Data-Driven Estimation of the Impact of Diversions Due to In-Flight Medical Emergencies on Flight Delay and Aircraft Operating Costs

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INTRODUCTION: In-flight medical emergencies (IFMEs) average 1 of every 604 flights and are expected to increase as the population ages and air travel increases. Flight diversions, or the rerouting of a flight to an alternate destination, occur in 2 to 13% of IFME cases, but may or may not be necessary as determined after the fact. Estimating the effect of IFME diversions compared to nonmedical diversions can be expected to improve our understanding of their impact and allow for more appropriate decision making during IFMEs.

METHODS: The current study matched multiple disparate datasets, including medical data, flight plan and track data, passenger statistics, and financial data. Chi-squared analysis and independent samples *t*-tests compared diversion delays and costs metrics between flights diverted for medical vs. nonmedical reasons. Data were restricted to domestic flights between 1/1/2018 and 6/30/2019.

RESULTS: Over 70% of diverted flights recover (continue on to their intended destination after diverting); however, flights diverted due to IFMEs recover more often and more quickly than do flights diverted for nonmedical reasons. IFME diversions introduce less delay overall and cost less in terms of direct operating costs and passenger value of time (averaging around $38,000) than do flights diverted for nonmedical reasons.

DISCUSSION: Flights diverted due to IFMEs appear to have less impact overall than do flights diverted for nonmedical reasons. However, the lack of information related to costs for nonrecovered flights and the decision factors involved during nonmedical diversions hinders our ability to offer further insights.

KEYWORDS: in-flight medical emergencies, flight diversions, flight delay, aircraft operating cost.

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In-flight medical emergencies (IFMEs) are estimated to occur on average in 1 out of every 604 flights,[18] and can have a wide variety of causes, recommended responses by flight crew or medical professionals, and outcomes. A meta-analysis by Chandra and Conry[3] of incidence studies between 1980 and 2010 found a broad range of reported incidences of IFMEs, ranging from 380 cases over the course of 10 yr for a single airline to 3386 over the course of 5 yr for another single airline. The apparent discrepancy is more likely explained by the lack of a common denominator, as airlines vary significantly in terms of their passenger traffic as well as nonstandardized procedures for reporting IFMEs. Regardless, the incidence of IFMEs is also predicted to rise as the world's population ages and an increasing number of older adults, who may be more likely to have chronic health problems, take to the skies.[12] The most frequent causes of IFMEs have been found to be syncope or near-syncope, gastrointestinal, respiratory, and cardiovascular.[16]

The variability in cases of IFMEs and the complexity of coordination required, particularly in the case of diversions, has led to the advent and proliferation of ground-based

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medical support (GBMS) consultants.[11] Today, virtually all U.S.-based airlines and the vast majority of major international airlines contract with GBMS. GBMS offers advice in in the management of IFMEs, including offering advice on whether the flight should be diverted. They also coordinate responses on the ground with dispatch, airport operations, and local emergency services. In addition to offering services during emergencies, GBMS consultants may also provide additional analysis and reporting in order to improve existing health and safety programs on board. Many airlines also carry GBMS-provided equipment in addition to the standard emergency medical kit and automated external defibrillator.

The Aviation Medical Assistance Act of 1998 provides protection against liability for medical personnel who are asked to provide assistance during an IFME as long as they do not "engage in any willful misconduct or commit gross negligence."[15] However, laws and coverage may vary widely depending on whether the flight or the airline is international.[7] Flight attendants are also instructed to grant access to the emergency equipment only to trained crewmembers or to qualified volunteers, with the final decision being left to each air carrier and its agents.[1] The Federal Aviation Administration (FAA) also notes that it would be preferable for the flight crew to check the credentials of volunteer personnel on board. However, there have been times where the media has noted issues with this method. For example, on a flight to Houston in December of 2018, a passenger became critically ill and was aided by an emergency physician who happened to be aboard the plane. During the incident, the physician claims to have been repeatedly asked for credentials and cited frustration with the amount of time it took for crewmembers to bring medical supplies.[17] A similar story from October 2018 detailed an incident during which a physician was asked for, and provided, medical credentials, only to be questioned by the flight crew as to their veracity.[14]

When all else fails and the flight crew, volunteers, or GBMS determine that the passenger needs more help than can be provided in the air, the decision may be made to divert the flight. During an IFME, the pilot-in-command and the air carrier hold the discretion to decide whether to divert the aircraft. The FAA does not explicitly require any actions by the carrier, flight crew, or passengers on board above and beyond having the required emergency equipment available.[1] Despite these protections, air carriers and pilots may come under fire or be sued for not diverting when an ill passenger suffers from any complication or does not survive.

