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## Estimating the Monetizable Safety Benefits of Prototype Air Traffic Control Technologies

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The Federal Aviation Administration (FAA) utilizes a formal investment analysis process to support the development, procurement and deployment of new air traffic control technologies. It is often unclear how to estimate the impacts of a new technology on aviation safety, both in terms of the probability that incidents and accidents could be prevented and in terms of the potential financial savings associated with reduced aircraft damage and personal injuries. With this in mind, the focus of this paper is twofold: (1) demonstrating the application of a method for generating probabilistic estimates of safety benefits for a future air traffic control technology, and (2) monetizing and extrapolating safety impacts from historical data to provide a quantitative estimate of savings over the lifetime of a new technology. The technologies explored in this analysis involve electronic flight data, enhanced surveillance and decision support tools for the air traffic control tower environment. From this initial analysis, the estimated total monetizable safety benefit of deploying all of these capabilities in a new system with an expected 2015-2035 lifetime across a set of major airports in the US ranges from \$155 million to \$2.1 billion. Implications of key data assumptions driving the lower and upper-bound estimates are discussed.

### INTRODUCTION

The Federal Aviation Administration (FAA) uses an investment analysis process to support the development, procurement and deployment of new air traffic control technologies within the National Airspace System. Computer modeling and human-in-the-loop experimentation efforts are often utilized to provide estimated efficiency and performance impacts associated with fielding a new technology. It is less clear, however, how to estimate the impacts of a new technology on aviation safety, both in terms of the probability that incidents and accidents could be prevented and in terms of the potential financial savings associated with aircraft damage and personal injuries. With this in mind, the focus of this paper is twofold: (1) demonstrating the application of a method for generating probabilistic estimates of safety benefits for future air traffic control technologies, and (2) monetizing and extrapolating safety impacts from historical data to provide a quantitative estimate of savings over the lifetime of a new technology to assist in cost-benefit analyses.

The prototype technologies explored in this analysis cover the air traffic control tower (ATCT) environment. Categories explored include electronic flight data (e.g., electronic flight progress strips), enhanced surveillance (e.g., conflict detection improvements to ASDE-X) and decision support tools (DSTs) (e.g., providing a means for front line managers and traffic management coordinators to perform strategic and tactical planning) (Davison Reynolds, Kuffner, & Yenson, 2011).

Historical accidents and incidents were analyzed to determine what types of real-world safety issues might be prevented or mitigated by the introduction of these categories of

ATCT automation enhancements. These findings were used to estimate potential benefits in future years using extrapolation protocols established for other air traffic control system analyses. Monetized safety benefits associated with the prevention of actual aircraft damage and personal injury costs over an expected 2015-2035 system lifetime are presented. The implications of the various analysis decisions upon the benefits estimates are provided to highlight their importance.

### METHOD

The safety analysis followed a structured approach in identifying current and future estimates of safety benefits, as shown in Figure 1. The first step in this process was to estimate current year benefits through the steps in the top half of the figure. We utilized archived accident and incident data to determine observed frequencies of airport-operations-related safety events (namely, those judged by a subject matter expert to have the potential to be prevented or mitigated by new ATCT automation systems). We specifically reviewed 247 National Transportation Safety Board (NTSB) reports focusing on commercial air carrier (i.e., Part 121) operations over a five-year period (2005-2009). Only final investigation reports were reviewed to ensure accurate reporting of causal factors.

Baseline safety dollar impacts of relevant incidents were generated utilizing FAA-recommended monetization values (see Table 1; FAA/ATO, 2011) and compared to the safety impacts associated with implementing automation capabilities in order to estimate the theoretical monetized benefit within the current year.

