Assessment of Air Medical Coverage Using the Atlas & Database of Air Medical Services (ADAMS); Correlations with Reduced Highway Fatality Rates

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Abstract

The Atlas and Database of Air Medical Services (ADAMS) is a web-based, password-protected, geographic information system (GIS) containing data on air medical service main and satellite base helipads, communication centers, rotor wing aircraft and major receiving hospitals for trauma in the United States. ADAMS was initially developed to provide the geographic information needed to support real-time, wireless routing of Automatic Crash Notification (ACN) alerts from a crashed motor vehicle to the nearest air medical transport service and nearest trauma center. This coupling of ADAMS and ACN technology to enhance emergency communications is expected to speed delivery of emergency medical care to crash victims and thereby reduce the deaths and disabilities caused by motor vehicle crashes each year. In addition to its planned use in ACN response, ADAMS is also a valuable data resource for trauma system research and homeland security applications.

This paper begins with an overview of ADAMS and briefly describes the features and rationale for its development. ADAMS is then used as a tool to assess the extent of air medical rotor wing service coverage across the country. Both geographic area and populations covered are determined for each of the 50 states. The correlation between increased air medical service coverage and reduced motor vehicle crash fatality rates is then examined.

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Introduction

Motor vehicle crashes (MVCs) are the major cause of trauma in this country. Each year, over 42,000 people die on the nation's highways and over 3 million people are injured. Two million of these injuries are disabling and 250,000 are life-threatening. This translates into an enormous cost, not only personally and financially for those involved, but economically for the entire country as well. A comprehensive research study by the U.S. Department of Transportation shows that the economic impact of motor vehicle crashes in this country has reached $230.6 billion per year, or an average of $820 for every person living in the United States[1].

Implementation of an organized system of trauma care has been shown to reduce crash fatalities.[2,3] With the new technologies now available, great opportunities are at hand for more timely delivery of definitive trauma care. Intelligent Transportation System technologies, such as Automatic Crash Notification (ACN), in-vehicle Global Positioning Satellite (GPS) receivers and wireless telematics, are now being installed in a growing number of vehicles. These systems are able to sense serious, un-witnessed crashes, and immediately report their occurrence and location. In a growing number of vehicles, information on crash severity, number of occupants, restraint use, whether the vehicle rolled, etc., is being sent wirelessly with the automatic crash notification,[4,5] transmitted from the car to a Telematics Service Provider (like ATX, Cross Country Group, or OnStar) and then to the appropriate 9-1-1 center.

Substantial life-saving and disability-reducing benefits are expected from these combined technologies. These benefits will be fully realized however, only when appropriate emergency medical response services nearest the scene are immediately notified and rapidly deployed[6]. In rural areas in particular, air medical services must be fully and appropriately utilized because they offer not only rapid transport, but also high-level care *at the scene,* as well as en route to definitive care at urban trauma centers[7]. One way to improve trauma system response, is to use ACN and supporting technologies to rapidly identify the air medical service bases and the hospitals or trauma centers nearest the scene and automatically route the crash alert to these emergency medical resources. This early alert of a serious crash will enable air medical and hospital teams to begin response preparations, even as first responders (dispatched by the 9-1-1 center) are traveling to the scene. Although air medical dispatch and triage will still be guided by local protocols, this parallel *system alert* will help to expedite delivery of optimal emergency medical care to seriously injured crash victims.

There are a number of air medical service directories compiled by various organizations[8] which have for years been valuable sources of information for the air medical industry. However, it became apparent several years ago that there was no national database which listed the geographic locations of all main *and* satellite bases for air medical rotor wing (RW), or which identified the actual helicopter assets supporting emergency medical response in the U.S. Furthermore, there was no separate listing of the air medical services which performed RW *scene* response (as opposed to inter-hospital transfers), an important distinction for ACN response. Therefore, to facilitate more effective and timely use of air medical services in the age of ACN and to create a research tool to support continuous improvement of emergency care, a detailed assessment of air medical rotor wing service coverage across the nation was initiated. The Center for Transportation Injury Research (CenTIR) in alliance with Association of Air Medical Services (AAMS) and the air medical industry, with support from U.S. DOT (FHWA and NHTSA) designed, developed and produced the *Atlas and Database of Air Medical Services (ADAMS).* ADAMS is a comprehensive, centralized source of descriptive and geographic information on U.S. air medical Rotor Wing services that respond to trauma scenes.[9,10]

This paper provides an introduction to ADAMS. After a brief description of the data collection and processing approach, the focus shifts to examining air medical rotor wing coverage across the country. Specifically, the percent of each state's area and population covered by at least one air medical service that responds to trauma scenes is determined. The study then examines whether there is any correlation between air medical service coverage and reduced motor vehicle fatality rates.