A recent meta-analysis by Martin-Gill et al.[16] surveyed 14 publications reporting a total of over 56,000 IFMEs and estimated that diversions occur in 4.4% of IFME cases. Additional research focused on factors that influence the decision to divert. DeJohn et al.[5] found diversions in 13% of their sampled cases, with diversions being more common when a physician was on board (16% vs. 11% of cases). The authors further indicated that up to 19% of the diversions studied may have been unnecessary in light of follow-up information (including cases of vasovagal syncope, dehydration, gastroenteritis, viral infections, noncardiac chest pain, anxiety, false labor, and sickle cell anemia). Peterson[18] found that aircraft diversions happened in 7.3% of studied IFME cases and that physicians and Emergency Medical Service providers were more likely to recommend diversions when they were the volunteer provider of medical assistance (over nurses or "other"). In an investigation of in-flight cardiac arrest, it was further found that although diversions were more likely when there was a reported shockable rhythm than a reported non-shockable rhythm, there was no significant correlation between diversions and survival to hospital.[2] Alves et al.[2] also found that when a nonphysician assisted during the IFME, the likelihood of a diversion in reported non-shockable rhythm cases increased compared to cases in which a physician volunteered, indicating that physicians may be more comfortable with the decision to cease resuscitation efforts when appropriate.

The decision to divert the aircraft is made by the Captain and the air carrier, often in consultation with a GBMS. The opinions of medical volunteers (doctors, nurses, Emergency Medical Technicians, etc.) on board are also considered. Ruskin et al.[21] cite the following factors that are often taken into account when considering a medical diversion:

- Potential medical benefit to the passenger;
- Ability to stabilize the passenger with available equipment and expertise;
- Reduction in flight time;
- Proximity and nature of medical resources at diversion airport;
- Airline practices;
- Weather;
- Fuel load (including the potential need to dump fuel or perform an overweight landing);
- Logistical issues with air traffic control and airport operations; and
- Diplomatic landing rights for international diversions.

Understanding the cost—in terms of both financial cost to the airlines and time lost by passengers of a diversion—is also important, particularly in cases where the potential benefit to the passenger is unknown or variable. The financial costs, in U.S. dollars, of a diversion vary widely in the literature, ranging from \$3000 to \$893,000 based on fuel load, passenger accommodations, crew needs, and even the scope of the estimate.[6,19–21] Cook et al.[4] created a model for estimated costs for passengers to estimate the effects of delay. Overall, however, the amount of delay incurred by passengers by an IFME diversion is as of yet unknown.

The goal of the current study was to improve the understanding of IFME diversions relative to flights diverted for nonmedical reasons and to calculate the impact of an IFME diversion on passengers, in terms of recovery likelihood, delay, and cost, in order to offer guidance on the management of IFME delays.

METHODS

Data

The final analysis dataset was created by merging multiple, diffuse datasets: medical data, diversion data, nominal flight data, passenger data, and financial data. As the only use of the medical database was to identify IFME diversions, it was determined that an IRB review was not required for the current study.

Medical data were collected over the period of 1/1/2018 to 6/30/2019 by MedLink, a GBMS advisory center operated by MedAire Inc., located in Phoenix, AZ. Included in the original dataset, which included data for diversions due to IFMEs only, were 1042 cases. Each case included narrative summaries of the IFME as well as operational and medical data including airline, origin-destination pairs, diversion airport, passenger age, gender and diagnostic impressions, the availability of onboard volunteer medical professionals, and passenger outcome. Cases were not separated by passenger type (i.e., crew illness was not excluded from the current data set). No personal identifiable information was collected and the specific medical variables in the database were not included in the final analysis dataset. The medical data included cases from 52 airlines, with mainline (large commercial) airlines representing the largest contributor (78.3% of cases). More than half of the cases were international flights (56%).