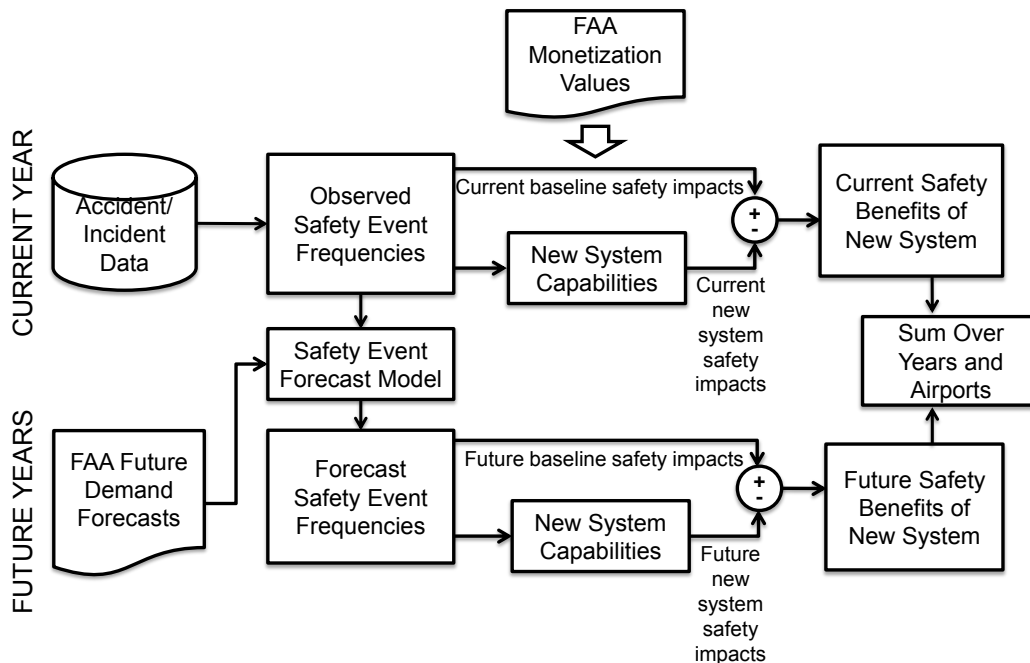


Figure 1. Safety assessment analysis methodology.

Table 1. FAA-Recommended Fiscal Year 2011 Economic Impacts by Aircraft Accident/Passenger Injury Category.

Category	Economic Impacts
Replacement aircraft cost	\$13,650,000
Restoration aircraft cost	\$4,410,000
Minor repairs aircraft cost	\$500,000 (MIT estimate)
Fatality	\$6,000,000
Critical injury	\$4,575,000
Severe injury	\$1,125,000
Serious injury	\$345,000
Moderate injury	\$93,000
Minor injury	\$12,000

A systematic method for generating probabilistic estimates of benefits for a technology not yet deployed (Barnett & Paull, 2004) was utilized to produce effectiveness ratings for future capabilities. We define effectiveness ratings as the probability that a given technological capability could mitigate or prevent an unsafe situation. While this method ideally involves a panel of experts to provide effectiveness ratings, for this study an aviation human factors expert with piloting experience rated the likelihood that historical accidents and incidents could have been mitigated or prevented by new automation components. Potential future automation components were considered incrementally in three steps: electronic flight data, improved surveillance, and decision support tools. Specifically, the rater considered three questions for each analyzed incident:

- Would the availability of electronic flight data have prevented the event?
- Would the availability of electronic flight data plus improved surveillance have prevented the event?

- Would the availability of electronic flight data plus improved surveillance and decision support tools have prevented the event?

It is important to note that these questions were framed so as to address the effectiveness of future components above and beyond benefits already assumed by existing technologies such as ASDE-X or Runway Status Lights. Responses to these questions were provided along a five-point scale ranging from “almost definitely no” to “almost definitely yes” with intermediate responses of “probably no,” “50/50,” and “probably yes.” These responses were translated into probabilities as follows:

- Almost Definitely No 0%
- Probably No 25%
- 50/50 50%
- Probably Yes 75%
- Almost Definitely Yes 100%

Importantly, two different sets of results were produced, driven by data scoping assumptions. A lower-bound estimate of safety impacts was generated by only considering accidents occurring at airports expected to have ASDE-X by 2015, because the technologies considered would require this surveillance capability. An upper-bound estimate was also generated by considering relevant accidents at all US airports, regardless of surface surveillance capabilities, under the assumption that such accidents could theoretically occur anywhere. An accident was considered relevant if the subject matter expert judged that future ATCT automation systems could have played a role in preventing that accident. Examples include automated alerts for an aircraft that deviates from its assigned taxi route or lines up on the incorrect runway.

For future year estimates, we utilized the 2011 FAA demand forecasts (FAA/ASPM, 2011) in combination with the observed safety event frequencies to build a safety event forecast model that predicted future frequencies of safety events in five-year increments out to 2030. This process was informed by future year safety models employed for other programs such as the ASDE-X system (Johnson, 2005). Future baseline (without new automation) safety monetized impacts were compared to the future monetized impacts of implementing new ATCT capabilities to estimate the safety benefits for 2015, 2020, 2025, and 2030. The key output metrics of this analysis included personal injury and aircraft damage monetized impact savings summed over years and airports.

