a very rare event, a false positive detection rate of 25 percent will generate at least 10^8 more false detection than real detections.

[17]If the baggage scanning function is done in a centralized manner, with multiple airlines involved, then an additional process is required to sort the baggage. The airlines are understandably very reluctant to entrust the airport or the government with the responsibility of ensuring that bags are suitably sorted. Missing bags will be blamed on the airlines, and it is the airlines that will be damaged by lost passenger loyalty. Mainly for this reason, the major airlines remain fairly adamant that they keep control of check-in luggage, even if it means they need to have EDS equipment dedicated to their needs.

[18]One EDS machine manufacturer offers a capability in which images obtained while the bag is being scanned in tier 1 are stored for later replay if the tier 1 scan does not judge the bag safe and send it to tier 2. In this case, tier 2 becomes a set of workstations (rather than EDS machines) where a human operator inspects the stored images in a manner similar to the tier 2 operation we assumed. This approach probably requires fewer EDS machines, although total throughput may not be significantly improved.

[19]We have been told that this is also consistent with operational experience, assuming a well-qualified operator.

[20]This percentage is at best a rough estimate. It is sensitive to the competence of the tier 2 inspector, the decision tools provided for explosive detection, and the amount of time used in the inspection. There is also controversy as to whether the bag's owner needs to be present when the bag is hand inspected. If the owner's presence is required, the inconvenience to the impacted travelers might be significant. Recently (2/1/02) the TSA announced during a teleconference with many large airports that it intends to do away with this requirement.

[21]Hand searching of suspicious bags can take up to 5 minutes and perhaps even more per bag.

Figure A.1 depicts the assumed operational concept of how passengers and check-in baggage flow through the airport. Tier 1 and 2 are shaded.[22]

The OAG provides scheduled arrival and departure times for individual aircraft. Each aircraft is designated by type (e.g., Boeing 737). Knowing the approximate number of seats per aircraft type, we derived an estimate of the number of available seats over any time increment.[23] Assuming a load factor of 70 percent,

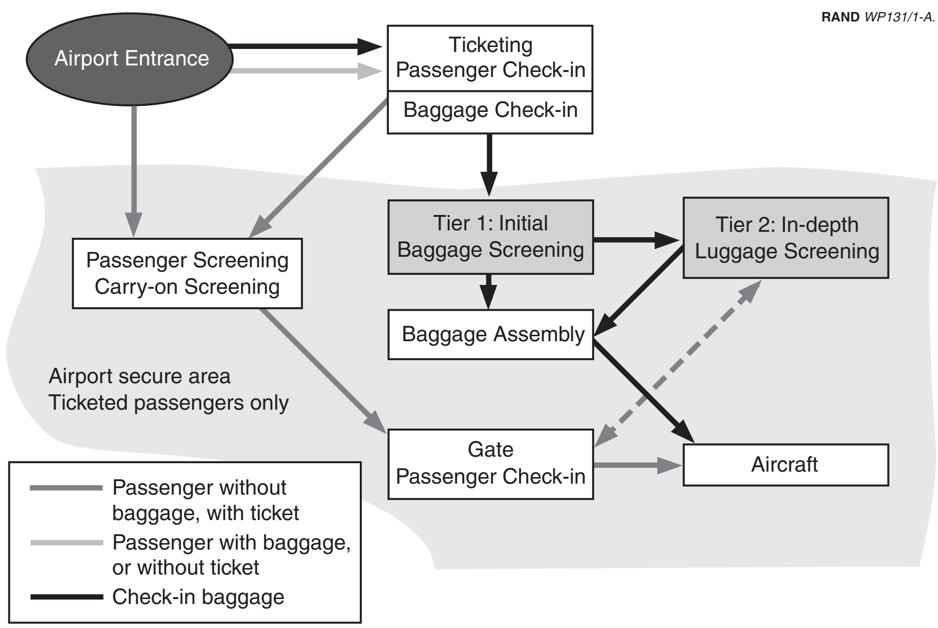

Figure A.1—Concept of Operations Used for Baggage Scanning

[22]Although two-tier scanning concepts have some operational advantages, other concepts—e.g., a single stage in which the scanning machine performs both functions—can provide comparable capabilities. Of the two-stage and the single-stage concepts, the latter are generally more flexible in handling unexpected performance variations.

[23]By 2010, many of the aircraft found in the 1998 OAG will have been upgraded or replaced by newer models. As such, it is expected that the number of seats per aircraft will grow over time. No consideration of this growth is included here. Such seat growth has been predicted in the recent past, but the real-world experience—exacerbated since September 11—has been exactly the opposite. The average number of seats per departure has declined, in fact, in recent years. Thus we have taken a neutral stance.

we translated the OAG into the number of passenger enplanements. The number of originating passengers was estimated by multiplying the number of enplanement passengers by the assumed O/D fraction of 50 percent. This assumes that originating passengers were only half of the total enplanements, the other 50 percent being transfers from arriving aircraft.

The number of passengers—passenger demand—using the flight departure time from the OAG was collected into 3-minute segments. We translated this into the number of bags that must be scanned before being placed in the aircraft. Based on discussions with a major airline, we assumed that

- 30 percent of all originating passengers have no check-in bags and go straight to the gate for check in.
- Of the remaining 70 percent, each passenger averages 1.67 check-in bags.

The overall average we used was 1.17 bags per originating passenger.[24]

Figures A.2 and A.3 show the number of baggage check-ins on a typical day using the 1998 and 2010 demand, respectively. The time shown is based on the aircraft's scheduled departure time, not passenger's arrival time at the airport. The peaks in baggage demand over the day stress the system and dictate how many EDS machines need to be bought. The actual time stamp is not important to our analysis. All originating passengers and their bags are included in these data. We show a similar demand curve for a single airline (American Airlines) at DFW later, when we evaluate decentralized baggage scanning operations.

Passengers do not arrive at airports at a precisely known time before departure. We would be overstating the load on the bag scanning system if we modeled their arrival as if they did. Actual arrival times vary, based on passenger risk aversion and anticipated airport congestion.[25] To reflect this we spread their arrival times uniformly over a 30-minute increment.[26] Figure A.4 shows how

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[24]This number is similar to that used in the FAA's estimate of machine buy-size requirements.

[25]Most experienced travelers, having bags to check in, know to arrive 45–75 minutes prior to aircraft departure time, assuming no airport congestion for bag or personnel screening (where curbside check-in is available, times may be somewhat shorter). A risk-averse person might come even earlier, while some passengers choose to arrive later. Currently, experienced travelers add as much as 1 additional hour to account for delays associated with more-extensive security screening.

[26]The "spread" can be distributed across the specified time in a variety of ways. For simplicity (and because it favors baggage handling), we chose to use a flat distribution. Thus, for a 30-minute spread, 1/30th of the passengers would arrive during each minute of the time span. We examined alternative distributions (e.g., triangular, binomial) and different lengths of time (from 15 to 60 minutes). The differences in outcomes were small except at the largest deployment sizes, where the maximum delays were calculated to be very small.

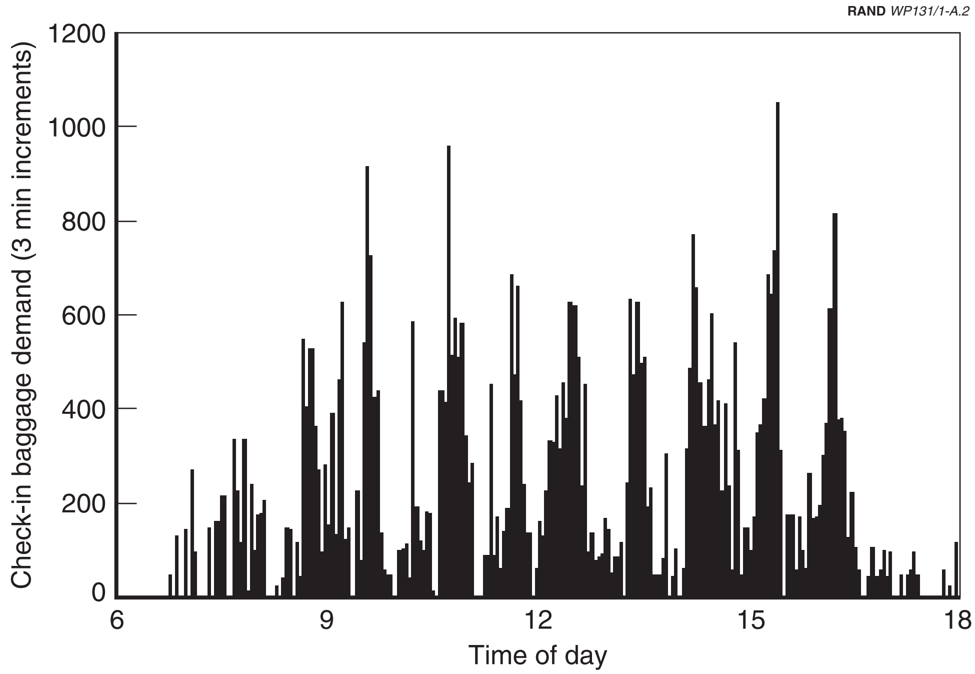

Figure A.2—Check-In Baggage Demand at DFW, 1998

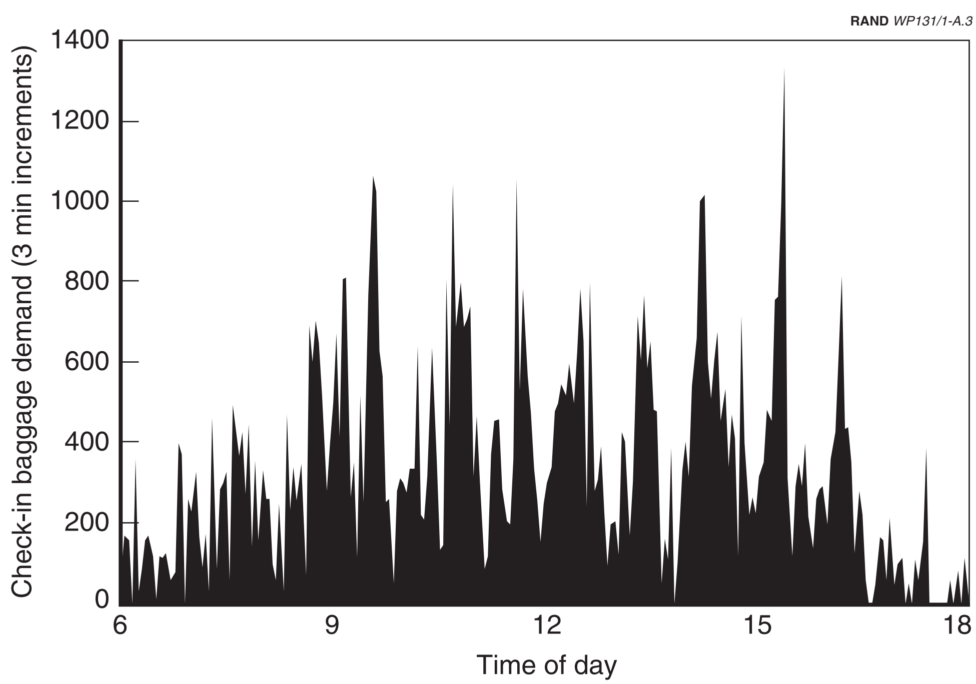

Figure A.3—Check-In Baggage Demand at DFW, 2010

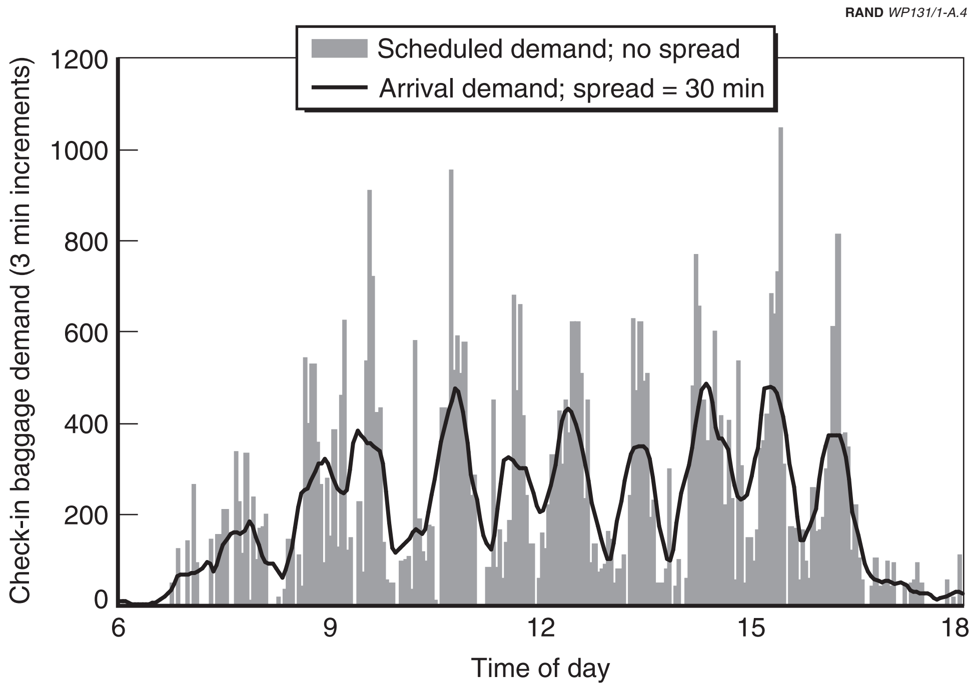

Figure A.4—Actual and Spread Demand for 1998 DFW Case

spreading the passengers and thus their baggage alters the baggage check-in demand arrival times for the case of all flights at DFW, 1998. Spreading the demand over time lowers the relative peaks, producing more-uniform baggage flows into the airport; it also makes the analysis more tractable. Accordingly,

- We calculated the baggage demand, based on input assumptions regarding the number of flights (all, or limited to a single airline), using standard input assumptions on O/D percentage of total passengers and the average number of check-in bags they bring. Demand was broken into 3-minute increments, a total of 240 over the entire day.
- Using this demand, we determined the length of baggage scanning queues at each time increment (in both tier 1 and tier 2) for the specified EDS deployment in tiers 1 and 2. We calculated the longest time required for scanning a bag at each increment and noted the maximum length calculated across all time steps.[27]

[27]The maximum and minimum delays are calculated for bags entering a specific 3-minute window. Those arriving first in the window experience the minimum delay; those arriving last, the maximum. Using a strict first-in, first-out queuing strategy for each tier, it can be shown that the largest delay that any bag experiences is the larger of the implied delay in tier 2 (assuming that 25 percent of all bags were directly sent to tier 2 and added to the existing queue in that tier) or the delay associated with simply passing through tier 1.

- Next, we varied the number of machines deployed in the tier 1 and tier 2, recording the maximum delay time for each deployment combination. Figure A.5 is a portion of a larger matrix that contains the full results from this calculation. The columns are for tier 2 EDS machine deployments, and the rows are for tier 1 EDS machine deployments.[28]
- We then selected a standard against which to judge the results. For example, using the data in Figure A.5, we could specify that the maximum delay can be no more than 10 minutes. This standard is met for a number of machine buys, but the one requiring the fewest machines involves 20 tier 1 machines and 29 tier 2 machines, for a total buy of 49.
- We also noted that machine reliability can differ between tiers 1 and 2, reflecting the likelihood that different machines will be used in the different tiers. We calculated the probabilities that an individual pair of tier 1 and tier 2 machines will be operating on a given day. Using these probabilities, we calculated the expected value outcomes and their distributions for delays averaged over a large number of days.
- We performed a sensitivity analyses on selected variables, and compare results.

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Number of Tier 1 machines	Number of Tier 2 machines											
	20	21	22	23	24	25	26	27	28	29	30	31
14	93.51	82.06	82.06	82.06	82.06	82.06	82.06	82.06	82.06	82.06	82.06	82.06
15	93.51	66.87	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58	49.58
16	93.51	66.87	47.29	33.63	31.86	31.86	31.86	31.86	31.86	31.86	31.86	31.86
17	93.51	66.87	47.29	33.63	28.55	24.86	24.86	24.86	24.86	24.86	24.86	24.86
18	93.51	66.87	47.29	33.63	28.55	23.93	19.72	18.76	18.76	18.76	18.76	18.76
19	93.51	66.87	47.29	33.63	28.55	23.93	19.72	15.99	13.51	13.51	13.51	13.51
20	93.51	66.87	47.29	33.63	28.55	23.93	19.72	15.99	12.53	9.41	9.23	9.23
21	93.51	66.87	47.29	33.63	28.55	23.93	19.72	15.99	12.53	9.41	8.39	7.79
22	93.51	66.87	47.29	33.63	28.55	23.93	19.72	15.99	12.53	9.41	8.39	7.46

Shaded rectangles house "balanced deployment" options.