Diversion data were collected using MITRE's Diversions algorithm. The algorithm analyzes all of the flight messages in the Traffic Flow Management System (TFMS) data and identifies when a change is made to a flight's original flight plan, verifies the findings using flight track data and Count of Operations data, and looks for a diversion recovery flight. A recovery flight is assumed if the same aircraft continues from the diversion airport to the originally scheduled destination airport within an expected time threshold. If a recovery flight is found, the recovery flight data are also appended to the diversion data. Passenger itineraries can be recovered using other forms of transportation (e.g., ground shuttle), which is not captured by this algorithm. Diversion data were mostly restricted to flights over the United States, with some limited data for Caribbean and Canadian flights. This includes general aviation aircraft as well.

Nominal flight data were collected from TFMS, which is archived close to real time in MITRE's internal repository. MITRE receives TFMS messages including departure, arrival, flight planning, and position tracking messages. These messages are captured, postprocessed, then the system "threads" the messages that belong to a flight together with a unique ID, which can be used to provide an end-to-end flight "story" for a given flight. To compute the average amount of delay associated with IFME diversions as compared to nondiverted flights, the median flight time for nondiverted flights was also estimated. The median flight time was calculated for all flights of each aircraft type on each origin-destination pair and filtered to the same time period as the medical diversion data (1/1/2018–6/30/2019).

The number of passengers affected by each diversion was estimated by multiplying the number of seat tickets available for each flight by the applicable average passenger load factor (a measure of the reported ratio of filled to unfilled seats for a given airline over a given time period). The number of seat tickets for each flight was obtained from Innovata, which is a source of worldwide flight schedule data, including most major carriers, and is used for data analysis by the FAA and airlines. Passenger load factors were taken from the Bureau of Transportation Statistics T-100 segment data. Load factors specific to the year, month, and (where possible) airline were applied. If the specific airline was not differentiated in the Bureau of Transportation Statistics data, the aggregate domestic or foreign load factor was used based on the airline.

The extra flight time associated with diversions was valued by applying aircraft operating cost factors derived from airline financial data. These financial data are reported by air carriers to the U.S. Department of Transportation (DOT) on a quarterly basis on DOT Form 41. Aircraft direct operating costs (ADOC) per hour were derived for the cost categories that most directly vary with aircraft usage, including fuel and oil, crew, and maintenance, in accordance with FAA benefit-cost analysis guidance.[10] These unit cost factors were calculated for each aircraft type represented in the diversion dataset using 2018 Form-41 data. Where cost data for specific aircraft model and series was of questionable quality (due to reporting inconsistencies or anomalies), costs of similar aircraft were used as proxies. In the single instance in which a proxy was not available, a generic 2018 FAA cost factor was applied. Diversion delays were also valued from passengers' perspective by applying the Passenger Value of Time (PVT) factor of $49 per hour, as prescribed by FAA guidance.[9]

For the current analysis, the dataset was limited to mainline, low-cost, and regional airlines (excluding general aviation, military, cargo, leisure, and for-lease aircraft). It was further restricted to the 52 carriers available in the provided medical data to allow medical diversions to be separated from nonmedical diversions with reasonable accuracy. The final analysis dataset was also restricted to only domestic flights for which complete flights were available in TFMS. The final dataset included 13,634 diverted flights between 1/1/2018 and 6/30/2019, including 9 carriers. Of those flights, 351 were diverted due to IFME and 13,283 were diverted for unknown, nonmedical reasons (which could include weather, unruly passengers, equipment failures and maintenance issues, or other reasons).

Statistical Analysis

Cross-tabulations are provided to summarize the descriptive data using counts and/or percentages of responses where applicable; otherwise, means (M) and standard deviations (SD) are presented in the text. When appropriate, minimum and maximum observed values are also presented for distributions. Independent samples *t*-tests and Pearson Chi-squared analyses were used as appropriate. Statistical significance was set to $\alpha = 0.05$ and all analyses were conducted using IBM SPSS Statistics version 26.[13] The metrics assessed in the current study are included in **Table I**.

Table I. Metric Descriptions.