**RESULTS and DISCUSSION**

Out of the 247 NTSB reports reviewed as part of this analysis, only a small subset of the 100+ reports deemed relevant by the subject matter expert could be monetized using the FAA-recommended personal injury and aircraft damage criteria. Many incidents did not meet NTSB-defined aircraft damage or personal injury thresholds and therefore could not be monetized according to the values in Table 1. Also, because some events represent potential accident or incident precursors (as opposed to actual accidents) there were no direct costs from fatalities, injuries, or aircraft damage.

Table 2 presents the safety-related costs associated with judged-relevant monetizable accidents over the 2005-2009 period reviewed, as well as the effectiveness ratings for various future capabilities assessed using the method previously described. Note that the “combined impacts (lower)” column does not include the 2006 Lexington, KY airport (LEX) accident in which an aircraft attempted to take off from the wrong

(and too short) runway. Since LEX is not projected to have ASDE-X, that airport would not be able to benefit from improved surveillance or decision support tools under the conservative assumption utilized in calculating the lower-bound economic benefits. Total safety costs therefore total a lower bound of \$42.8 million. As an alternative assumption that the LEX accident could theoretically occur at any airport, the additional monetizable amount from the LEX accident was included in the “combined impacts (upper)” column, generating an upper-bound total safety cost of \$350.8 million (i.e., nearly a factor of ten higher than the lower bound). Had enhanced surveillance coupled with electronic flight data been available at LEX, there is at least the potential that an automation system could have generated alarms in time to abort the takeoff, preventing this type of accident. The difference between the lower and upper-bound safety costs therefore arises from the accident at LEX which involved 49 fatalities, 1 serious injury and a destroyed aircraft for a total cost of \$308 million.

The raw personal injury and aircraft damage safety costs presented in the second and third columns of Table 2 were weighted by the effectiveness ratings shown in the last three columns to determine the potential monetizable safety benefits of different capabilities according to the equation:

$$\$Safety\ benefit_{current\ years} = \sum_{\substack{Historical \\ incidents\ i}} ER_i \cdot \$Incident\ cost_i$$

where  $ER_i$  and  $\$Incident\ cost_i$  are the effectiveness ratings for each capability and injury/damage costs of each of the historical incidents  $i$  outlined in Table 2.

Table 2. Economic Values and Effectiveness Ratings (ERs) Per Accident.

Accident/ Incident	Personal Injury Impacts	Aircraft Damage Impacts	Combined Impacts (Lower)	Combined Impacts (Upper)	ER Integration/ Electronic Flight Data	ER + Improved Surveillance	ER + Decision Support Tools
DEN 2008	\$2.6m	\$4.4m	\$7.0m	\$7.0m	0%	0%	75% (\$5.25m)
DCA 2008	---	\$4.9m	\$4.9m	\$4.9m	0%	50% (\$2.45m)	50% (\$2.45m)
ORD 2007	---	\$4.9m	\$4.9m	\$4.9m	0%	50% (\$2.45m)	50% (\$2.45m)
LAS 2007	---	\$0.5m	\$0.5m	\$0.5m	0%	100% (\$0.5m)	100% (\$0.5m)
ATL 2007	---	\$0.5m	\$0.5m	\$0.5m	0%	75% (\$0.37m)	100% (\$0.5m)
ORD 2007	---	\$4.9m	\$4.9m	\$4.9m	0%	50% (\$2.45m)	50% (\$2.45m)
LGA 2006	---	\$4.9m	\$4.9m	\$4.9m	0%	50% (\$2.45m)	75% (\$3.67m)
LEX 2006	\$294.3m	\$13.7m	---	\$308m	0%	0%	100% (\$308m*)
PHX 2005	---	\$4.9m	\$4.9m	\$4.9m	0%	50% (\$2.45m)	50% (\$2.45m)
PDX 2005	---	\$4.9m	\$4.9m	\$4.9m	0%	50% (\$2.45m)	50% (\$2.45m)
EWR 2005	---	\$5.4m	\$5.4m	\$5.4m	0%	50% (\$2.7m)	50% (\$2.7m)
<b>Total Impacts</b>			\$42.8m	\$350.8m	*Upper bound only		
<b>Total Weighted Impacts</b>			\$18.3m <sup>†</sup> or \$24.9m <sup>‡</sup>	\$332.9m	†Weighted by improved surveillance values ‡Weighted by DST values		