Figure A.5—Typical Maximum Delay Matrix

[28]The lightly shaded entries in the matrix reflect where tier 1 and tier 2 buy sizes are "balanced." In all other parts of the matrix, either tier 1 or tier 2 is the bottleneck (those above the lightly shaded entries are limited by tier 1 capabilities; those below, by tier 2.

To understand how our centralized scanning assumption affected our conclusion, we examined how a single airline might operate if scanning were done at a number of independent locations. We generated a demand profile for each of these locations by dividing the OAG schedule uniformly into mini-OAG schedules (the results of this decentralized scanning example are shown later in this appendix). Centralization requires fewer machines for a given capability, and it is part of our base case assumptions. However, the more realistic assumption is decentralization. Current airline incentives and practices all point toward it.

General Results for EDS Machines

We examined three cases:

- *Case 1*: All flights at DFW, circa 1998 (based on an "old" OAG schedule).
- *Case 2*: All flights at DFW, circa 2010 (based on a "futuristic" OAG schedule).
- *Case 3*: All American Airlines (both American and Eagle—AAL/EGL) flights at DFW (based on the "old" OAG schedule). This case includes the decentralized scanning example.

The first case is the most comparable to the analysis done for the FAA by its contractor, as we discussed earlier. The second case extends the analysis to 2010. The third case explores the issue of centralization, giving us an assessment of the inefficiency associated with fractionating the baggage scanning equipment among individual airlines and the number of additional machines that would be required.

General Comments on Criteria for Sizing the Buy

We include in this appendix several "measures of merit" to help determine the performance of different cases and to understand the value of increasing or decreasing the number of machines installed. No single measure of merit captures all the different interests of the various stakeholders. One set of stakeholders, the airlines, is interested in keeping its passengers happy, which translates into an incentive to get all checked-in bags onto the proper aircraft before departure time. Security is also important for the airlines, as is meeting the demands of their passengers for convenient, on-time performance. If these objectives come into conflict, the airlines face a dilemma. Other things being equal, the airlines will want the government to install sufficient equipment to assure that, under almost all circumstances, baggage scanning will not prevent on-time departures.

Another stakeholder, the new Transportation Security Administration, was created to make certain that bombs do not get onto aircraft. If this objective forces passengers to come to the airport earlier so that they and their baggage get onto the aircraft in time, that is the "price" of security. Rapid deployment of scanning machines and 100 percent baggage scanning appear to be the government's primary concern.

The flying public is obviously interested in flight safety. For business travelers, however, timeliness and convenience are also important. They want rapid transit through the airport so as not to waste more time than necessary boarding the aircraft. Time is money to them. They may well seek alternative forms of travel if the time spent traveling by commercial airline gets to be too long or too inconvenient.[29]

Business travelers often choose not to check their bags, motivated mainly by the inconvenience and delays associated with baggage check-in and retrieval. Those that do check bags want a high probability that those bags will be waiting for them at their destination. Because they value their time, they are interested in the risk associated with arriving at the airport too late for their bags to get onto the aircraft. This suggests a measure of merit that looks at the fraction of bags that make it onto the aircraft as a function of passenger arrival time at the airport.

The results shown below attempt to capture these various viewpoints. The principal measures of merit examined are as follows:

- The maximum check-in bag delay encountered over the entire day, assuming all deployed machines are operating, for each EDS deployment. We call these *point delays*.
- The total number of EDS machines deployed (the sum of the machines in tiers 1 and 2).
- The number of bags suffering delay as a function of the magnitude of that delay, assuming all deployed machines are operating, for each EDS deployment.

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[29]The well-documented increase in the use of private jets (owned or leased by businesses) subsequent to September 11 may be a reflection of this. While some of the increase may be safety related, the data suggest that a major portion of it is convenience related.

- The expected value of the maximum bag delay, where the number of operating EDS machines varies randomly because of reliability losses, for each EDS deployment.
- The expected number of bags experiencing delays as a function of the time between bag arrival at the queue and flight departure. The number of operating EDS machines is a random variable, based on reliability losses, for each EDS deployment.

In addition, we show a number of results not related to these measures of merit that provide additional insight into what various sizes of machine deployments mean to the airlines and the flying public.

Case 1: All Flights at DFW, Circa 1998

Focusing on the size selection problem from the perspective of the airlines (maximum queues short enough that all bags can get on the aircraft at any time of the day), we constructed a list of machine deployment options using the maximum delay measures of merit. Figure A.6 shows a set of plausible EDS machine deployments for demand generated by the 1998 OAG. The short descriptive phrase associated with each entry relates to the measures of merit used to derive the deployment. The tier 1 and 2 numbers relate to the equipment deployed and not to the actual number of machines in operation at any specific time. We also assumed that machines cannot be reallocated from one tier to the other.[30]

Option 1 entails installing a sufficient number of machines to scan all the bags within a 16-hour workday at the airport. If demand were "flat" over time, this deployment would be sufficient to handle the load without delays. However, demand is not flat, so substantial queues occur. As the results show, the maximum delay would be over 5 hours. This is obviously not a good option.

Option 2 shows the "not in excess of one hour" standard for maximum delay used by the FAA's contractor. A total of 37 machines satisfies this standard. The difference between our number and the FAA's estimate of 30 machines is most likely due to differences in our input demand numbers.

The resulting maximum delay in option 2 was just under 50 minutes. We suggested earlier that maximum delays of this magnitude are unacceptably large.

[30]Our primary rationale for this assumption is the size of the machines, the virtual impossibility of moving them from one location to another on short notice, and the inherent fixed structure of the conveyor belts that deny flexible routing options between tiers.

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All flights at DFW (CY1998 traffic)	Number of machines			Results								
				Max delay (min)		Criteria (% less than)			Days over criteria			
	Tier 1	Tier 2	Total	Point	Exp value	10 min	30 min	60 min	10 min	30 min	60 min
1 Estimate based on daily averages	10	15	25	303.2	Total bags = 55,452						
2 No queue greater than 60 min	15	22	37	49.58	131.1	0.0	0.0	2.0	365.0	365.0	357.6
3 No queue greater than 30 min	17	24	41	28.55	73.61	0.0	1.3	43.0	365.0	360.1	208.1
4 No queue greater than 15 min	19	28	47	13.51	31.82	0.0	60.5	94.8	365.0	144.1	19.2
5 No queue greater than 10 min	20	29	49	9.41	24.87	0.6	81.2	98.3	362.9	68.7	6.4
6 Reliability hedge	22	32	54	6.66	14.17	37.2	97.9	99.9	229.1	7.8	0.4
7 Exp value less than 10 min	24	34	58	5.21	9.39	80.6	99.8	100.0	70.6	0.7	0.0
8 Impact of variations in input											
Reliability = 85%	22	32	54	6.66	21.64	9.2	86.3	98.4	331.4	50.0	6.0
Reliability = 80%	22	32	54	6.66	33.03	1.4	60.7	90.5	359.7	143.3	34.6
a Hedge vs. 80% reliability	25	37	62	3.97	14.07	49.9	95.0	99.4	182.9	18.3	2.2

Figure A.6—EDS Deployment Options Considered, All Flights at DFW, 1998

Less than perfect reliability is one reason. For the purposes of this analysis, we assumed the operating reliability of the EDS machines was 90 percent.[31] Given this reliability, the expected value of the maximum delay exceeds 2 hours. A similar measure of merit—the median delay, where 50 percent of passengers would experience greater delays and 50 percent would experience lesser delays (not shown in the figure)—also results in delays slightly over 2 hours. The far-right column shows that the 60-minute measure of merit would only be satisfied on fewer than 8 days of the year. The calculation of number of days on which the standard is not satisfied is, we believe, a useful measure of the deployment's adequacy.

Before proceeding, more must be said about how we selected our "preferred" options. Maximum delays obviously decrease as we add machines to tiers 1 and 2. If properly balanced between the two tiers, the added machines are

[31]For analytic simplicity, we assumed that if a machine were out of service, it remained so for the entire day. In the real world, equipment would be maintained constantly, with outages for a particular machine probably lasting a few hours at most. Having machines going off line and then coming back at various times of the day, with average availability being 90 percent, would increase the "noise" of the outcomes, reducing performance somewhat.

always going to yield better results. But is it worth the added cost? Not having an economic measure of merit related to delay reduction, nor knowing the cost of additional deployments, we cannot conclude that adding more machines is the cost-effective answer. What we can note is the degree to which the flying public is inconvenienced. Below we show curves depicting the probability of bags not reaching the aircraft as a function of number of machines deployed and passenger arrival time at the airport. These curves are strongly correlated with maximum delay estimates, showing decreasing benefit as the number of machines grows. Thus, our judgment about "preferred" outcomes has led us to select buy sizes consistent with point delays somewhat below the 10-minute mark. Selecting a buy option with higher point delays would likely result in many bags missing their intended aircraft even if passengers arrived 90 or 120 minutes early.

Returning to Figure A.6, it can be seen that option 3 reduces the maximum delay standard to 30 minutes. Options 4 and 5 further reduce it to 15 and 10 minutes, respectively. The associated delay numbers are reduced substantially. The median delay for the deployment of 20 machines in tier 1 and 29 in tier 2 (the case of maximum delay less than 10 minutes) is about 25 minutes, matching the expected delay. The expected and median delays of 25 minutes and higher suggest that the average traveler will be forced to arrive at the airport significantly before the plane is scheduled to leave if he expects his bag to reach the aircraft in time for departure (peak hours only).

Figure A.7 is a plot of the calculated delays over the day. Two deployment options are shown—option 2 (the FAA-equivalent case) and option 5 (no queue greater than 10 minutes). Option 2 yields relatively small delays until mid-afternoon, when delays rise to their peak of just under 50 minutes before falling back to zero. A person who flies frequently would quickly learn that afternoons are a bad time in terms of check-in baggage delays and would adjust his airport arrival timing (or check-in baggage propensity) accordingly. Nevertheless, arrival times of approximately 90 minutes before flight would be needed, adding up to 45 minutes to what would be normal earlier in the day. Option 5 shows almost no delays across the entire day. This option would not affect passenger behavior, assuming that the screening equipment is in full operation.

We selected option 6 (a deployment of 22 machines in tier 1 and 32 in tier 2) as our "preferred" option. It yields a maximum point delay of 6.66 minutes, and an expected and median delay of around 14 minutes. Maximum delays of 60 minutes or greater would only occur one day every two years, a totally acceptable outcome. However, option 6 is still sensitive to the assumed reliability of the equipment, as shown toward the bottom of Figure A.6.

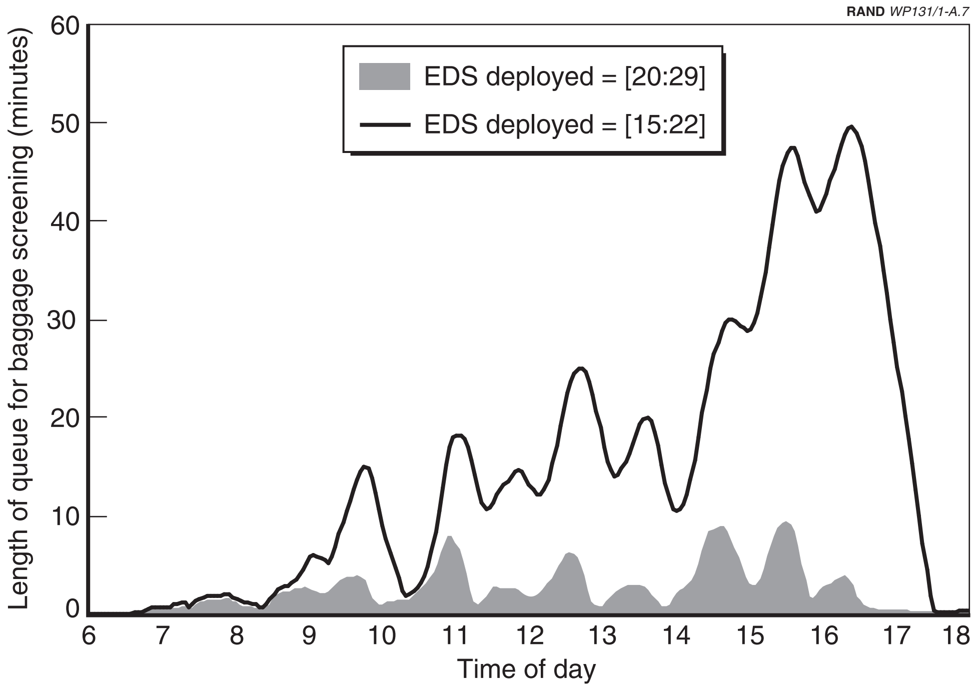

Figure A.7—Bag Screening Delays as a Function of Time of Day, All Flights at DFW, 1998

Maximum delays increase sharply when the reliability degrades to 0.85 or (worse) 0.80.

Our preferred option requires the FAA to install at DFW approximately 80 percent more EDS machines than originally planned. Our estimate for equipment requirements; even without considering future demand needs, is thus almost double that of the FAA.

Figure A.8 shows estimates of point and expected-value maximum delays as a function of total number of deployed EDS machines. The deployments between tiers 1 and 2 were "balanced" to yield the lowest maximum delays for the number of machines plotted on the ordinate.

Figure A.9 extends these results. It assumes that an airline will alert passengers to the need to come to the airport earlier. The calculation starts with the assumption that the airline would want a window of at least 35 minutes before flight departure to assure that the passenger and his bag can make it onto the

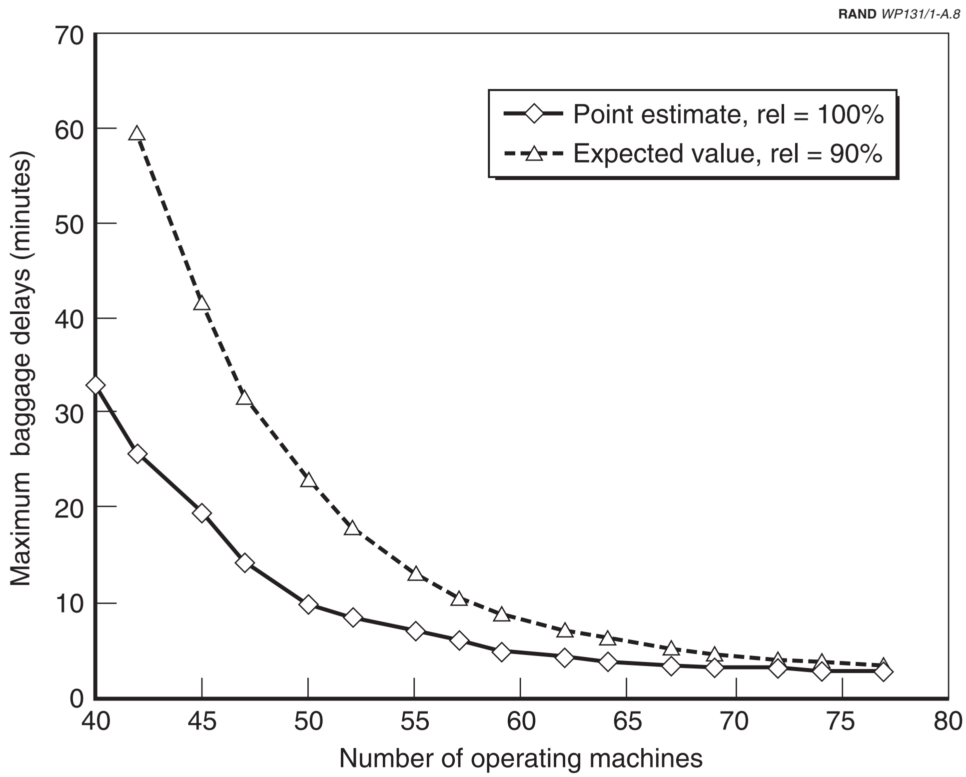

Figure A.8—Maximum Delays per Number of EDS Machines in Operation, All Flights at DFW, 1998

aircraft.[32] Anticipated bag queuing delays would simply add to this window. The figure plots the probability that all bags get onto the aircraft as a function of the "recommended" early arrival time of the passenger. The preferred buy of 22 tier 1 and 32 tier 2 EDS machines depicted as [22:32] allows the airlines to be confident that they can handle virtually all check-in bags, assuming passengers arrive 1 hour before departure. Only under extraordinary circumstances—say, when a large number of the EDS machines are out of operation simultaneously—would the airlines have a problem. The nonpreferred deployment curves in the figure tell a different story, requiring substantially earlier arrival times for high-confidence baggage handling.

Passengers also want their bags to be carried on their aircraft. When planning their trip to the airport, they instinctively balance their desire to be certain that

[32]Airlines are probably capable of processing and loading onto the aircraft most check-in luggage within a window of 15–20 minutes. However, airlines will want to allow additional passenger time for check-in, and check-in queues often reach 15 minutes or more. Thirty-five minutes seems to be a reasonable time to handle both of these considerations.