Metric	Description/Calculation
Recovery	Did the flight recover (take back off to the originally intended destination assuming the same passengers on board)?
Diverted Flight Time	Time from takeoff at departure airport to landing at original arrival airport for flights that are diverted in minutes.
Median Flight Time	Median time for all flights between departure-arrival pairs for the same aircraft type.
On-the-Ground Time	Time between landing at diversion airport and takeoff at diversion airport in minutes.
Total Diversion Delay	The amount of time attributed to the diversion, controlling for average flight time.
Additional Flight Time	Diverted Flight Time – (Average Flight Time + Delay at Diversion Airport) in minutes.
Diversion Location	The location at which the diversion was notated in the Traffic Flow Management System (TFMS) data (including distance to destination respective of the original route).
Number of Passengers	How many passengers were likely to have been on the flight (airline, aircraft, and month specific)?
Volunteer Presence	Was there a healthcare professional who volunteered to assist on board?
Cost of Time Lost	Calculated total cost of all time attributed to the diversion, including additional flight time and on-the-ground time, estimated by combining Aircraft Direct Operating Costs (ADOC) and Passenger Value of Time (PVT) costs. All costs are U.S. dollars.

RESULTS

Of the 13,634 airline-matched domestic diversions available in the Diversion dataset, 71.8% (9787) of flights recovered. Medical diversions had a significantly higher proportion of recoveries than nonmedical diversions [$\chi^2(1, N = 13{,}634) = 97.171$, $P < 0.001$]. Medical diversions recovered 95.2% of the time (344 of 351) and nonmedical diversions recovered 71.2% of the time (9453 of 13,283).

The likelihood of recovery (indicated by percentage of diversions that recovered) and the total count of diversions were tabulated and compared by hour of the day. There was a significant correlation between the number of diversions in a given hour of the day and the likelihood of recovering, such that recovery was less likely at times when fewer diversions occurred ($r = 0.536$, $N = 24$, $P = 0.007$), implying that the likelihood of recovery may be related to peak operational times, which are considered to be between 1500 Greenwich Mean Time (GMT) and 2200 GMT[8] or between 0200 and 0900 local time as shown in **Fig. 1**.

An independent samples *t*-test was conducted to compare on-the-ground time for IFME and nonmedical diversions. Results of the test indicate that, when flights did recover, medical diversions spent significantly less time at the diversion airport (M = 129.72 min, SD = 61.96 min) than nonmedical diversions (M = 193.31 min, SD = 82.87 min) [$t(632.2) = -6.022$, $P <$ 0 0.001].

Medical diversions diverted to airports that were significantly farther away from their originally intended destination (M = 725 nmi, SD = 435 nmi) than nonmedical diversions (M = 228 nmi, SD = 335 nmi) [$t(360.476) = 21.125$, $P <$ 0 0.001]. IFME diversions also happened on flights that had significantly longer median flight times (M = 216.07 min, SD = 76.88 min) than flights diverted for nonmedical reasons (M = 126.61 min, SD = 71.49 min) [$t(366.171) = -21.556$, $P < 0.001$]. However, flights diverted for IFMEs spent significantly less additional time in the air when compared to median flight times for the same origin-destination pairs than did flights diverted for nonmedical reasons [M = 28.02 extra minutes in the air, SD = 21.19 min, and M = 67.22 extra minutes in the air, SD = 35.00 min, respectively, $t(400.185) = -32.282$, $P < 0.001$]. For 33 of the included flights, the additional flight time was negative (minimum of −21 extra minutes spent in the air as compared to the median flight time between the same origin-destination pair).

Fig. 2 shows the median, minimum, and maximum delay in the air and on the ground added to the median typical flight time. As previously reported, flights diverted for IFMEs had longer median typical flight times than nonmedically diverted flights. The median additional flight time for flights diverted for IFMEs was 26 min, with 87.5 min of extra on-the-ground time vs. an additional flight time of 64 min with 105 min of on-the-ground time for flights diverted for nonmedical reasons. Results indicate that the average number of passengers of flights diverted due to IFME was higher (M = 138, SD = 27) than those diverted for nonmedical reasons (M = 106, SD = 44) [$t(403.077) = 21.790$, $P < 0.001$].