Methods and Materials

ADAMS contains both descriptive and geographic information on air medical services in five data categories: Service Provider Administration, Communication Center, Base Helipads, Rotor Wing Aircraft and the Receiving Hospitals which receive emergency transports. ADAMS includes commercial and not-for-profit air medical services, public service (i.e., police and fire) as well as selected military air medical units (i.e., Coast Guard, National Guard and MAST units) which complement civilian air medical transport in remote areas.

ADAMS is different from traditional compilations of air medical services in three important ways. First, ADAMS includes the street locations of main <u>and</u> satellite bases, as well as the N-number, make and model of each RW aircraft utilized for medical and trauma scene response. Second, ADAMS is structured as a *relational* database, an important distinction since it allows data to be accessed, extracted, added to, or reassembled in many different ways without having to reorganize the original database tables. Third, this relational database has been imported into a Geographic Information System (GIS), a system of computer hardware, software and data which enables the analyst to view the database in an interactive map context and link mapped objects or locations with related text information. A GIS is a powerful tool because it allows the analyst to overlay other geographic data layers including physical, topographical and demographic data (e.g., cities, counties, roads, airports, railroads, elevation, census data, etc.) Implementation of the database in a geographic framework was originally stimulated by viewing the book of air medical base descriptions and coverage maps created for the German air medical system[11]. This map framework was expanded to a full geographic information system approach in the ADAMS project, to take advantage of the interactive and analytical capabilities and tools offered by a GIS.

Data collection is accomplished using web-based forms accessible by each air medical services via a username and private password. (Only services that operate RW aircraft and respond to trauma scenes are included in the discussion here.) The data collected are subsequently imported into a Microsoft® Office Access relational database. A customized program script written specifically for the ADAMS project by the Department of Geography at the University at Buffalo[12] imports the data into ARC View® 8.3 (ESRI's GIS software) and converts the street addresses to latitude and longitude (geo-coding). The streets database used in the geo-coding is ArcGIS® StreetMap USA 8.3. Ten, twenty and thirty minute fly circles are then created using the cruise speeds of the actual RW aircraft stationed at each base. In addition, the program performs extensive data quality control assessments and creates other specialized GIS output files.

Various geographic analyses are performed within the ARC View® GIS operating on a desktop PC. However, a subset of the ADAMS database has been imported into a password-protected GIS on the web using ARC IMS® 4.01 GIS publishing software. The ADAMS GIS website (which is password-protected for homeland security reasons) is made available to registered air medical service providers, AAMS members, disaster response management and homeland security groups, ACN Message Centers, trauma system researchers, public health agencies and other EMS (Emergency Medical Service) providers. Both the data collection web forms and the web-based GIS can be accessed via the ADAMS home page (www.ADAMSairmed.org.) A public site, also accessible from the home page, contains a compendium of state and national maps (The Atlas) showing air medical coverage in the U.S as of October 2004.[13]

To assess air medical service coverage across the nation, both the geographic area covered by the RW fly circles and the populations residing within them were calculated using the GIS. The latter was accomplished by overlaying the computed fly circles around the air med bases onto the population data layer in the GIS. If the centroid of a population census block was within the fly circle, that census block was included in the population covered. Population data in the GIS is based on Y2000 census data. (Since the Y2000, total U.S. population is estimated to have increased 1.3% by Y2001 and 3% by Y2003.[14])

The source of the motor vehicle crash fatality data used in the analyses presented here was NHTSA's Fatality Analysis Reporting System (FARS) data[15]. In addition to fatality data, the number of injuries from motor vehicle crashes was also compiled by surveying national and state sources for published motor vehicle crash-related injury data for the target year 2001. Major data sources included state Departments of Transportation, Departments of Health/EMS and Departments of Motor Vehicles. For some states, Year 2001 injury data was not available. In those cases, data on injuries and fatalities from the year closest to Y2001 was used. It is important to note that in all cases, for each state, data from the same year was used for fatalities and injuries. Injury data was obtained for 43 states total. Y2001 data was available for 34 states: AK, AL, AR, AZ, CA, CO, FL, GA, ID, IL, KS, KY, MI, MN, MO, MT, NC, ND, NE, NM, NV, NY, OH, OK, OR, SC, SD, TN, UT, VA, VT, WI, WV and WY. Data from the latest year available (1998-2000) was used for the following 8 states: IN, IA, MD, ME, MS, NJ, PA and TX. A later year (2002) was used for MA because Y2001 data was not available and earlier data was viewed as being less accurate. Motor vehicle injury data was not readily available for the remaining 7 states: CT, DE, HI, LA, NH, RI and WA.