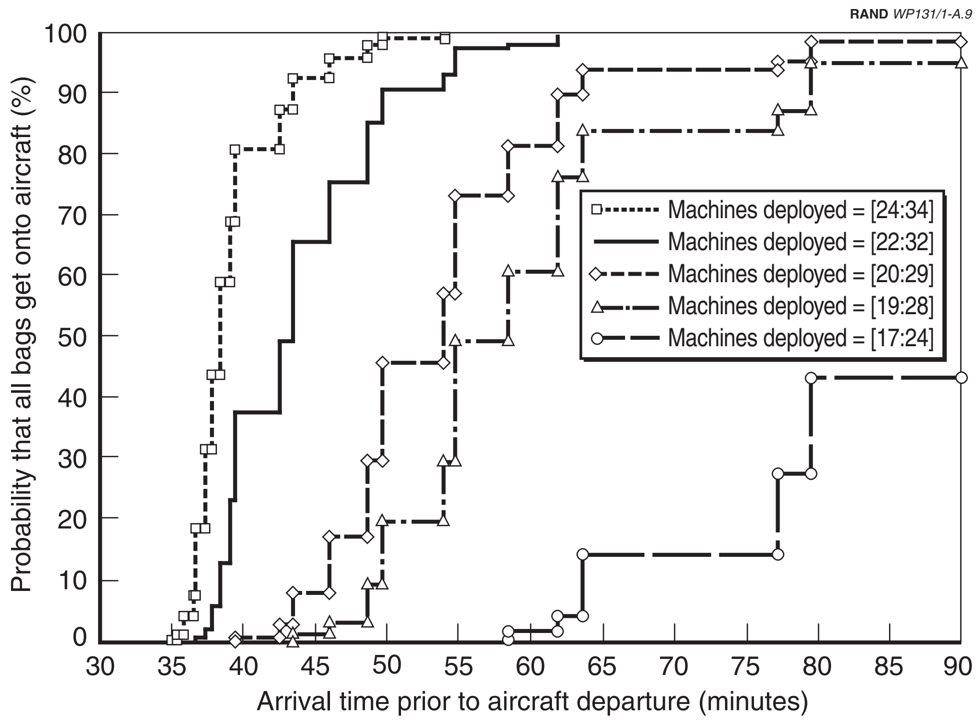

Figure A.9—Passenger Arrival Time for All Bags to Get Onto Aircraft, All Flights at DFW, 1998

their baggage will be successfully placed on the aircraft against the inconvenience of having to spend a lot of time at the airport. Figure A.10 attempts to capture passenger concerns by plotting the planned arrival time of a passenger against his estimate of risk in not having the bag loaded on the aircraft. The risk is a function of the amount of screening equipment deployed at the airport. Of course, in reality, the passenger is likely to discover the risk only through experience.

The results presented above are based on the passenger demand profile calculated from the 1998 OAG. Predicting the magnitude of future demand is a risky business, especially after September 11. It is, however, reasonable to predict that traffic demand will grow over time, and that with that growth will come the need for larger deployments of bag scanning equipment. The forecasts have never been wrong in predicting the magnitude of future growth—only in predicting the exact year in which it would occur.

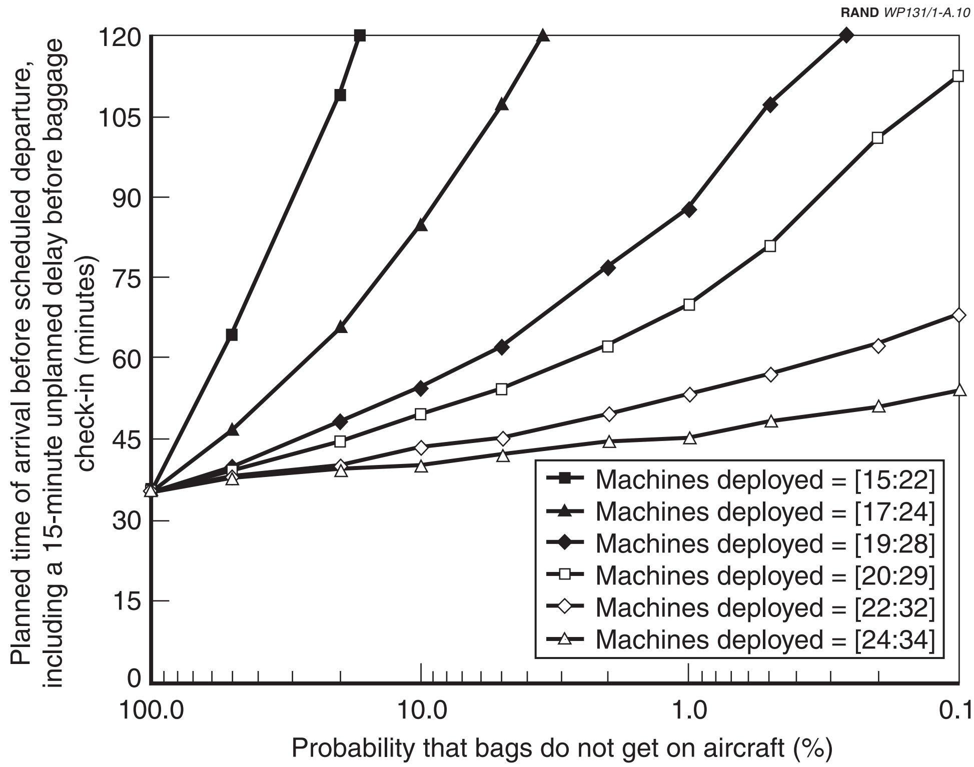

Figure A.10—Planned Time of Arrival According to Passenger Propensity to Accept Risk, All Flights at DFW, 1998

Case 2: All Flights at DFW, Circa 2010[33]

Except for the magnitude of the demand, the 1998 and 2010 cases are quite similar, so we do not go into comparable detail here. As explained earlier, we believe selection of an appropriate EDS buy should be based on future demand.[34] We chose the 2010 demand as our preferred base case and used it to perform most of our sensitivity analyses.

Figure A.11, the options chart for this case, closely parallels Figure A.6. Following the same logic as before suggests an equipment deployment of 31 tier 1 machines and 44 tier 2 machines [31:44] as a preferred option. This deployment

[33]As noted earlier, the FAA has altered its forecast of future passenger demand, now predicting that the 2010 demand we used in our analyses will not occur till 2012.

[34]This hypothetical OAG was constructed at a time when passenger air travel was expected to grow at approximately 3.5 percent per year. The recent downturn in the nation's economy raises valid concerns about whether the traffic levels shown in the case are realistic for 2010. The results given here scale more-or-less linearly with the gross level of demand, so this can be suitably scaled when better demand data are available.

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All flights at DFW (CY2010 traffic)	Number of machines			Results							
				Max delay (min)		Criteria (% less than)			Days over criteria		
	Tier 1	Tier 2	Total	Point	Exp value	10 min	30 min	60 min	10 min	30 min	60 min
1 Estimate based on daily averages	16	24	40	260.3	Total bags = 89,946						
2 No queue greater than 60 min	23	34	57	54.29	126.5	0.0	0.0	0.2	365.0	365.0	364.1
3 No queue greater than 30 min	25	36	61	22.08	87.68	0.0	0.2	15.5	365.0	364.4	308.6
4 No queue greater than 15 min	26	38	64	13.73	63.73	0.0	6.4	49.7	365.0	341.7	183.8
5 No queue greater than 10 min	28	40	68	9.6	36.47	0.1	43.7	85.1	364.7	205.5	54.4
6 Reliability hedge	31	44	75	6.62	13.68	34.1	94.2	99.4	240.4	21.1	2.2
7 Exp value less than 10 min	32	47	79	5.22	9.73	71.5	98.6	99.9	103.9	4.9	0.3
8 Impact of variations in input											
Reliability = 85%	31	44	75	6.62	27.45	5.6	65.7	91.1	344.4	125.3	32.4
Reliability = 80%	31	44	75	6.62	52.98	0.5	26.9	63.4	363.3	267.0	133.7
a Hedge vs. 80% reliability	35	51	86	3.86	15.15	41.1	89.1	97.8	215.1	39.7	8.0
Load factor = 0.8	31	44	75	11.95	48.79	0.2	64.2	94.8	364.4	130.7	18.8
Hedge option 1	34	50	84	6.99	15.77	14.0	92.8	99.4	313.8	26.1	2.2
Hedge option 2	36	53	89	5.60	10.25	60.0	99.1	99.9	146.0	3.4	0.2
False positives = 30%	31	44	75	17.27	63.61	0.0	5.5	54.6	365.0	344.8	165.8
b Hedge option	32	56	88	5.22	9.77	70.7	98.7	99.9	106.8	4.6	0.3
Passenger spread = 45 min	31	44	75	4.13	10.60	78.3	94.2	99.6	79.2	21.1	1.3
Passenger spread = 60 min	31	44	75	3.68	9.07	85.4	98.0	99.6	53.2	7.2	1.3

Figure A.11—EDS Deployment Options Considered, All Flights at DFW, 2010

provides a reasonable hedge against uncertain machine reliability. At a total deployment of 75 machines, this option calls for 45 more machines than the original estimate of 30 that the contractor provided the FAA, and 22 more than our own estimate of 54 in the 1998 case. Note that 75 divided by 30 equals 2.5, the EDS machine buy growth estimate given in the main part of this paper.

Figure A.11 also shows the impact of degraded reliability on our preferred buy and suggests a deployment of 86 machines if reliability turns out to be only 80 percent. The actual operational reliability is often not well known until the machines are fully fielded, and the degree of hedging needed is not easily known at this point.

Our prior calculations assumed a uniform load factor of 70 percent. Most airports, in sizing their facility needs for the future, assume an 80 percent load factor as their stressing case. We have followed their example, testing the impact of an 80 percent load factor. Increasing the load factor for our nominal [31:44] deployment caused delays to rise sharply. The desired machine buy increased into the mid to high 80s.

Actual results are also sensitive to the false positive detection rate achieved in tier 1. Increasing the rate to 30 percent resulted in an increase in delays[35] and required the number of machines between the two tiers to be rebalanced, with a higher fraction of machines going to tier 2. We say more about sensitivity to these factors later.

To summarize this case, our analysis shows that

- A buy size of 75 is a reasonable design point for deployments expected to handle airline passenger growth up to 2010.[36]
- A variety of uncertainties could push this buy size into the mid to high 80s and, if multiple uncertainties exist, even into the 90s. In light of this, our preferred buy size of 75 is at the low end of what we believe to be a reasonable design point.
- Given the various uncertainties that might determine actual baggage scanning throughput, these numbers are approximate at best.
- In light of this, it is essential that the airports and airlines collectively examine the opportunities and constraints associated with equipment deployment and baggage system operation.

It is important to note that most major airports (and certainly DFW) probably do not have sufficient space for installing the equipment needed for the 2010 demand case. This simply underscores the need for serious airport planning

[35]This is as it should be. Given the balancing of our machine deployments between tier 1 and 2, where neither tier becomes the dominant bottleneck, any growth in traffic in either tier is going to cause comparable increases in machine buy requirements. The percent increase in bags to be scanned in tier 2 was about 14 percent for the load factor increase and 16 percent for the increase in the false positive detection rate.

[36]An analysis of single-tier concepts of operations (not discussed here) led to total buy sizes that were about 10 machines lower than those reported here. Single-tier operations (using higher-speed scanning machines) yield total buy results that are approximately 15 percent lower than those shown here. Operational considerations (e.g., starting and stopping of the high-speed machines for detailed scanning purposes) would lessen this difference somewhat, but it appears that some reduction in total buy size might be possible with a single-tier operation.

involving all parties—airlines, airports, and the government. In addition, it reinforces the need to examine alternative ways to achieve the desired security goals while simultaneously providing airline passengers and their baggage with a relatively easy and swift transit through the airport.

Figures A.12 through A.15 are replications of Figures A.7 through A.10, modified to reflect the forecast demand in 2010. Figure A.12 shows maximum baggage screening delays for two EDS deployments as a function of time during the day. In contrast to the result for the 1998 OAG data, the delays here for the 60-minute maximum delay criterion rise steeply by mid-morning and persist and grow throughout the remainder of the day. This suggests that by 2010 a larger fraction of the flying public will have to face delays associated with baggage scanning, further reinforcing the point that "getting it right" is important. The preferred option shows delays that would not hinder passenger or baggage flow through the airport.

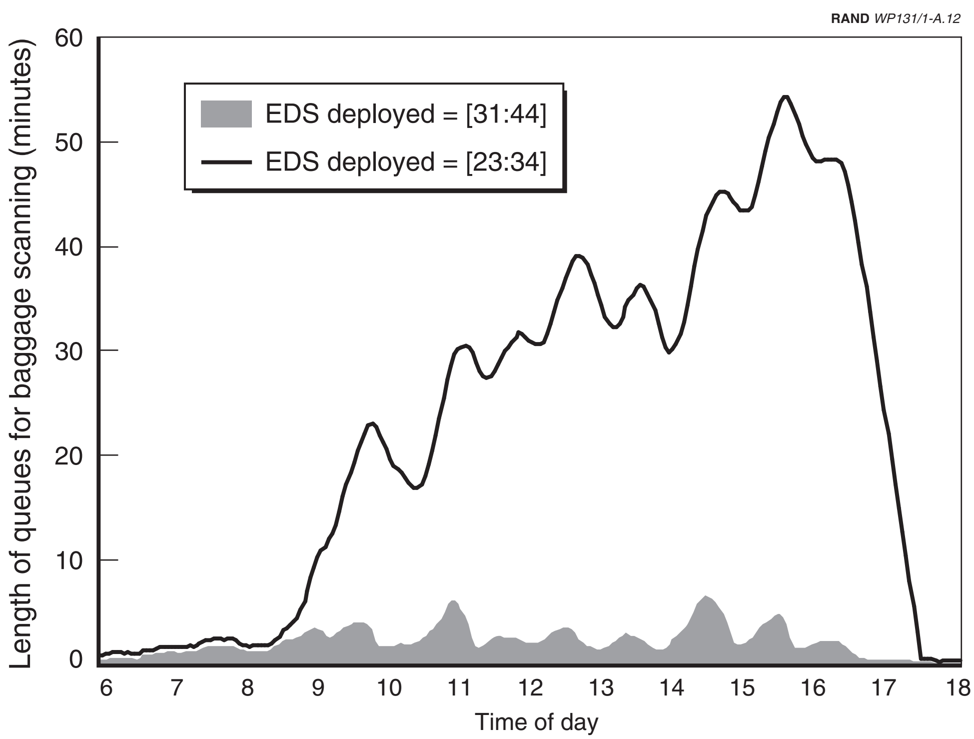

Figure A.12—Bag Screening Delays as a Function of Time of Day, All Flights at DFW, 2010

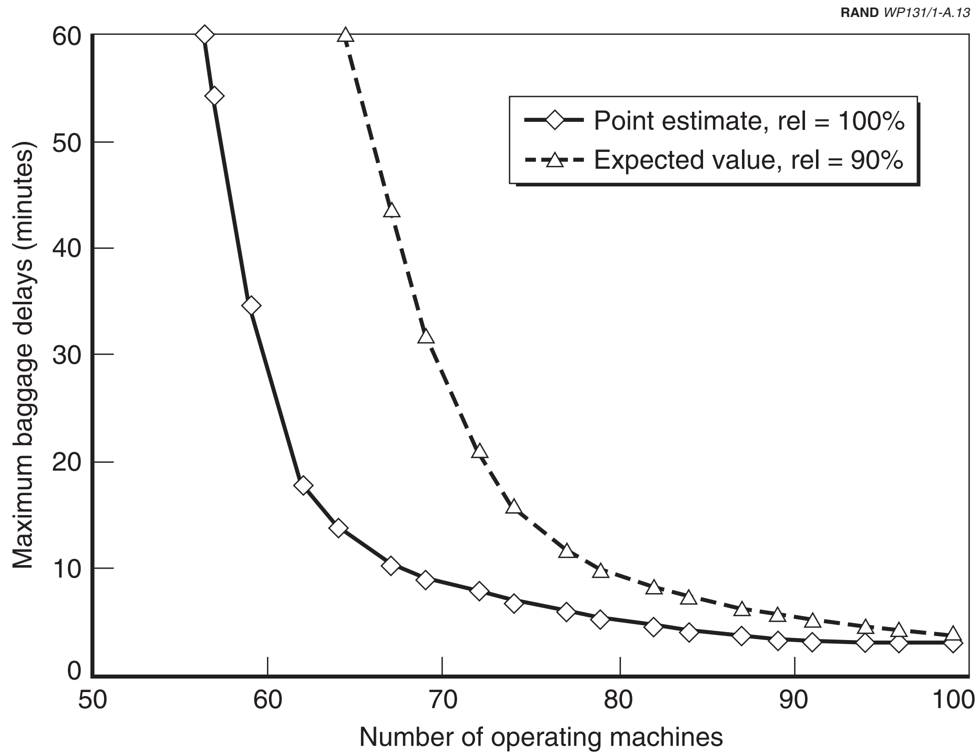

Figure A.13—Maximum Delays per Number of EDS Machines in Operation, All Flights at DFW, 2010

The implications of the results shown in Figures A.13, A.14, and A.15 are the same as those for the 1998 demand case. The overall observations are essentially unchanged, although the actual number of machines required obviously has grown.