A volunteer health care professional was reportedly on board in 76.1% of cases (267 of 351). When there was a volunteer on board, the final diversion recommendation was relatively equally likely to be MedLink (54.7%) or the Pilot (45.3%); however, when there was no volunteer present, the recommender was almost three times as likely to be the Pilot (72.6%) as it was to be MedLink (27.4%). The presence of a volunteer did not significantly affect recovery [$\chi^2(1, N = 351) = 1.267$, $P = 0.254$], on the ground delay [$t(332) = 0.835$, $P = 0.404$], or extra in the air time [$t(332) = 1.350$, $P = 0.178$].

Over half (60.3%, 5897 of 9787) of the aircraft-specific financial data was available from the DOT 2018 Form-41 data for the current dataset, and a further 38.5% (3767 of 9787) had usable proxy data for similar aircraft. Only 1.3% (123 of 9787) of the included flights required generic costing data to be used. As shown in **Fig. 3**, the median total cost, in U.S. currency, of a diversion in the current data set was \$38,596, with the 10th percentile being \$19,311, and the 90th percentile being \$78,379. The maximum total cost was \$254,353.

Flights diverted for nonmedical reasons had significantly higher total average costs (M = \$45,411, Median = \$38,884, SD = \$27,567) than flights diverted for IFMEs (M = \$38,299, Median = \$32,942, SD = \$20,086) [$t(378.755) = -6.266$, $P < 0.001$]. **Fig. 4** shows the breakdown of ADOC in the air, ADOC on the ground, and PVT.

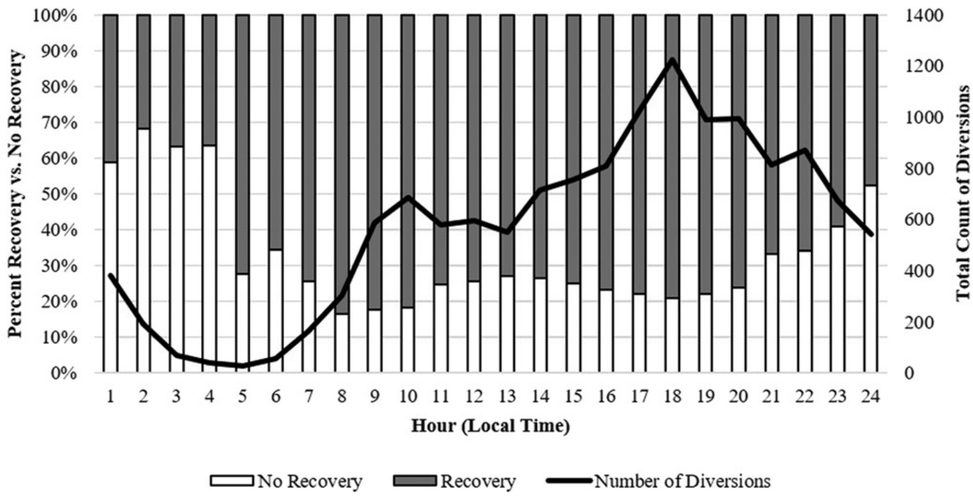

Fig. 1. Recovery likelihood and number of diversions by hour of the day at which the diversion occurred.

DISCUSSION

Using a matched dataset including medical, diversion, flight, passenger, and financial data, we were able to estimate recovery likelihood, additional flight time, on-the-ground time, and ADOC and PVT costs. Our results indicate that over 70% of domestically diverted flights recover. It is not unexpected that recovery was more frequent for medical diversions than for diversions for nonmedical reasons. For medical cases, often the removal of the passenger who is unwell is the only constraint to recovery. Operational constraints such as weather and mechanical issues, not present medical cases, would have certainly primarily prevented recovery in those nonmedical situations. There was also a significant correlation between the number of diversions occurring at a given time of day and the likelihood of recovery for flights diverted at that time, such that flights that divert during peak hours are more likely to recover than those which divert during nonpeak times.