The types of injuries ‘counted’ in this assessment were incapacitating injuries, non-incapacitating injuries and possible injuries. These classifications were usually entered on the accident report submitted by the responding police agency.

Assessments of air medical coverage are provided for all 50 states and the District of Columbia. The assessments that utilize injury data are limited to the 43 states that had injury data readily available.

Results

Main and Satellite Rotor Wing Base Locations

Figure 1 is a topographical map which provides a national view (as of Oct 2004) of the main and satellite base locations of all the Rotor Wing air medical services in the U.S. who perform trauma scene transports. Ten minute fly circles with a gold star in the center indicate the main base location. Fly circles without a gold star indicate a satellite base.

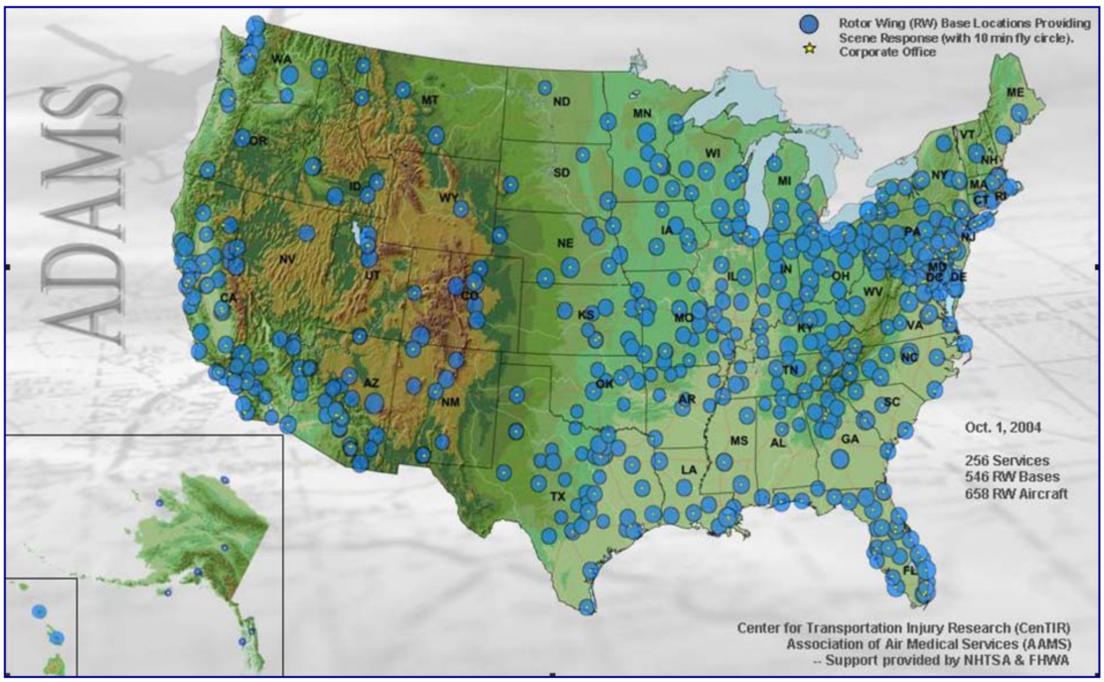

Figure 1. National View of RW Air Medical Service Base Helipad Locations with 10 Minute Fly Circles (Adapted from reference 13)

Table 1 provides a summary by state of the air medical rotor wing services which support trauma scene response. For each state and the District of Columbia, the number of air medical services with bases in the state, the number and type (hospital, airport or public/private helipad) of RW bases and the number of RW aircraft are listed. As of October 2004, there were 256 Air Medical RW Services included in ADAMS, with 658 RW aircraft stationed at 546 helipad bases. We estimate that this includes 95% of the RW services who provide scene response. Of the 546 bases, 227 are located at hospitals, 244 at airports and 75 at stand alone helipads. To place these figures in context, state populations and geographic area are provided for reference. National totals for each category are provided at the bottom of the table. **Figure 2** is a bar chart that graphically displays the base helipad total by type, for each state.