The next three figures contain the sensitivity analyses for EDS equipment reliability, aircraft load factor during peak hours, and EDS false positive detection rate. Figure A.16 shows the impact of reductions in EDS equipment reliability on the probability of getting bags onto the aircraft. The performance of our preferred buy size of [31:44] rapidly deteriorates as reliability falls toward 0.8, reinforcing the message that reliability is an important factor in overall EDS screening performance. Care needs to be taken to ensure that the reliability of the EDS machines remains high and is well bounded.

Figure A.17 shows how maximum point delays change as a function of the maximum load factor in the afternoon. To compare results evenhandedly, we held total demand constant, shifting some demand in the early hours to the afternoon. The maximum load factor during the afternoon was varied to as high as 0.875. The increase in maximum point delays leads to the observation that

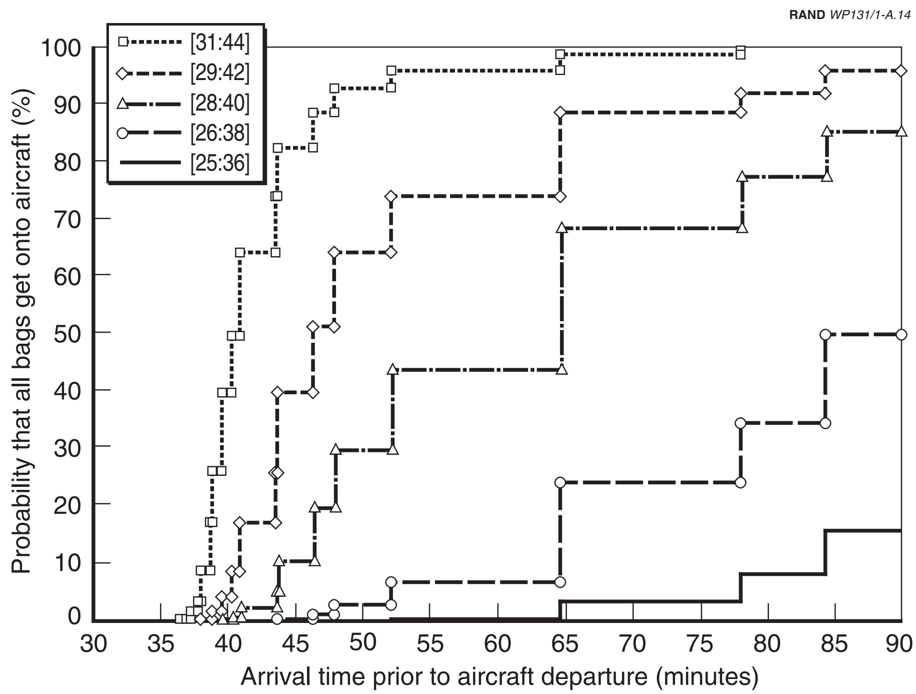

Figure A.14—Passenger Arrival Time for All Bags to Get Onto Aircraft, All Flights at DFW, 2010

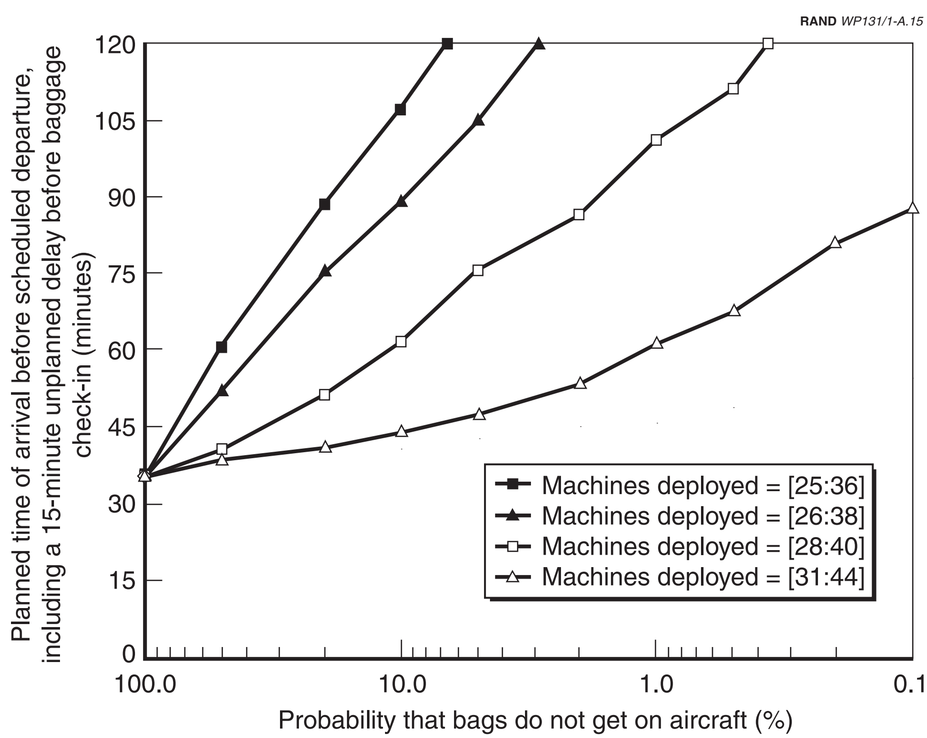

Figure A.15—Planned Time of Arrival According to Passenger Propensity to Accept Risk, All Flights at DFW, 2010

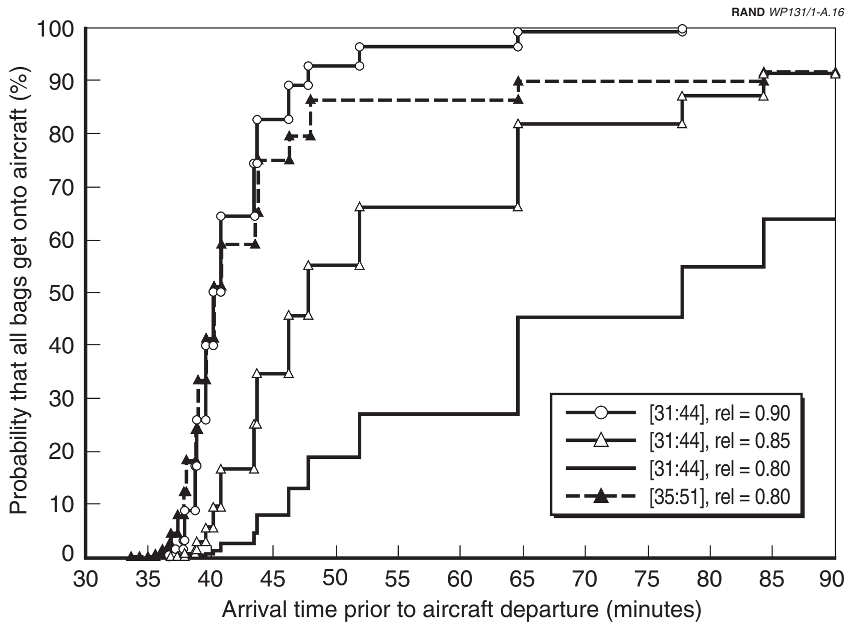

Figure A.16—Sensitivity of Results to Reductions in Equipment Reliability, All Flights at DFW, 2010

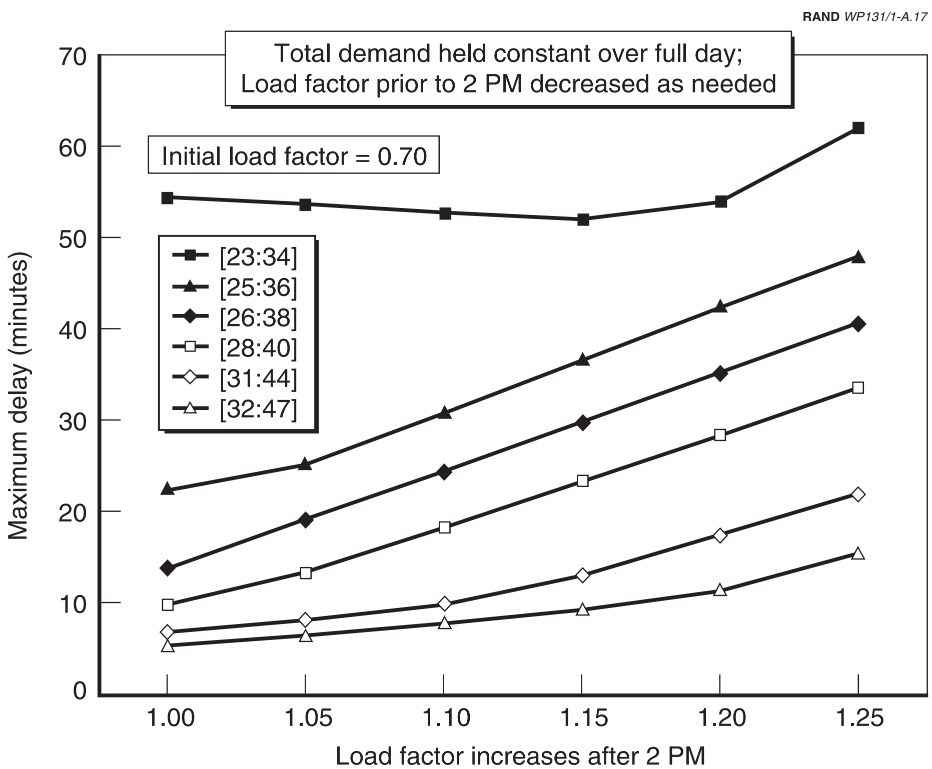

Figure A.17—Sensitivity of Results to Increases in Load Factor During Peak Afternoon Demand, All Flights at DFW, 2010

even modest increases in the load factor during peak afternoon hours would substantially lower performance. This suggests that our assumption about constant load factors over the day is likely to yield estimates that are lower than what is really needed.

Figure A.18 varies the false positive detection rate from 0.2 to 0.33 (0.25 was the nominal value in all our previous calculations). Reductions in this rate below 0.25 show no gain because the demand on tier 1 is unchanged and the tier 1 queue becomes dominant. The rapid rise in delays as the false positive detection rate rises above 0.25 reflects the increased demand on tier 2, with tier 2's queue now dominant.

It is generally accepted that the real false positive detection rate for the deployed EDS equipment will be well known only after the machines are installed and some operational experience is gained. Thus, the upside sensitivity to this rate is a matter of concern. Some of that upside can be mitigated if the two tiers are rebalanced. Figure A.19 shows the benefits of rebalancing, assuming that it is possible. There are obvious limitations (e.g., redoing the baggage flow conveyer lines, hiring more trained operators for the more-challenging scanning job in

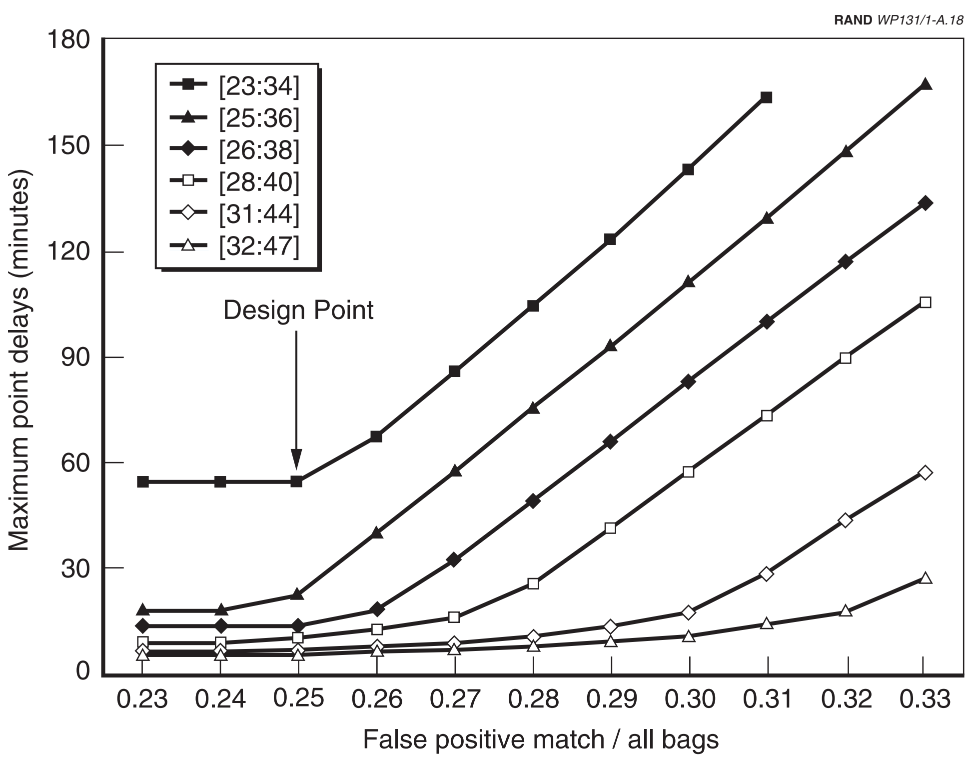

Figure A.18—Sensitivity of Results to Changes in the False Positive Detection Rate, All Flights at DFW, 2010

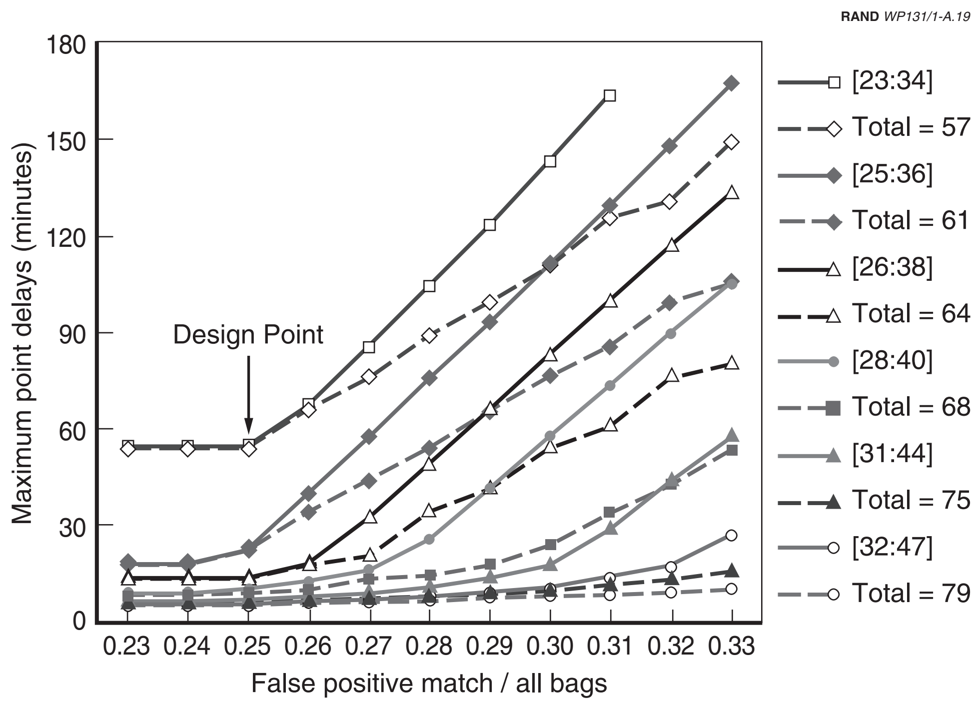

Figure A.19—Benefits of Flexible Tier 1/2 Deployment for Countering Uncertainty in False Positive Detection Rate, All Flights at DFW, 2010

tier 2), but additional flexibility in sizing the two tiers would be a substantial aid to dealing with uncertainty.

Case 3: All American Airlines Flights at DFW

Our final case focuses on a single airline at DFW. The purpose of examining a single-airline scenario is to permit us to calculate the inefficiency associated with the baggage screening being performed by individual airlines. For our purposes, looking at a single airline is sufficient to obtain an approximate answer to whether this inefficiency is large or small.

Figure A.20, which is similar to Figures A.2 and A.3, is the demand profile for American Airlines at DFW. The total number of bags that get checked at the counter is 36,857, or about 41 percent of the total for all DFW in the 2010 case.[37] The demand has more individual spikes than are seen for the other cases,

[37]The single-airline case is the American Airlines flight schedule in 1998. As such, it does not reflect (nor is it expected to reflect) American's traffic levels in 2010. However, it is a useful device for constructing a comprehensive schedule that would be typical of a single airline with 41 percent of the traffic in 2010.