The integration and electronic flight data elements were considered to have an *ER* value of zero, i.e. no potential to mitigate or prevent the incidents given in Table 2 and hence would not have any monetizable safety benefit (but could be an important element in non-monetizable benefits such as user acceptance). However, improved surveillance was considered capable of mitigating or preventing \$18.3 million in monetizable safety impacts for both the lower and upper-bound cases for these historical incidents. The addition of decision support tool capabilities was estimated to lead to \$24.9 million and \$333 million of monetizable benefits for the lower and upper-bound cases, respectively, for these historical incidents.

In order to estimate potential future monetizable safety benefits, the results based on historical incidents were projected into the future accounting for traffic growth according to the equation:

$$\$Safety\ benefit_{Future\ year\ s} = \left(\frac{N_{Future\ years}}{N_{Current\ years}}\right)^k \cdot \sum_{\substack{Historical \\ incidents\ i}} ER_i \cdot \$Incident\ cost_i$$

where *N* is the traffic level in the air transportation system, *k* = 1, 2, or 3 depending on the extrapolation method (i.e., linear, quadratic, or cubic), and *ER<sub>i</sub>* and *\$Incident cost<sub>i</sub>* are the effectiveness ratings and injury/damage costs of each of the historical incidents *i* outlined in Table 2 (the sum of these *ER<sub>i</sub>*·*\$Incident cost<sub>i</sub>* products are the \$18.3 million-\$333 million values presented previously). Future year traffic levels were determined from the 2011 FAA Terminal Area Forecast (FAA/ASPM, 2011) using values for total operations at towered airports over five-year periods. From this, *N<sub>Current years</sub>* =

187 million; *N<sub>2015-2019</sub>* = 206 million; *N<sub>2020-2024</sub>* = 223 million; *N<sub>2025-2029</sub>* = 243 million and *N<sub>2030-2034</sub>* = 255 million.

With respect to the extrapolation method, other aviation system enhancement safety benefits assessments conducted for the FAA have utilized a (traffic level)<sup>2</sup> relationship between traffic level and safety incidents (Barnett & Paull, 2004; Barnett, Paull, & Jaedeluca, 2000). This quadratic relationship is considered most appropriate for incidents involving two aircraft, and may actually be a conservative estimate given the probability of error due to increased controller workload associated with increased traffic levels over time. Most of the analyzed accidents in this study did involve two aircraft, but the influential LEX accident, for example, involved only one aircraft. Other extrapolation techniques (i.e., linear, cubic) exist and are utilized in this assessment to form a range of potential benefits for both the lower and upper-bound estimates.

While the (traffic level)<sup>2</sup> relationship is the recommended extrapolation method, the resulting estimates of monetizable safety benefits in future years for all three extrapolation methods are shown in Figure 2. The estimated total monetizable safety benefit for an expected 2015-2035 lifetime is \$155 million for the lower-bound estimate and \$2.1 billion for the upper-bound estimate using quadratic extrapolation. These values are simply the totals from Figures 2a and 2b. The lower-bound estimate varies from \$124-194 million with the alternate linear and cubic extrapolation methods, while the upper bound varies from \$1.7-2.6 billion. Again, the large difference in lower and upper-bound estimates is driven by the absence or presence of the LEX accident in the extrapolation method (i.e., whether at least one fatal accident is estimated to be prevented every 5 years through the deployment of new ATCT technologies).