Table 1. 2004 State Summary of Air Medical Rotor Wing Services, Bases & RW Aircraft Currently in ADAMS[13]

State	Services Headqrtd in State	Out of State Services with Bases in State	Total Bases in State	Bases at Hospitals	Bases at Airports	Bases at Stand Alone Helipads	Total RW Aircraft (Scene Transports)	State Population (Y2000)	Total State Area* (Sq Mi.)
Alabama	2	2	7	0	4	3	7	4,447,100	52,423
Alaska	8	0	8	1	6	1	25	626,932	656,425
Arizona	9	0	37	13	19	5	46	5,130,632	114,006
Arkansas	1	2	9	2	3	4	9	2,673,400	53,182
California	27	2	48	8	34	6	60	33,871,648	163,707
Colorado	4	1	9	9	0	0	9	4,301,261	104,100
Connecticut	1	0	2	2	0	0	2	3,405,565	5,544
D.C.	2	0	1	0	0	1	3	572,059	68
Delaware	2	0	3	1	2	0	5	783,600	2,489
Florida	26	0	35	10	23	2	42	15,982,378	65,758
Georgia	4	0	12	2	9	1	14	8,186,453	59,441
Hawaii	2	0	2	0	2	0	5	1,211,537	10,932
Idaho	5	0	7	5	2	0	8	1,293,953	83,574
Illinois	7	3	16	9	5	2	17	12,419,293	57,918
Indiana	3	3	9	4	3	2	11	6,080,485	36,420
Iowa	6	0	7	7	0	0	7	2,926,324	56,276
Kansas	4	1	10	2	8	0	10	2,688,418	82,282
Kentucky	3	1	14	9	4	1	14	4,041,769	40,411
Louisiana	4	0	10	3	5	2	9	4,468,976	51,843
Maine	1	0	2	2	0	0	2	1,274,923	35,387
Maryland	1	2	12	0	10	2	16	5,296,486	12,407
Massachusetts	2	0	3	1	1	1	4	6,349,097	10,555
Michigan	7	0	9	6	3	0	11	9,938,444	96,810
Minnesota	5	0	8	3	5	0	11	4,919,479	86,943
Mississippi	3	0	3	2	0	1	4	2,844,658	48,434
Missouri	7	1	26	8	10	8	29	5,595,211	69,709
Montana	4	0	4	4	0	0	4	902,195	147,046
Nebraska	4	1	7	6	1	0	7	1,711,263	77,358
Nevada	1	2	6	3	2	1	6	1,998,257	110,567
New Hampshire	1	0	1	1	0	0	1	1,235,786	9,351
New Jersey	2	0	3	2	1	0	3	8,414,350	8,722
New Mexico	3	1	7	2	4	1	8	1,819,046	121,593
New York	12	0	18	3	9	6	26	18,976,457	54,475
North Carolina	8	0	10	7	2	1	13	8,049,313	53,821
North Dakota	2	0	2	2	0	0	2	642,200	70,704
Ohio	7	1	23	7	11	5	24	11,353,140	44,828
Oklahoma	2	2	9	5	4	0	11	3,450,654	69,903
Oregon	3	0	4	1	3	0	4	3,421,399	98,386
Pennsylvania	10	0	35	15	15	5	37	12,281,054	46,058
Rhode Island	0	0	0	0	0	0	0	1,048,319	1,545
South Carolina	4	0	4	3	0	1	5	4,012,012	32,007
South Dakota	4	0	4	4	0	0	4	754,844	77,121
Tennessee	5	1	18	10	4	4	21	5,689,283	42,146
Texas	17	3	43	25	13	5	54	20,851,820	268,601
Utah	2	0	6	5	0	1	7	2,233,169	84,904
Vermont	0	0	0	0	0	0	0	608,827	9,615
Virginia	9	1	14	2	11	1	18	7,078,515	42,769
Washington	2	0	7	1	5	1	9	5,894,121	71,303
West Virginia	1	0	3	3	0	0	3	1,808,344	24,231
Wisconsin	6	2	8	6	1	1	10	5,363,675	65,503
Wyoming	1	0	1	1	0	0	1	493,782	97,818
Totals	**256**	**32**	**546**	**227**	**244**	**75**	**658**	**281,421,906**	**3,787,419**

*State total area (land & water) from http://www.netstate.com which references World Almanac of the USA by A. Carpenter, C. Provorse, 1996.