Medical diversions were significantly further from their destination at the time of diversion than nonmedical diversions. IFMEs can happen during any phase of flight and, for those which happen later in the flight, the most prudent course of action may not be to divert, depending on services available at potential diversion airports. Weather-related diversions tend to occur for flights that are closer to their final destination, which might at least partially explain the finding. Note that short flights (around an hour or less) are unlikely to divert for medical reasons, as the best course of action would be to continue to the final destination. The same happens to flights between Hawaii and continental United States, where in most occasions flights would return to their origin or continue depending on their location along their route of travel. Flights diverted due to IFMEs also carried significantly more passengers compared to flights diverted for nonmedical reasons, which may indicate the increasing likelihood of a medical emergency based on the number of passengers present, though without analyzing nondiverted IFMEs, these results should be interpreted with caution.

A volunteer was present in the majority of the cases. When there was no volunteer present, the Captain was three times more likely to be the one recommending the diversion than was MedLink. This finding is most likely due to a limitation of the study: in some cases contact with the medical advisory service was limited or did not happen. This happens when the decision to divert has already been made and MedLink is only engaged to arrange for EMS services upon arrival. It is possible that, under those circumstances, a volunteer on board was present and advising the pilot to divert, but MedLink was not fully informed of their presence and it is therefore not reflected in the data. Another explanation may be related to the lack of perceived or real ability to assess the passenger's stability by the flight crew when no medical professional is available or may reflect a desire to "play it safe" when a passenger's health is deemed at risk. No effect of volunteer presence was found on recovery likelihood or passenger delay.

Flights diverted due to IFMEs recovered significantly more often than flights that diverted for nonmedical reasons. For those flights that recovered, flights diverted due to IFMEs spent significantly less time delayed at the diversion airport and delayed overall, and cost

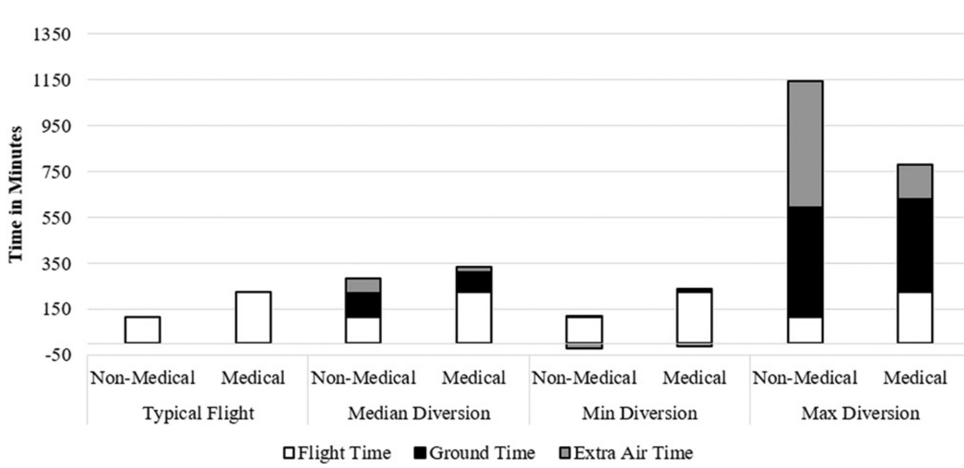

Fig. 2. Median, minimum, and maximum delay attributed to IFME and nonmedical diversions.