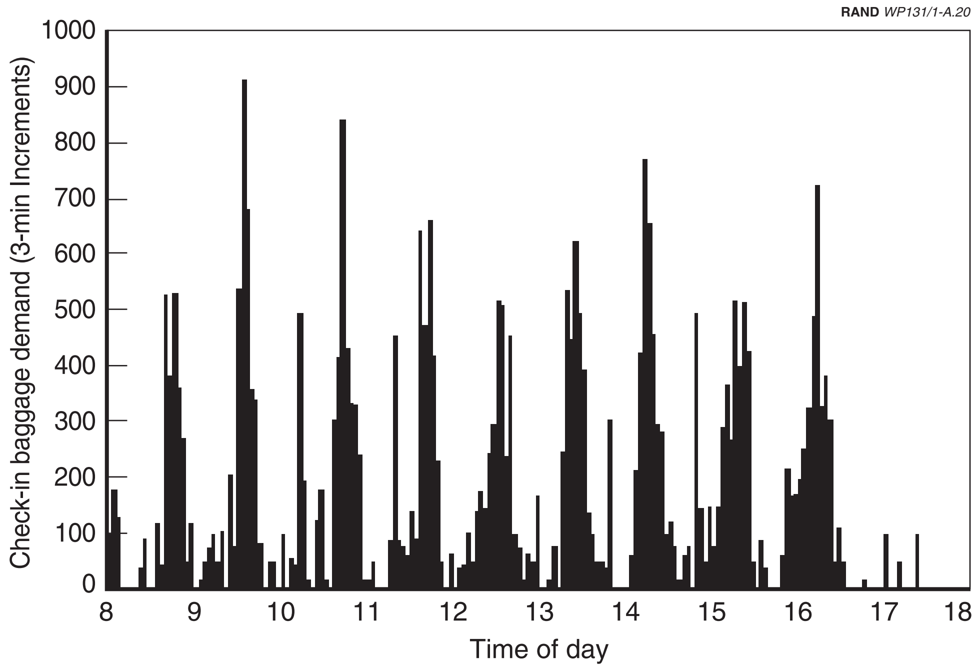

Figure A.20—Check-In Baggage Demand for Single Airline at DFW (41 Percent of Total Bags), 2010

suggesting that the total number of machines needed to keep delays within reason will be greater in percentage terms than it will be for either of the other cases.

Figure A.21 lists the EDS machine deployment options using the same selection criteria used above. Stepping through the same logic used above, we concluded that deployment option 6, involving a total machine buy of 37 machines, is our preferred choice on the list. As before, changes in assumed reliability (shown), load factor (not shown), and other factors would tend to increase this number to 44 and above.

Figure A.22 shows the sensitivity of point and expected delays to total size of the EDS deployment. To achieve maximum-delay expected-value outcomes of under 10 minutes, total buys must be in the 57–58 range.

Figure A.23 is similar to Figures A.9 and A.14. Our preferred [15:22] deployment size performs relatively well, requiring little on the part of the airline in advising

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AAL/EGL flights at DFW (1998)	Number of machines			Results							
				Max delay (min)		Criteria (% less than)			Days over criteria		
	Tier 1	Tier 2	Total	Point	Exp value	10 min	30 min	60 min	10 min	30 min	60 min
1 Estimate based on daily averages	8	11	19	243.1	Total bags = 36,857						
2 No queue greater than 60 min	11	15	26	56.11	133.1	0.0	0.0	6.5	365.0	365.0	341.4
3 No queue greater than 30 min	11	16	27	28.87	110.0	0.0	5.8	16.2	365.0	343.8	306.0
4 No queue greater than 15 min	12	18	30	14.77	58.71	0.0	48.4	59.4	365.0	188.5	148.1
5 No queue greater than 10 min	14	20	34	9.92	21.89	2.8	91.5	94.5	354.8	31.2	20.0
6 Reliability hedge	15	22	37	7.25	13.69	34.0	98.3	98.6	240.7	6.2	5.0
7 Exp value less than 10 min	17	24	41	4.95	8.77	83.9	99.9	99.9	58.6	0.4	0.3
8 Impact of variations in input											
Reliability = 85%	15	22	37	7.25	13.69	34.0	98.3	98.6	240.7	6.2	5.0
Reliability = 80%	15	22	37	7.25	13.69	34.0	98.3	98.6	240.7	6.2	5.0
a Hedge vs. 80% reliability	18	26	44	3.65	12.99	53.5	97.6	98.1	169.6	8.8	6.8

Figure A.21—EDS Deployment Options Considered, Single Airline at DFW, 2010

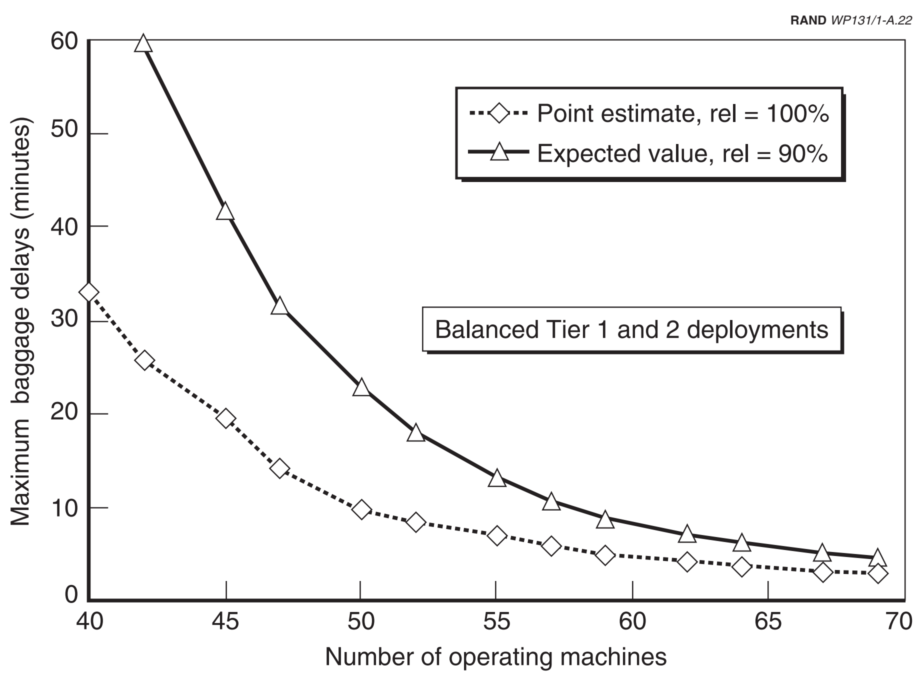

Figure A.22—Maximum Delays per Number of EDS Machines in Operation, Single Airline at DFW, 2010

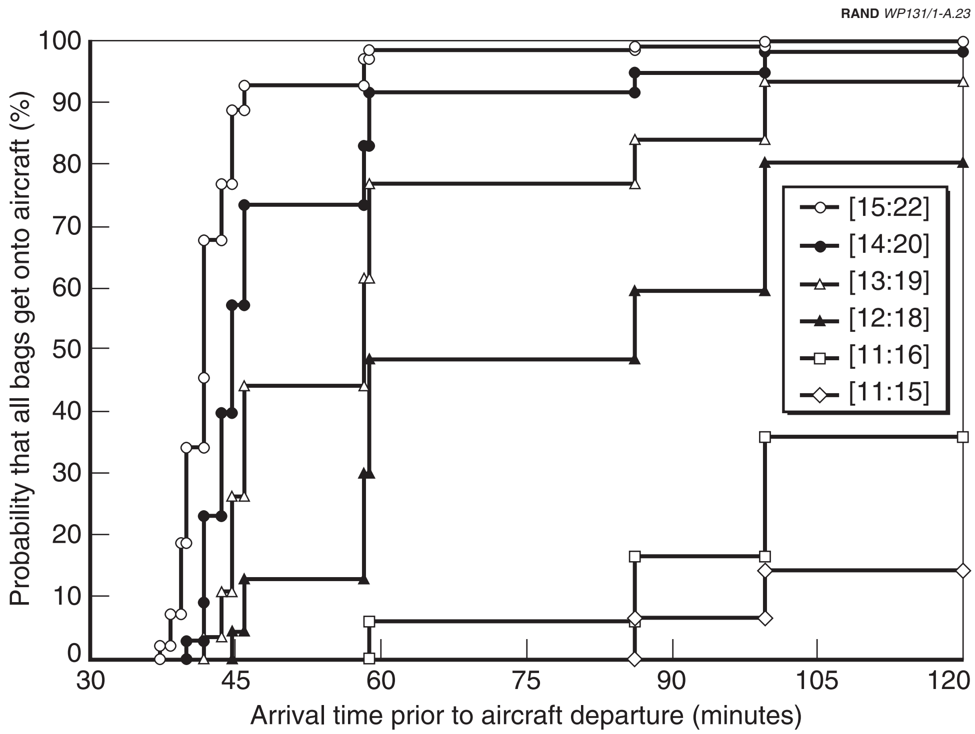

Figure A.23—Passenger Arrival Time for All Bags to Get Onto Aircraft, Single Airline at DFW, 2010

passengers to arrive early at the airport. Smaller deployments perform poorly, pointing out the sensitive nature of these outcomes to buy size.

We compare the machine buy calculation for American Airlines at DFW against the total DFW requirement after we look at a further partitioning of the demand within the airline itself.

Case 3A: American Airlines Flights at DFW Partitioned Into Six Individual Scanning Locations

As a variant of case 3, we examined how total EDS buy size would change if we partitioned the baggage scanning operation into six equal but separate locations corresponding to the terminal arrangement at DFW. American's current operations essentially fill two terminals. Assuming that DFW chooses not to totally reconfigure the airport and to instead find a way to "stuff" the machines into existing space, the result will probably be six individual scanning locations.

Figure A.24 shows the outcome of our analysis for one partition. Following the logic above, we concluded that option 5 with eight machines was best.

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0.16 of AAL flights at DFW	Number of machines			Results							
				Max delay (min)		Criteria (% less than)			Days over criteria		
	Tier 1	Tier 2	Total	Point	Exp value	10 min	30 min	60 min	10 min	30 min	60 min
1 Estimate based on daily averages	2	2	4	165.1	Total bags = 36,857						
2 No queue greater than 60 min	2	3	5	17.13	136.2	0.0	59.0	59.0	365.0	149.5	149.5
3 No queue greater than 30 min	3	3	6	15.1	82.59	0.0	70.9	70.9	365.0	106.4	106.4
4 No queue greater than 15 min	3	4	7	5.84	31.53	47.8	92.1	92.1	190.4	28.8	28.8
5 No queue greater than 10 min	3	5	8	4.29	20.71	67.0	96.4	96.4	120.6	13.3	13.3
6 Reliability hedge, exp value < 10 min	4	5	9	2.99	8.73	87.1	98.8	98.8	47.3	4.5	4.5
7 Impact of variations in input											
Reliability = 85%	3	5	8	4.29	81.50	34.6	80.1	80.1	238.8	72.5	72.5
Reliability = 80%	3	5	8	4.29	124.74	25.1	69.0	69.0	273.4	113.1	113.1
a Hedge vs. 80% reliability	3	7	10	2.14	8.07	91.1	98.9	98.9	32.6	4.1	4.1
8 Reliability hedge, all AAL flights	15	22	37	7.25	13.69	34.0	98.3	98.6	240.7	6.2	5.0
Scaled AAL partitioned flights	18	30	48	4.29	81.50	34.6	80.1	80.1	238.8	72.5	72.5
Percent increase			29.7								

Figure A.24—EDS Deployment Options Considered, Single Airline Partitioned Into Six Separate Scanning Locations

Assuming the other five partitions are comparable, this suggests a total deployment of 48 machines, compared to the nonpartitioned American Airlines requirement for 37 machines. Thus, the partitioning leads to an increase of 11 in total machines required for American, or an increase of about 30 percent.

Comparisons Across the Three Cases

What do these three cases mean in terms of anticipated EDS machine buy sizes? The top part of Figure A.25 compares the 1998 and 2010 EDS buys given comparable "maximum delay performance standards." Given the scaling for

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Percent increase in total bags = 62.2% Total bags = 55,452

Comparing 2010:1998 deployments		Number of machines			Results							
					Max delay (min)		Criteria (% less than)			Days over criteria		
		Tier 1	Tier 2	Total	Point	Exp value	10 min	30 min	60 min	10 min	30 min	60 min
9	Reliability hedge (1998)	22	32	54	6.66	14.17	37.2	97.9	99.9	229.1	7.8	0.4
	Scaled to full baggage traffic	36	52	88								
	Reliability hedge (2010)	31	44	75	6.62	13.68	34.1	94.2	99.4	240.4	21.1	2.2
	Percent increase			–14.8								

Ratio of bags (AAL vs. all Flts) = 0.410 Total bags = 36,857

AAL flights only (CY1998 traffic)		Number of machines			Results							
					Max delay (min)		Criteria (% less than)			Days over criteria		
		Tier 1	Tier 2	Total	Point	Exp value	10 min	30 min	60 min	10 min	30 min	60 min
10	Reliability hedge (AAL only)	15	22	37	7.25	13.69	34.0	98.3	98.6	240.7	6.2	5.0
	Scaled to full demand	37	54	91								
	Single partition (< 10 min delay)	3	5	8	4.29	20.71	67.0	96.4	96.4	120.6	13.3	13.3
	Scaled to full demand	44	74	118								
	All flights reliability hedge	31	44	75	6.62	13.68	34.1	94.2	99.4	240.4	21.1	2.2
	Percent increase (AAL, no part)			21.3								
	Percent increase (AAL, 6 parts)			57.3								

Figure A.25—Comparison of 2010, 1998, and Single-Airline Deployment Needs

additional traffic, the required growth in EDS deployments actually is slower than the growth in baggage screening demand. The primary reason for this is the overall reduction in the difference between the traffic peaks and valleys. The new flights (those added to the 1998 OAG) are spaced between the existing flights, filling the valleys without comparable increases in the peaks. This leveling effect still leads to higher demand for EDS equipment, but at a rate lower than that of the new traffic. Of course, centralization is the principle reason why such economies of scale were possible.

The lower part of Figure A.25 compares American Airlines flights in 2010 with all flights in 2010, allowing us to judge the inefficiency of having individual airlines assume the responsibility for scanning baggage that is to be placed on their aircraft. Assuming that American can centralize its baggage scanning equipment, a 21 percent increase is implied, which suggests that a reasonable requirement for equipment deployments at DFW in 2010 might be 88 machines, assuming that airlines continue the current practice of assuming responsibility for scanning their own baggage. If American cannot centralize its equipment and has to partition it into six separate scanning areas, the total climbs to 118 machines, for a total increase in buy size of over 50 percent. The ratios of these two buy sizes over the original FAA estimates are 3.03 and 3.93, respectively.

Estimating a Total Buy Size for All Airports

To scale our findings to total EDS machine buys for all airports, we took the straightforward approach of simply multiplying the planned total buy of 2,051 EDS machines by 2.5, the scaled increase derived for DFW. The result is 5,077. We believe this number to be conservative. As our analysis demonstrated, there is an economy of scaling when traffic grows at an airport. Because most airports have fewer scheduled operations than DFW does, we would expect their scaled requirements to be somewhat larger.

Our estimate is also conservative because it assumes centralized baggage scanning, which is currently inconsistent with the practices of U.S. domestic airlines. Many foreign airports practice (at least to some degree) centralized baggage handling, enabling them to have a central facility for EDS scanning. U.S. airlines and airports could follow suit, albeit only with major modifications to the airports. If centralization does not occur, a buy size closer to 6,000 may be required. Scaling the two machine buy estimates for the American Airlines cases, we get total buy sizes of 6,221 and 8,067 respectively. Adding in other uncertainties (e.g., reliability) to the nonpartitioned American case, the real number could easily grow to 7,000.

Finally, to repeat what we said earlier, the real EDS equipment buy size needs to be determined with calculation tools far more sophisticated than the simple spreadsheets used here. We are confident that our work does not overstate the need. How much the need is understated is uncertain.

Would the Results Have Been Worse If the Input Variables Were Treated as Stochastic?

Our calculations assumed that the stated values of all the variables were fixed for a particular run. Clearly, this is not the case. For example, the likelihood of detecting an object in a bag that has the right density to be potentially threatening is a random event. Our calculations assumed that every fourth bag in the sequence would have an object with suitable density to send the bag to tier 2. In the real world, sometimes none of the four bags would be sent to tier 2, and sometimes all four bags would be sent. Our question here is whether random outcomes of this kind would alter the conclusions we reached.