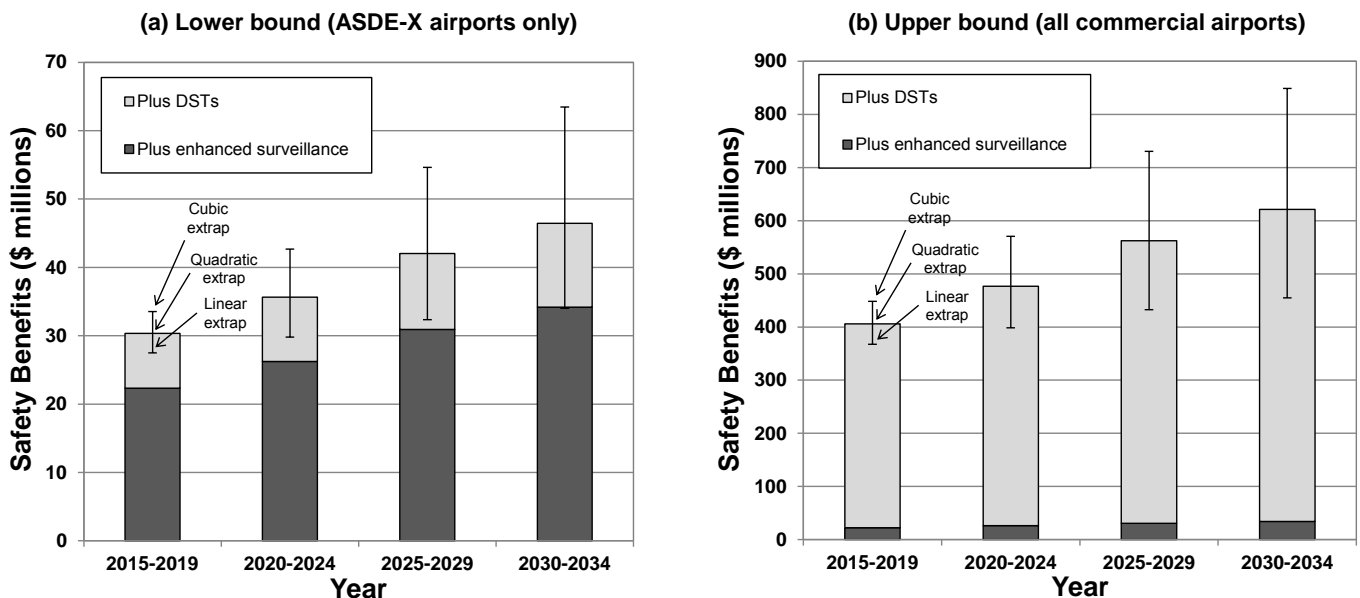


Figure 2 (a) Lower bound (b) Upper bound future year monetizable safety benefits by capability and extrapolation method. Note: different vertical scales on Figure 2(a) and 2(b).

The extrapolation method is seen to have a much smaller impact on the monetized results compared to the choice of whether to use the lower or upper-bound airport set as the basis for that extrapolation. The order of magnitude difference between the lower and upper bound airport set could have a profound impact on whether the overall program cost-benefit analysis turns out positive or negative. Therefore, it is important to note that this one analysis decision could ultimately drive whether system procurement/deployment goes ahead or not.

These initial results also indicate that there are minimal monetized safety benefits from electronic flight data aspects (although user acceptance and efficiency benefits of these aspects might be significant); improved surveillance aspects are the major element of the lower-bound safety benefit estimate; while decision support tool aspects are the major element of the upper-bound safety estimate (due to the high effectiveness rating value for decision support tool prevention of the LEX accident).

## CONCLUSIONS

This work focused on: (1) demonstrating the application of a method for generating probabilistic estimates of safety benefits for a technology not yet deployed, and (2) monetizing and extrapolating safety impacts from historical data to provide a quantitative estimate of savings over the lifetime of potential future air traffic control tower technologies.

Future analysis efforts could focus on increasing the sample size of historical data by expanding the review of reports beyond a five-year time period and also by including additional aviation operations (e.g., Part 129 (foreign carriers), Part 135 (air taxi and commuter), and Part 91 (general aviation)). Alternative extrapolation techniques, methods for quantifying uncertainty of the lower and upper bound estimates, and potential risks associated with implementing future technologies could also be explored.

Not having access to a panel of aviation experts to provide effectiveness ratings of future capabilities is a clear limitation of this safety assessment. As discussed by Barnett and Paull (2004), individual effectiveness ratings provided by a panel of experts could be averaged to provide a collective assessment of the degree to which future technologies could have mitigated or prevented historical accidents and incidents. Furthermore, the variability in responses would provide a quantifiable margin of uncertainty.

In conclusion, this effort documents a potential protocol for estimating the impacts of a new technology on aviation safety, both in terms of the probability that incidents and accidents could be prevented and in terms of the potential financial savings associated with aircraft damage and personal injuries. Assumptions made by the analyst have been shown to have a profound impact on the safety benefits estimates. As a result, analysts must carefully consider what assumptions (or sets of assumptions) to make and ensure that decision makers are provided with appropriate insight into the impacts of different assumptions so they can be factored into results interpretation.

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