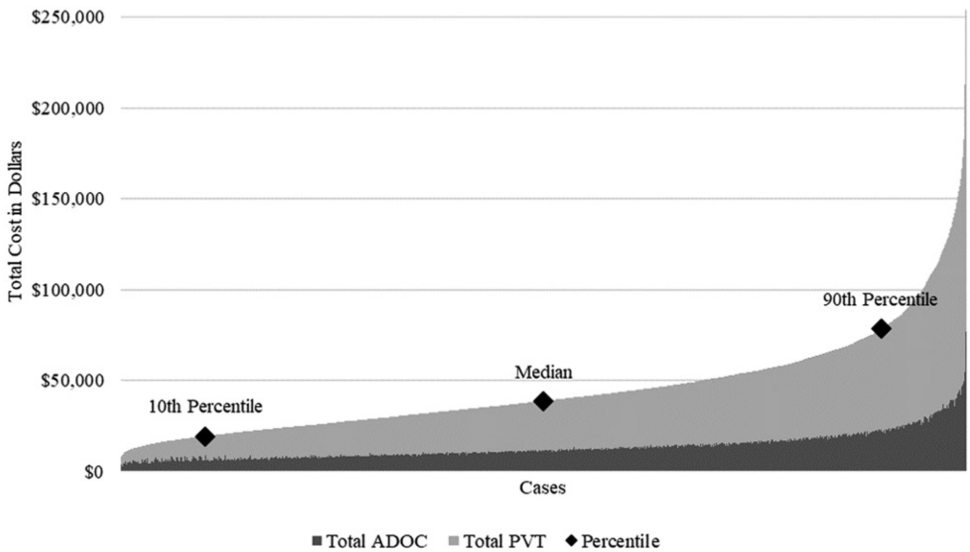

Fig. 3. Total ADOC and PVT for all costs by percentile.

significantly less in terms of ADOC and PVT. IFME diversions, while still disruptive to passenger travel, have significantly less of an overall impact in terms of delay and cost than do diversions for other reasons. Therefore, it may be unwise to use general diversion costing and analysis to assess the impact of IFME diversions. Our findings shed light on the costs of medical diversions for domestic flights. Those figures provide a more accurate basis for better applying cost/benefit analysis in order to assess the value of additional resources such as medications and equipment to be carried on board commercial flights.

The current analysis has notable limitations. First, the dataset was limited to retrospective analysis, meaning that no follow-up to clarify reasons for diversion or factors affecting the decision to divert could be made. This is particularly limiting in the case of nonmedical diversions where we are unable to differentiate between diversions due to weather, mechanical issues, or other nonmedical passenger or crew issues. Second, the data available to assess the issue at hand is extremely diffuse, requiring the merging of multiple sources, and, in some cases, available only to the specific airline for the diverted flight. To that point, for the 3830 nonmedical diversions and 17 medical diversions for which a recovery flight could not be found, it is impossible to retrospectively assess passenger delay or cost from the data available. It is also unknown what additional costs may have been incurred due to a diversion, whether there was a need to dump fuel to reach an appropriate landing weight, whether flight crew duty limits were exceeded or the crew were unable to continue the flight, whether the airline compensated the delayed passengers, and whether additional accommodations needed to be made. Findings and conclusions cannot be extrapolated for international flights, particularly if the diversion airport is not in the United States, as recovery indices could be significantly different given the impact in flight duty time and overall additional servicing of the aircraft involved.

The findings of the current research indicate a need for future work to broaden the scope of the analysis to include data from nondiverted IFME flights and to enhance cost modeling. There is also a need to improve the reporting of diversions to the FAA. Currently, diversions are captured in the TFMS data, but the reason for the diversion and any other outcomes are not explicitly addressed, meaning that the conclusions that can be drawn from the comparison between medical and nonmedical diversions remain limited.

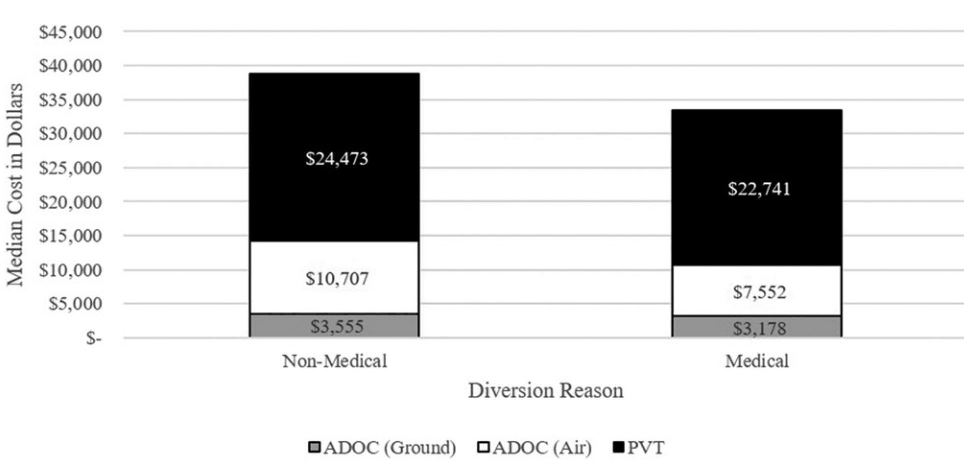

Fig. 4. Median ADOC in the air, ADOC on the ground, and PVT by diversion reason.

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