Using the all flights at DFW, 2010, case, we selected the balanced tier 1 and 2 deployments shown in Figure A.11 for our calculations. For each deployment we ran 100 trials. Two separate cases were run for each trial—one in which we randomized only the arrival of bags with suitably dense objects for detection and assignment to tier 2, and one in which we also randomized the arrival of the bags themselves. In both cases we balanced the outcomes to ensure that the overall statistics were identical to the nonrandom results (we did not want to skew the results by altering the overall demand statistics). The results were averaged over the 100 trials, and each outcome was compared against the outcome for the case in which no randomness was permitted.

Figure A.26 shows the results. Overall, the maximum delays increased by a few percent.[38] Based on this result, we conclude that stochastic outcomes are going to yield results somewhat higher than those shown in our outcome charts, but by an amount that will raise the total buy requirements by only a small amount. While this factor should not be ignored (and would obviously be a prominent output in any large-scale simulation of airport throughput), it also should not be cause for serious concern.

The Potential Role of Passenger Profiling in Reducing the Buy

Passenger profiling has the potential both to increase in the near term the likelihood that those bags most likely to pose a threat get scanned and to lower in the long term the total buy size. The goal of 100 percent scanning of all baggage

[38] The negative change in maximum delays shown for the smaller deployment sizes is not an outlier. It persists even when the number of trials is greatly increased. The overall delays increase slightly, but the peaks drop.

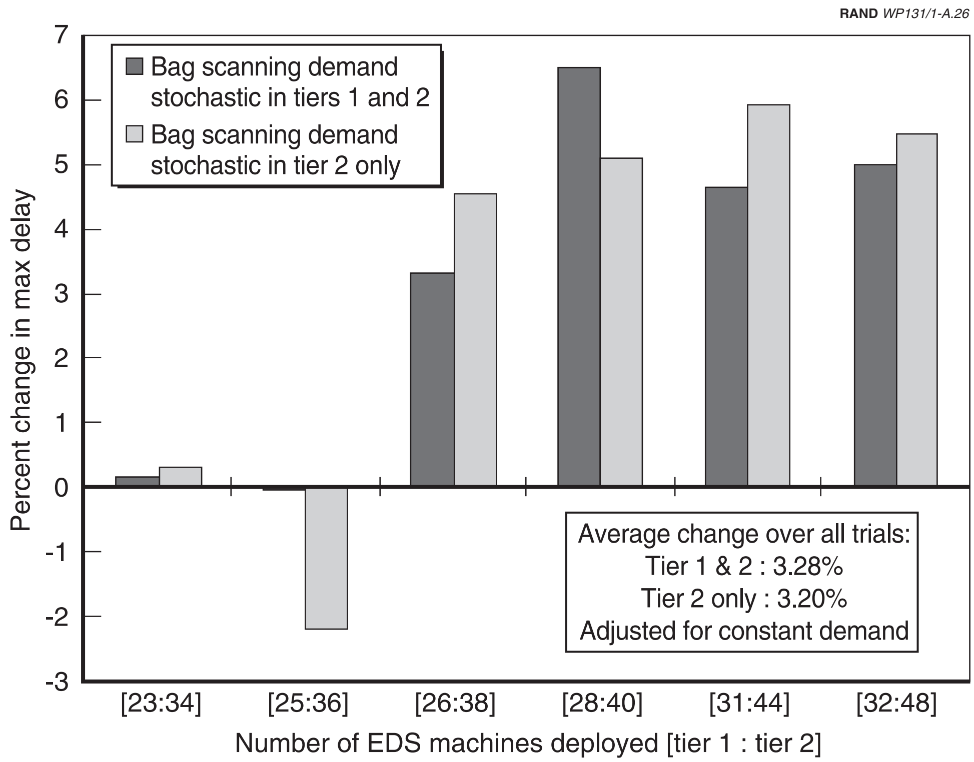

Figure A.26—Stochastic Results Versus Expected Value Results, All Flights at DFW, 2010

cannot be met for several years if airport throughput is to remain at a reasonable rate. Thus we are left with the question of how many bags must be *removed* (i.e., judged *not* to be a potential threat) from the baggage scanning queue so that all remaining bags can be scanned within a reasonable time.[39]

Figure A.27 plots the maximum delay times associated with total machine buy size, assuming that all equipment is fully operational and being used. The baggage demand at DFW was reduced by excluding from the baggage queue a fraction of all bags arriving at the check-in counter. The chart shows reductions of up to 50 percent. Not surprisingly, the drop in demand is almost exactly matched by a drop in the number of machines needed to achieve a specific value

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[39]As noted in the main part of this paper, profiling can be used in two ways—to identify potential threats and to identify nonthreats. The latter is probably the best approach to use if we are talking about reductions of 50 percent in the total baggage flow. Having a list of those passengers most likely to be terrorists would greatly reduce the number of bags to be scanned but would raise some serious questions about (a) the list's completeness and (b) unequal treatment of some people who fall too close to the class of people deemed threatening. Both approaches can and should be used simultaneously, but it is likely that something close to 50 percent of all fliers have histories that would rule out terrorist behavior as even remotely likely.

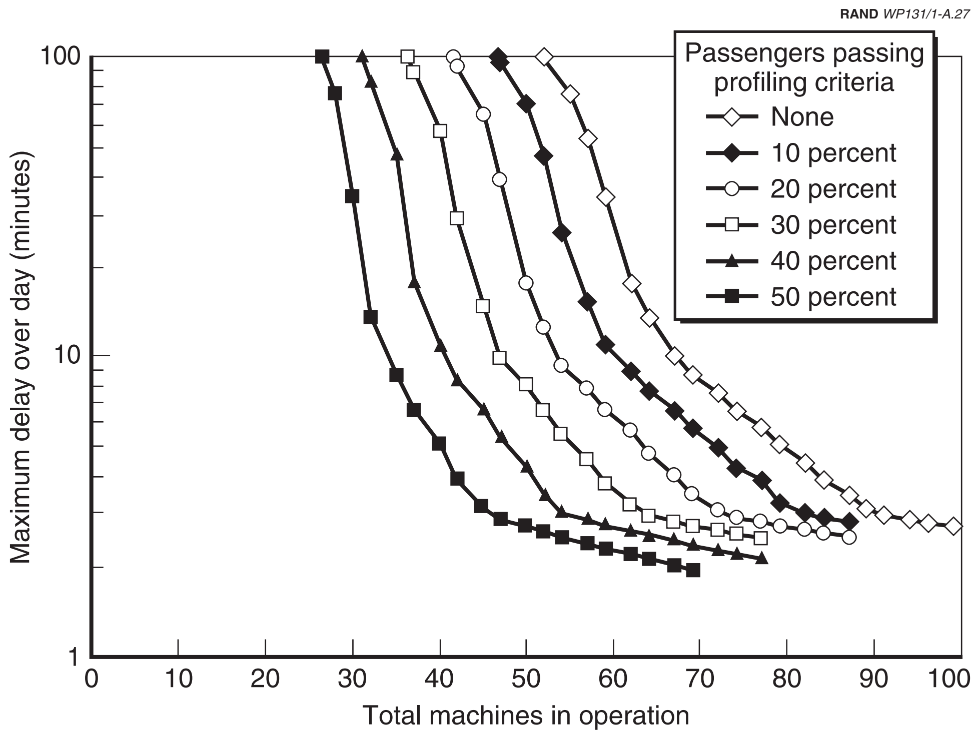

Figure A.27—Effect of Reduced Number of Bags Needing to Be Scanned on Maximum Delays

of the maximum delay point estimate. Thus, if passenger profiling can eliminate 50 percent of the bags as threats, the number of machines required to handle the remaining bags is about half what we estimated above.

Obviously, the successful use of profiling can have a dramatic impact on how many EDS machines need to be acquired and deployed in order to scan all bags likely to be threatening. We do not know how many travelers might confidently fall into the "safe" category; nor do we know what additional data would have to be provided to the airlines/airports/FSA to achieve demand reductions that would enable airports to avoid costly facility modification/replacement. On the one hand, it seems logical to expect that people who fly frequently will disproportionately satisfy the positive profiling criteria. And because these people often fly at peak hours, we might expect profiling to have a greater impact on reducing peak demand than is indicated here. On the other hand, those who fly frequently also tend to carry their bags onto the aircraft, which means the effect could be less than is indicated. Without data, it is impossible to know which factor is the most important.

Figure A.28 parallels earlier figures, showing the performance results for various equipment deployment options at the 50 percent demand reduction level.

The smaller deployment numbers make the outcomes more sensitive to reliability, suggesting that reasonable buy sizes might be about 60 percent (rather than 50 percent) of those recommended at the 100 percent scan level. Figure A.29 shows how the deployment options in Figure A.28 vary as demand is reduced. Noteworthy is that the indicated buy sizes scale almost linearly with reductions in demand. This gives us an easy way to assess the value of passenger profiling in managing both baggage check-in delay and overall EDS buy requirements.

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All flights at DFW, 50% bag reduction	Number of machines			Results							
				Max delay (min)		Criteria (% less than)			Days over criteria		
	Tier 1	Tier 2	Total	Point	Exp value	10 min	30 min	60 min	10 min	30 min	60 min
1 Estimate based on daily averages	9	12	21	274.84	Total bags = 36,857						
2 No queue greater than 60 min	12	17	29	47.90	125.00	0.0	0.0	4.7	365.0	365.0	347.8
3 No queue greater than 30 min	13	18	31	22.08	89.39	0.0	3.8	28.0	365.0	351.1	262.9
4 No queue greater than 15 min	13	19	32	13.73	73.28	0.0	10.7	43.8	365.0	326.0	205.0
5 No queue greater than 10 min	14	20	34	9.6	45.93	2.8	39.6	73.0	354.8	220.6	98.6
6 Reliability hedge	15	22	37	6.76	22.30	34.0	76.5	92.7	240.7	85.7	26.6
7 Added reliability hedge	16	23	39	5.55	13.92	63.7	91.1	97.7	132.4	32.7	8.3
8 Reliability hedge, exp value < 10 min	17	24	41	4.59	9.64	83.9	97.1	99.4	58.6	10.7	2.3
9 Reliability hedge +, exp value < 10 min	18	26	44	3.30	6.55	96.0	99.3	99.9	14.5	2.6	0.5
10 Impact of variations in input											
Reliability = 85%	16	23	39	5.55	27.75	30.3	69.6	87.8	254.4	111.0	44.4
Reliability = 80%	16	23	39	5.55	51.62	10.4	41.6	67.1	326.9	213.3	120.2
a Hedge vs. 80% reliability	20	29	49	2.81	8.99	86.8	96.1	98.8	48.1	14.2	4.4
11 Reliability hedge, all bags	31	44	75	6.62	13.68	34.1	94.2	99.4	240.4	21.1	2.2
Reliability hedge, 50% of bags	15	22	37	5.55	13.92	63.7	91.1	97.7	132.4	32.7	8.3
Percent decrease			50.7								

Figure A.28—EDS Deployment Options When Passenger Profiling Reduces Total Bags in Queue, 2010

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		Number of machines			Results comparing EDS buys and delays versus reduced demand							
					Max delay (min)		Criteria (% less than)			Days over criteria		
		Tier 1	Tier 2	Total	Point	Exp value	10 min	30 min	60 min	10 min	30 min	60 min
Criterion PV < 10 min	100%	28	40	68	9.60	36.47	0.1	43.7	85.1	364.7	205.5	54.4
	90%	25	36	61	9.60	39.04	0.2	54.3	54.5	364.4	166.9	56.5
	80%	22	32	54	9.60	42.04	0.3	37.2	75.0	363.8	229.1	91.3
	70%	20	28	48	9.60	38.01	0.6	60.2	82.1	362.7	145.2	65.4
	60%	17	24	41	9.60	40.90	1.3	43.0	83.9	360.1	208.1	58.6
	50%	14	20	34	9.60	45.93	2.8	39.6	73.0	354.8	220.6	98.6
Reliability hedge	100%	31	44	75	6.62	13.68	34.1	94.2	99.4	240.4	21.1	2.2
	90%	28	40	68	6.38	13.44	43.7	96.7	99.4	205.5	12.1	2.3
	80%	25	36	61	6.08	13.06	54.3	94.4	98.8	166.9	20.5	4.3
	70%	22	32	54	5.70	12.88	48.9	97.0	99.2	186.6	10.8	2.8
	60%	19	28	47	5.46	12.38	60.5	94.8	99.0	144.1	19.2	3.6
	50%	16	23	39	5.55	13.92	63.7	91.1	97.7	132.4	32.7	8.3
Exp value < 10 min	100%	32	47	79	5.22	9.73	71.5	98.6	99.9	103.9	4.9	0.3
	90%	29	42	71	4.24	9.98	73.9	99.2	99.8	95.1	3.1	0.6
	80%	26	38	64	4.86	9.55	81.7	98.5	99.7	66.7	5.6	1.2
	70%	23	33	56	4.98	9.87	72.2	99.0	99.8	101.6	3.6	0.8
	60%	20	29	49	4.46	9.20	81.2	98.3	99.7	68.7	6.4	1.0
	50%	17	24	41	4.59	9.64	83.9	97.1	99.4	58.6	10.7	2.3

Figure A.29—Comparison of Profiling Results Across Criteria Categories and Total Demand

Sizing the Buy

We started this appendix by assessing equipment buy sizes corresponding to the FAA's assumed maximum delay standard of no more than 60 minutes. The results suggest that average delays could be far longer, especially if equipment reliability is taken into account. In various examples we suggested alternative standards, including maximum delays of 10 minutes or less.

The actual standard should be determined, however, based on an assessment of the potential damage that excess delays might cause the air transport industry and the nation's economy. Understanding how passengers will react to growing airport congestion and the increased ticket price associated with security measures is central to such an assessment.[40] Unfortunately, basic data on passenger preferences are not robust and, in some cases, apparently do not exist. Nevertheless, based on similar analyses, we believe it is almost certain that the potential loss to the national economy would, as a minimum, be measured in billions of dollars—and potentially in tens of billions of dollars—per year. Judgments about the proper size of the buy should be weighed against these numbers.

Some Additional Considerations

Our analysis was based on current EDS technology. The performance of any feasible alternative detection technologies would surely alter our calculations. The Aviation Security Technology Conference held in Atlantic City in November 2001 discussed a broad range of future options. This is not the proper place to discuss these options and their potential. Nevertheless, it is possible that future detection technology may alter our assessments. To assess this potential, we scaled machine buy requirements against hypothetical scanning rates.

For simplicity we assumed a single-stage system. The operating assumption is that the machine first scans the bag to see whether there is anything suspicious. If it finds nothing, the bag is sent to the baggage assembly area; if it finds something suspicious (perhaps via the machine's automatic threat detection algorithms), the bag is stopped, backed up, and exposed to a more detailed scan. If that scan still finds something troubling, the bag is sent to an area where it is opened and inspected by humans. We assume that the latter is a low probability occurrence and does not materially alter the general throughput calculation related to bags making it onto aircraft.

For calculation purposes, we used the demand profile taken from the 2010 OAG for DFW (see Figure A.3). Figure A.30 shows the resulting maximum queuing delays as a function of the operational scan rate. We included three passenger spread assumptions (0, 30, and 60 minutes) to demonstrate the sensitivity to this parameter. It is clear that total system scan rates above 150 bags per minute are needed to keep the maximum bag delay below the 10-minute mark.

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[40] There is a growing movement in Congress and at the DOT to require that the flying public bear most of the cost of making flying safe and secure. This movement has not as yet considered the consequences of increasing ticket prices by an amount that could raise the overall price 25 percent or more. Existing estimates of the elasticity of passenger willingness to fly as a function of ticket price are between –0.7 and –1.0. If these elasticities are close to correct, the drop in passenger demand would be substantial if the cost of security were fully added to ticket price.

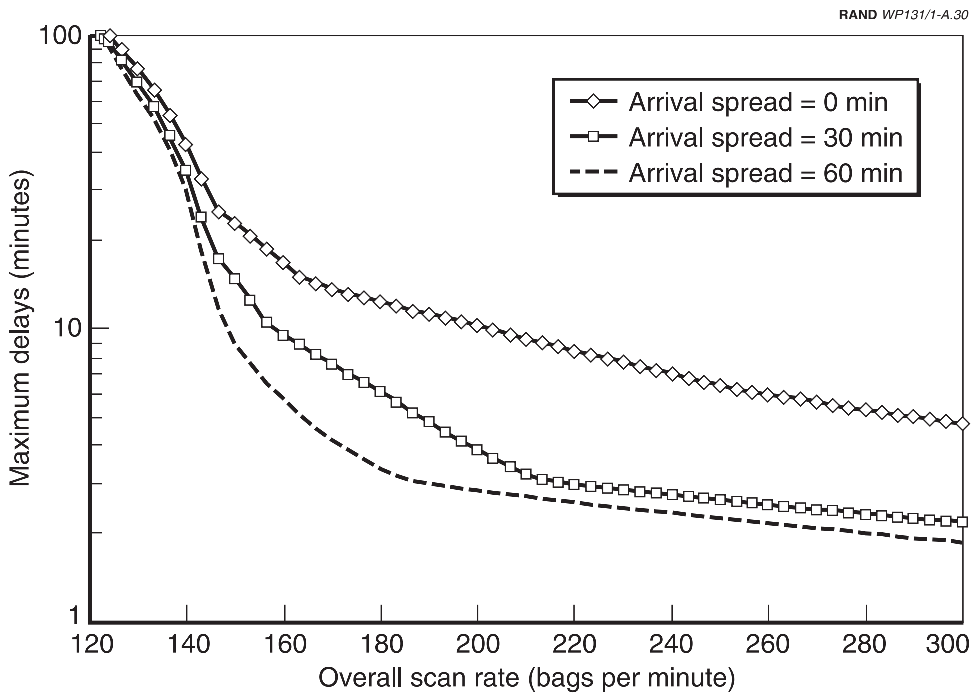

Figure A.30—Maximum Queuing Delays Versus System Scan Rate

If we use the high-speed EDS machines in a single-stage mode and assume the same scan rates (350 bags per hour in tier 1, and 60 bags per hour in tier 2) and the same probability of false positives, we end up with a single-machine combined rate of 142 bags per hour. Figure A.31 shows the single-stage point and expected values resulting from this scan rate. Comparison of the single-stage and two-tier results shows essentially no difference for point delays and slightly better performance for the single-stage operation. Two-tier performance is worse because of possible asymmetric EDS outages (e.g., more tier 2 than tier 1 machines fail). Single-stage EDS outages reduce both rapid scan and detailed scan capabilities evenly, as each machine is doing both.

Single-stage systems naturally adapt to uncertainties in the balancing between rapid scan (tier 1 operations) and detailed scan (tier 2 operations). One example of the importance of this was mentioned in the discussion of false positive detection rate. Figure A.32 plots the maximum point delays as a function of assumed operational false positive detection rate, selecting the all flights at DFW, 2010, "preferred" option of 31 machines in tier 1 and 44 in tier 2. Also shown in the figure is a plot of the maximum point delays assuming a single-stage deployment with the same number of machines (75). The delays match at the two-tier design point of a false positive detection rate equal to 0.25. But they

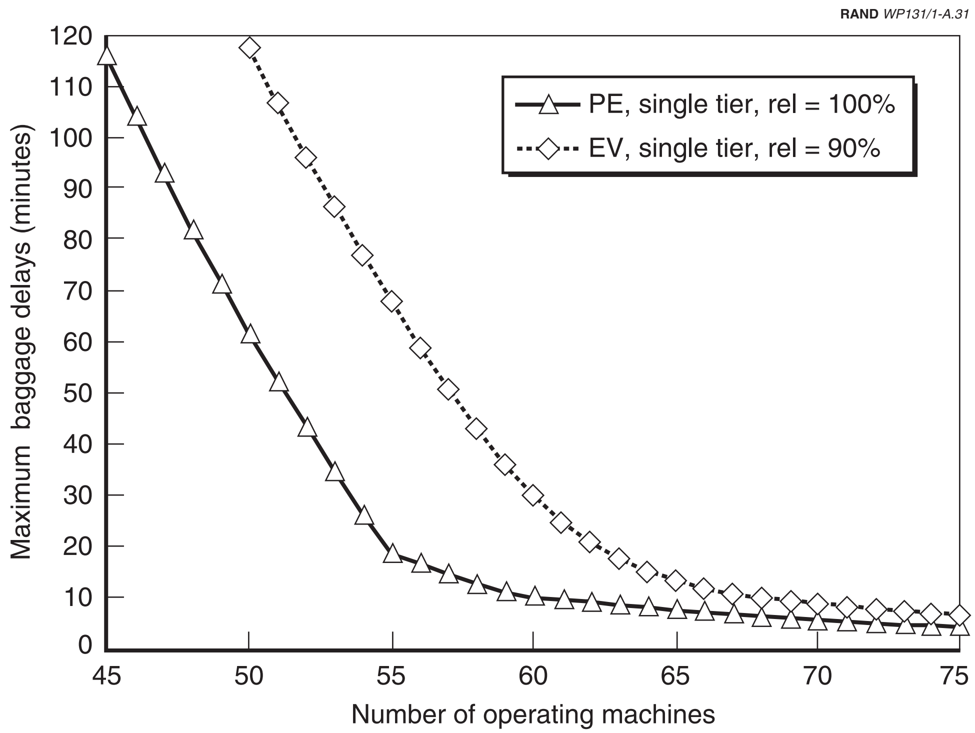

Figure A.31—Point and Expected Values for Maximum Delays as a Function of Total EDS Machine Buy Size

diverge substantially at off-design points. The same outcome would occur if the EDS machines could be swapped between tiers without degradation in performance. Whether this is practical remains to be shown.

The single-stage scan rate (bags per hour) per EDS machines at a false positive detection rate of 0.25 is about 142 bags per hour. This scan rate could be improved if we could lower the false positive detection rate or the time needed for the detailed scan. A number of briefings at the Technology Security Conference proposed approaches that would do both. Others claimed that their technology would achieve rates well over 1,000 bags per hour. Details on realistic detection performance and other factors were generally missing or classified. But it appears that promising technologies are being developed and should allow significant scanning capabilities at reduced deployment numbers.

Trace Scanning Options

One technology that is well developed is trace detection. Trace detection machines "sniff" molecules that emanate from explosive materials. These

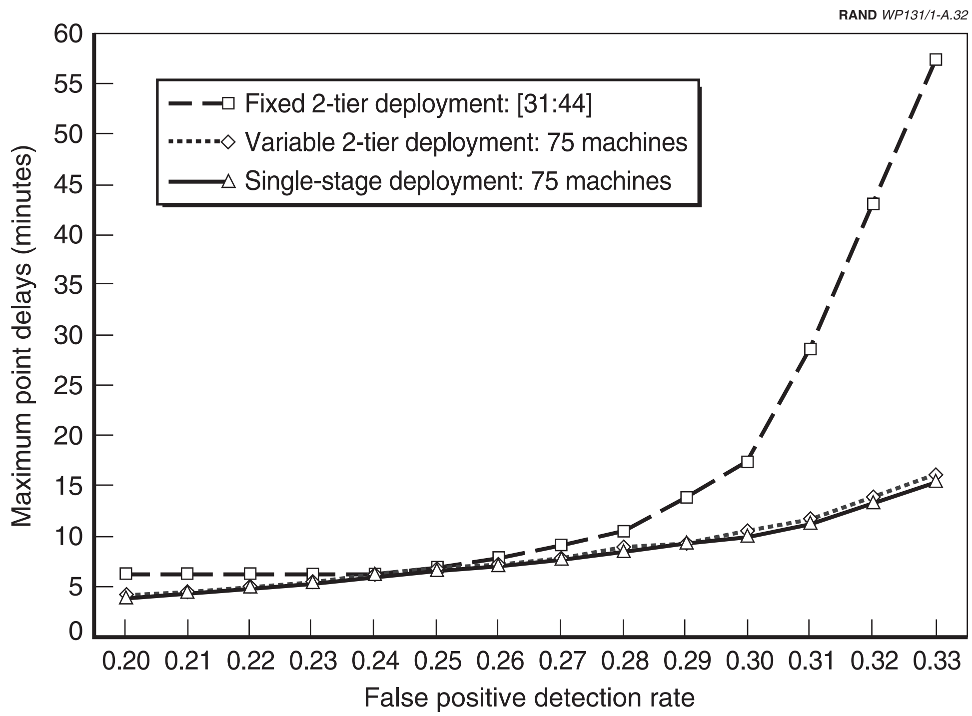

Figure A.32—Sensitivity of Performance of Different Concepts of Operation to System False Positive Detection Rate

molecules could come from the bomb itself or from the environment around the bomb, assuming that a small quantity of the bomb material was inadvertently spread onto them. Trace detection equipment is already deployed at many carry-on baggage inspection sites, and elsewhere. No surprisingly, trace detection equipment has been mentioned as a potential stopgap measure for bomb detection in case adequate EDS equipment is not available by the end of this year.

Trace detection equipment can replace or augment EDS equipment at any stage in the detection process. We initially considered two ETD (electronic trace detection) options:[41]

1. A stand-alone single-stage ETD system.
2. A combined multistage EDS/ETD system, where the EDS equipment is used in the first tier and ETD equipment is used in the second.

[41] There is a third option—following the trace detection scan with a second-stage EDS scan whenever the trace scan yielded evidence of a potential bomb. We will address this option parenthetically later in this section.

In both options, we initially assumed that adequate trace detection performance would require a full scan of the bag and its contents, including the opening of individual bags and a thorough sweep of their interior contents. Less intrusive options—those involving opening the bag but not intrusively sweeping the bag's contents or (even less intrusive) not opening the bag but only sweeping its exterior—were not considered in our initial look because of their inherently lower bomb detection probability.[42] In the first option we assumed that the baggage scan would be undirected, i.e., there would be no a priori information regarding which part of the bag has a suspicious object. In the second option, we assumed that the EDS machine provides an approximate location in the bag needing trace scanning, allowing a directed search.

Option 1: Single-Stage ETD Scanning Options

We will address the ETD single-stage standalone option first, assuming no a priori knowledge about potential threats within the individual bags. Fortunately, we have data supporting trace search options involving open-bag scanning.

The FAA run operational evaluation tests on stand-alone ETD baggage scanning at Eppley Airfield (OMA) in Omaha, Nebraska, and at Stewart Airport (SWF) in upper New York.[43] That data include two distinct cases:

- An undirected search (labeled NDT) of the contents inside the bag, where no prior x-ray existed, or
- A prior x-ray scan that identified objects in the bag that needed to be scanned, leading to a directed search (labeled MDT) of the contents inside the bag.

Figure A.33 shows the overall results of these tests. The mean scanning time results from the tests showed relatively small differences between the two search strategies (directed versus nondirected) at the two airports, but a fairly large difference between airports (just under 3 minutes per bag at Omaha, compared to 4 minutes per bag at Stewart). The distributions in scan time were broad in all cases, suggesting a lot of variability from one bag to the next. This variability

[42] A full scan would include both an external scan of the bag and a scan of the exterior of the interior of the bag prior to intrusively sweeping the bag's interior contents. We subsequently looked at ETD options that did not require opening the bag (these options are covered later in this section).

[43] See Roy Mason, *Directed Trace and Non-Directed Trace Efficiency Study*, Proceeding of the Third International Aviation Security Technology Symposium, November 2001

could easily lengthen queue times, extending them significantly over a mean average, but we did not attempt to include this factor in our calculations.

Figure A.34 comments on these results and shows the number of single-stage ETD machines (under the NDT column) that would be required at DFW if the 2010 baggage demand were assumed.[44] These numbers are large and would stress the airport's floor space capacity even though the trace detector's footprint is relatively small. Furthermore, the likelihood of detecting the presence of the bomb was only 85 percent in the tests, an outcome not as close to 100% as almost everyone would like.

Single-stage trace detection systems prompt a question that needs addressing, i.e., how to respond when the ETD machine reports a detection. Current procedures at airports call for evacuation of the terminals when a serious bomb threat exists. Such procedures would be unacceptable under the circumstance where alarms were common and even frequent during the working day, as would be likely even assuming the very low false alarm rates currently attributed to ETD machines (less than 1.0 percent). An additional stage is needed. For purposes of this analysis, we assumed that it would be a hand search, where the full contents of the alerted bag would be "dumped" onto a table and each object inspected.[45] The above analysis added no time for this search, recognizing that it would involve only a small number of bags.

Recent TSA work with the airports suggests a trace detection approach different from what we assessed above. Rather than a full bag scanning procedure, TSA is looking at a baggage scanning strategy that included only partial scans. It is our understanding that current studies associated with ETD buy requirements are assuming that only 20 percent of the bags would receive a full scan, i.e., the nondirected open-bag intrusive scan that we assumed in our option 1. An additional 40 percent of the bags would receive only an exterior scan, and the remaining 40 percent would receive only a nonintrusive interior scan. [46] It is also our understanding that the following scanning times have been specified for assessment purposes:

- ETD scan of the exterior of bag only: 60 seconds.

[44]The MDT results require some sort of scan in a prior stage.

[45]For safety reasons, we also assume that this stage would be performed in a location well removed from the passenger-heavy part of the airport, thus adding substantial delay to the search of that bag.

[46]These fractions are obviously tentative and likely to change prior to full deployment. However, random selection will be used to determine which bags are given which degree of search.

RAND *WP131/1-A.33*

- Performed by Hughes Technical Center at two airports (OMA, SWF)
- Two operational concepts tested
  – Directed search, using x-ray machine input (MDT)
  – Nondirected search (NDT)
- Results (time per bag)

	Elapsed Time (seconds)		
	min	max	mean
Omaha (OMA)			
MDT bag processing time	32	602	156.0
NDT bag processing time	12	761	176.7
Stewart (SWF)			
MDT bag processing time	32	1131	239.1
NDT bag processing time	18	1015	243.1

- Percentage of bombs detected = 85.7%

Figure A.33—Experimental Experience on Trace Detection Performance in the Field

RAND *WP131/1-A.34*

- Trace detection equipment has small footprint, relatively easy to install
- But
  – Detection probability substantially less than 100% (~85% in ops tests)
  – Time for bag search is substantial
- Using 10-minute max delay scanning rate requirements, the number of trace detection stations would be as follows:

Number of ETD stations required (DFW, 2010)

	Bags/min=173.2	
	MDT	NDT
Omaha (OMA) results	451	511
Stewart (SWF) results	691	702

Figure A.34—Maximum Delays Versus Minimum Required Number of ETD Machines in Tier 2

- ETD scan of the exterior of an opened bag (the scan does not penetrate into the bag's interior contents): 105 seconds.
- ETD scan of the contents of an opened bag (the equivalent of the above NDT search): 165 seconds.

In all cases, a false positive detection probability for any scanned bag was specified to be 0.6 percent.[47] The authors know of no comparable detection probabilities for the partial scans.[48]

We are not aware of the data that support the above timelines. The previously discussed FAA tests included neither an external-to-the-bag trace detection scan only option nor one that involved only an exterior scan of the bag's interior contents. However, they are not unreasonable, albeit perhaps slightly optimistic compared to the FAA's test data.[49]

Using the above assumptions we find that the number of trace detection machines needed at DFW is substantially smaller than calculated using the FAA's test results. Figure A.35 shows the maximum delay encountered as a

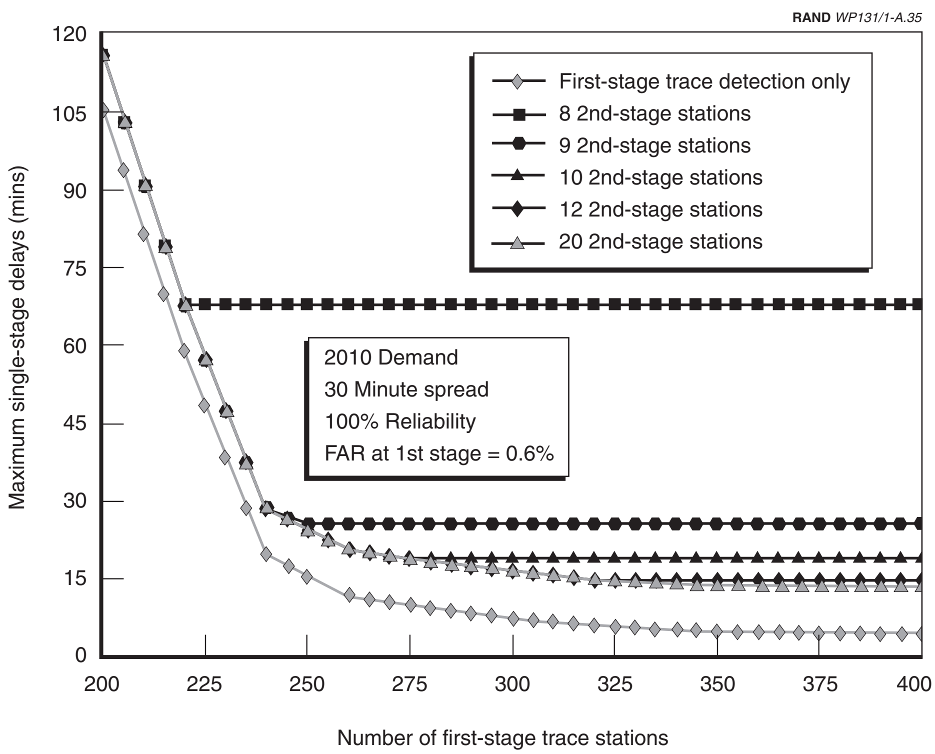

Figure A.35—Required Second-Stage ETD Stations Versus Maximum Delays

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[47] This assumption is obviously subject to question. Without real test data, we had no reason to select a different false alarm rate.

[48] Detection probabilities and false alarm rates are coupled; higher detection rates usually imply higher false alarm rates, assuming a common sensor and a fixed target characteristics.

[49] The only comparable datum point is the time needed for an intrusive, non-directed interior scan. The TSA-specified time of 165 seconds is somewhat shorter than the OMA test result of 176 seconds, and considerably shorter than the Stewart result of 243 seconds.

function of the number of trace stations in operation. If the ETD machines were 90 percent reliable, the required number of ETD stations to keep average delays below 10 minutes would be approximately 300 machines.

The aforementioned studies also recognized the need for a second stage to handle the infrequently false positive trace detections. They posited an additional 10 minutes for the "dump the bag" hand search. We have used the 10 minute number to show in Figure A.35 how many stage-two stations would be needed.

Option 2: A Combined EDS/ETD Scanning System

Trace detection systems can be used in conjunction with other machines. This option assumes that the first stage uses EDS machines in their rapid scan mode and the trace detection machines in the second tier to resolve any alarms that may have resulted. Assuming the more favorable full baggage scan rates (under the MDT label) recorded at Eppley Airfield in Omaha, we balanced trace detection total scan rates to match the tier 1 rates where EDS machines are used. The results are shown in Figure A.36. Not surprisingly, the total number of trace

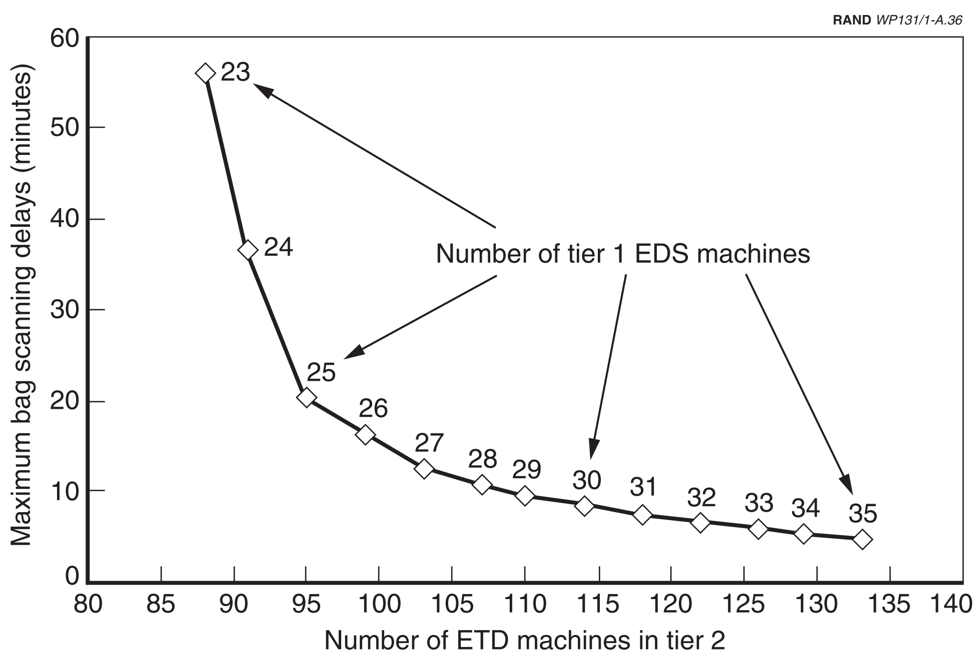

Figure A.36—Maximum Delays Versus Minimum Required Number of Trace Detection Machines in Tier 2

detection systems is still very large, more than 110 for maximum bag queuing delays of less than 10 minutes. If we use instead the recent data from the studies mentioned above, that number would fall to approximately 70.

The above simply confirms that trace detection equipment can substitute for EDS machines, but the number of such machines will have to be large to get the scanning done. Lacking sufficient EDS machines, trace detection equipment can offer a degree of additional bomb detection capability that will increase overall security. But, as was true for the EDS equipment, care must be taken not to force all bags to be subjected to in-depth trace detection when the resultant delays would grow beyond reasonable. And, although the footprint of trace detection equipment is considerably smaller than for the large EDS machines, it is still unlikely that the full amount of equipment and personnel needed for 100 percent scanning can be installed and operated within the current configurations of the large metropolitan airports. As noted in the main paper, facility space considerations are likely to remain the long pole in the deployment tent.

Summary

Our overall results are as follows:

- Using a 1998 OAG for Dallas–Fort Worth Airport (DFW), 37 in-operation EDS machines were required to achieve a maximum delay of less than 1 hour. This is somewhat larger than the FAA's assessment of only 30 machines. But the closeness of the two estimates gives us confidence that our analysis is consistent with what the FAA did earlier.
- Assuming an equipment reliability factor of 90 percent, and demanding that only a small percentage of all outcomes produce delays larger than 60 minutes, at least 49 EDS machines need to be deployed in the 1998 OAG case.
- Holding scanning performance constant, other factors could raise this deployment requirement by 50 percent or more. Among those factors considered were:

  — A 10 percent increase for peak-hour load factors of 80 percent.

  — A 15 percent increase for operational reliabilities of 80 percent.

  — A 20–30 percent increase for lack of consolidation of all scanning equipment at the airport.

- Using a postulated 2010 OAG for DFW, similar assumptions lead to deployments in the 75–85 range. In percentage terms, this growth is substantially less than the forecast increase in passenger growth at DFW.[50] However, given the need for significant airport redesign and expansion to house this number of machines, as well as the time required to achieve that redesign/expansion, building the capability to handle this many machines would appear to be wise. The lower of these two numbers is the factor we used in estimating a 2.5 increase (or 5,000 total machines) needed before 2010.
- Partitioning the baggage scanning process among individual airlines would increase these numbers by up to 30 percent. Thus, total EDS requirements at DFW could exceed 100 before everything is done.
- Reducing the baggage scanning requirements through the use of passenger profiling would lower the total buy size requirements commensurately. The scaling is nearly one-to-one. It suggests a short-term approach to meeting the spirit of the Aviation and Transportation Security Act's "scanning 100% of all checked-in bags (that have any likelihood of containing a bomb)" when not enough scanning equipment is available to do the entire job. It also suggests a longer-term approach that integrates profiling into the baggage scanning system, thereby lowering the total costs of providing security while meeting the highest standards of performance.

No matter how we slice the results, it is impossible to conclude that the FAA's estimates for EDS deployment requirements at DFW are going to produce satisfactory results. We believe that, overall, a planned deployment of at least 5,000–7,000 machines is in the ballpark of what is truly needed.

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[50] The postulated OAG adds new flights in the "holes" in the existing aircraft arrival and departure schedule. These additions tend to smooth out the peak demand, essentially adding new baggage demand at times when there is a relative lull. As a result, the equipment is able to accommodate the new demand without a concomitant increase in the number of machines needed.

B. Simulation Modeling of Airport Security Operations[1]

Simulation modeling provides airports, airlines, and government agencies with a tool for evaluating the performance of new security procedures and equipment prior to implementation. The benefit of a simulation approach is that one can evaluate not only the security process, but also all the up-line and down-line effects that process has on the entire airport. Therefore, simulation modeling is invaluable in developing procedures and equipment plans that achieve the highest levels of security and, to the extent possible, preserve passenger convenience.

Modeling Approach

Computer simulation modeling uses mathematical models to represent the design and operations of airport terminals. Although flow models and other simulation methods exist, the most robust approach is to use stochastic, discrete-event simulation modeling. With this approach, individual entities—such as passengers and baggage—travel through the airport processes all dependencies and interactions between them and those processes being captured as they go.

The simulation logic models both the physical layout of and the rules that govern facility operations. For example, the model includes the travel distance between the ticket counter and the security checkpoint, as well as ticket counter and security checkpoint staffing by time of day, processing rate distribution, and work method. The simulation model is thus a very realistic representation of an operating airport terminal.

Because the objective of simulation modeling is to evaluate system performance, it is critical that accurate passenger and baggage demand be used. A 24-hour, design-day schedule best represents passenger and baggage demand. As the simulation model is executed, the passenger and baggage demand from the design-day schedule flows through the airport system, and passenger terminal and baggage handling system statistics are collected. The model collects

[1]This discussion of simulation modeling of airport security operations was provided to RAND for inclusion in this paper by TransSolutions, an independent consulting group specializing in the analysis of passenger and baggage flow at airports. TransSolutions has worked at more than 80 percent of the world's largest airports, including 24 of the top 25 airports in the United States. Currently, TransSolutions is helping several airport clients improve the efficiency of security checkpoint areas and planning for 100 percent EDS inspection of all checked baggage.

performance statistics for all areas of interest within the airport process (e.g., passenger queue lengths and baggage inspection delay times before each EDS machine). Finally, the appropriate number of replications of the design-day schedule are made in order to reach statistically valid conclusions.

Benefits

Three important factors make analyses based on stochastic, discrete-event simulation the best approach for evaluating prospective security systems for airports.

1. *Variability of human behavior.* In the airport environment, passengers travel in different-size groups, move at various speeds, and are served in different ways depending on their origination or destination point, citizenship, travel class, etc. Other analytic methods, such as simple queuing theory or flow modeling, are unable to capture these details and must make unrealistic, simplifying assumptions. Stochastic, discrete-event simulation analysis captures the effects of variability in human behavior, thus providing the most accurate estimate of system performance.
2. *Interdependence of airport processes.* A passenger's path through an airport is a sequence of processes (e.g., ticketing, security inspection) and decision points. The discrete-event simulation model moves individual passengers and baggage through this complex sequence. Each process within the airport affects both up-line and down-line areas of terminal processing. These rippling effects are impossible to capture using other analytic methods. A discrete-event simulation model can capture all the cascading effects resulting from a single change to the airport system.
3. *Many diverse solutions require what-if analyses.* U.S. airports are all unique. They were constructed at different times, to serve the needs of local markets and air carriers. As a result, the passenger and baggage processing areas of airports differ in size and layout, producing unique passenger and baggage processing sequences. Moreover, many different technologies are used to accomplish passenger and baggage security inspection. As a result, the security solution for each airport will be unique. A computer simulation model provides a tool that can be used to quickly and economically evaluate numerous schemes. The objective performance measures produced by the simulation can be used to identify the scheme that achieves the most-effective screening for the least cost and least passenger delay.

Simulation Output

Discrete-event simulation modeling can provide performance data for every passenger and every bag at each step in the journey through the airport. Performance data can include queue lengths, wait times, and area occupancies for all airport processes (e.g., ticket counters, primary security inspections). Performance figures of merit include not only averages, but also wait time histograms, occupancy by time-of-day graphs, and maximum or percentile values. For example, simulation output for a security checkpoint may show an average wait of 2.5 minutes, a maximum wait of 24 minutes, and a statement that 95 percent of passengers wait no more than 12 minutes. Histograms and time-of-day graphs, shown in Figure B.1, provide a clear picture of system performance.

Computer simulation can also provide an animation of passenger and baggage movement through the airport. This animation is invaluable in illustrating the benefits of the preferred system and how it will work prior to installation. Figure B.2 shows examples of computer simulation animations.

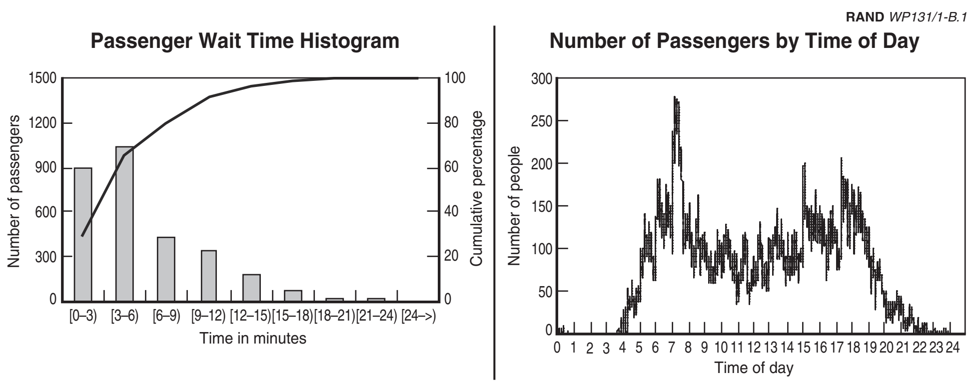

Figure B.1—Sample Output from Discrete-Event Simulation

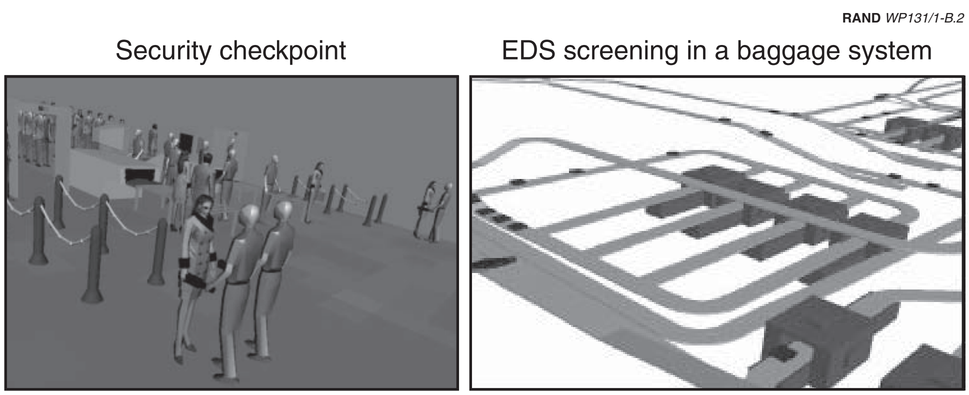

Figure B.2—Samples of Computer Simulation Animations

C. Trusted Traveler Program

Passenger profiling is widely used by civil aviation authorities throughout the world as a way to focus security protocols. Some countries use techniques that could not be used in the United States, such as singling out passengers because of their national origin or religious preference. In America, profiling relies extensively on behavioral characteristics that have been exhibited by people involved in terrorist attacks. For instance, people who buy one-way tickets at the last moment, pay cash for them, and have no checked baggage are likely to get more attention from security personnel. In the past, civil aviation personnel lacked access to information from law enforcement and intelligence organizations about people who were on watch lists, who had overstayed their visas, or had for other reasons drawn suspicion on themselves.

Establishing a "trusted traveler" program would turn the current approach on its head. Rather than trying to identify suspicious people, the objective would be to identify people who do not need to be subjected to intensive scrutiny except on a random basis. For example, such a program might begin by issuing biometrically verifiable identification cards to military personnel, government employees, law enforcement personnel, and private sector employees who hold security clearances or who have had recent, thorough background checks. Encouraging people to volunteer and pay for an appropriate background check could expand the number of people having trusted traveler cards. Anyone who volunteers would pay an amount sufficient to cover the cost of the investigation whether or not a card was issued.

To avoid penetration of the program by terrorists, security of the trusted traveler database and of the nature of the adjudication process would have to remain paramount. A voluntary program does not raise issues of civil liberties or privacy so long as the database remains secure. Enrollment in a trusted traveler program would not be a right. Government employment requires a background check; many private companies scrutinize employment history and financial status and require drug tests before offering jobs to people. People who do not want trusted traveler status are not necessarily threats, but, compared to trusted travelers, they will receive more-intense scrutiny at airports and are more likely to suffer some inconvenience.

Department of Defense (DoD) experience shows that the most important parts of background checks are the national agency check, verification of employment, and an understanding of an individual's financial history. The most time-consuming portion of the traditional background investigation—interviews with friends and neighbors—is the least revealing and predictive.

The Office of Personnel Management (OPM) and DoD have relied on contractors to conduct background investigations. While safeguards need to be in place to ensure the integrity of the contractors and the investigative process, ample precedent exists in both OPM and DoD for managing contractor efforts. The Department of Transportation (DOT) could also certify the investigative programs of individual companies and accept their findings for the purposes of issuing trusted traveler cards.

The information required to obtain trusted traveler status does not need to be as extensive as that required for security clearances. The key indicators would be

- An unexceptional National Agency Check
- A fingerprint check against criminal and civil files
- A verified, stable employment history
- A record demonstrating firm community roots
- A record of financial security with no unexplained deviations from typical patterns
- A travel history consistent with occupational history
- An employer's statement of confidence.

Some of this information can be obtained from existing databases (e.g., financial, employment, and travel histories) provided the individual agrees to grant access to them for the purpose of obtaining a trusted traveler card. The decision of whether to grant a card should be made by the DOT.

A trusted traveler program used in conjunction with the Computer Assisted Passenger Profiling System (CAPPS) augmented by information from intelligence and law enforcement agencies (both domestic and foreign) will provide both the security and efficiency air travelers and the nation deserve.