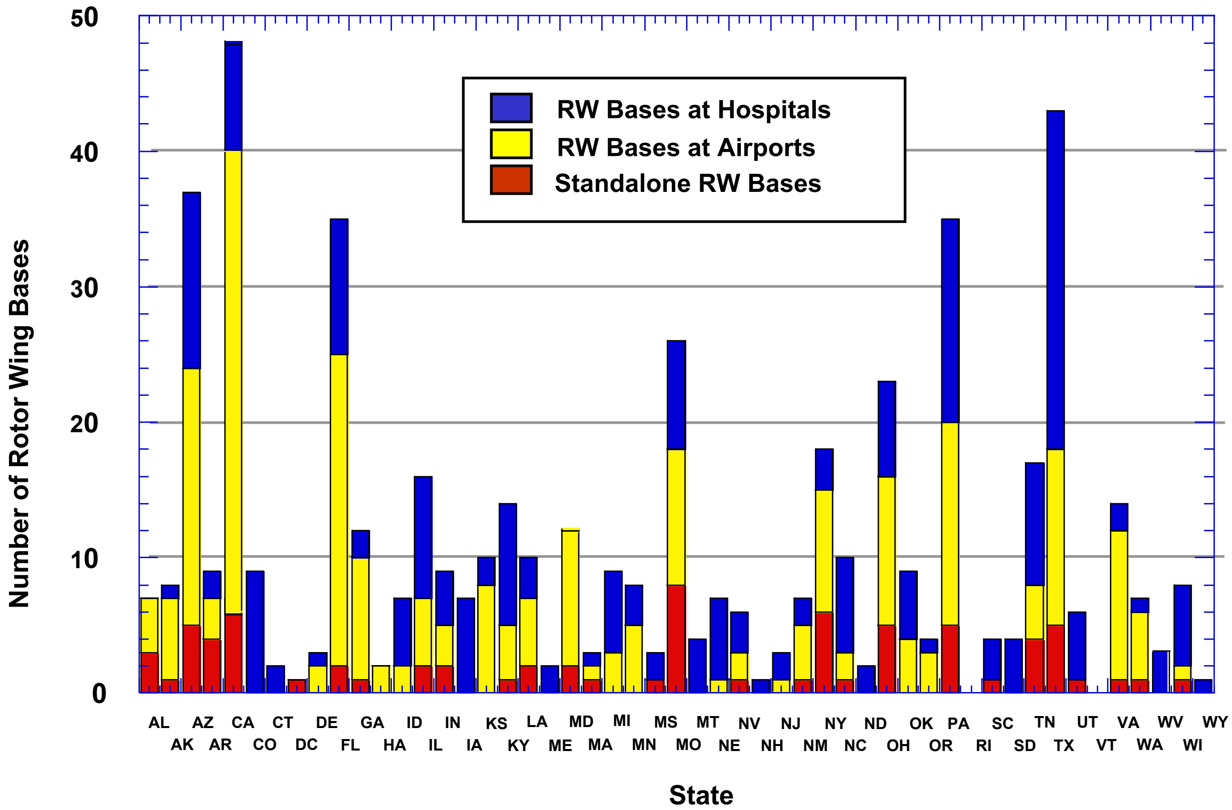

Figure 2. Bar Chart Showing Number of Air Medical RW Bases by State and by Base Type[6]

Figure 3 provides a sample map showing air medical helipad base locations at the state level, as viewed on the ADAMS GIS website. Alabama, Mississippi and part of Georgia are shown. The circles represent 10 minute fly zones around each base with at least one RW. The size of the 10 minute fly circle varies with the cruise speed of the particular RW make and model resident at that base. Note that a 10 minute fly circle translates into an approximate 15 minute response time, assuming a nominal 5 minutes for preflight and launch. (The GIS database also includes twenty and thirty minute fly circles, which translate into nominal 25 and 35 minute response times respectively). The largest cities in the state are also included on the map as are interstate highways.

The 'Layers' list in the legend on the right of **Figure 3** indicates the various stored data layers that can be viewed/plotted on the map by clicking in the adjacent box to make the layer 'visible'. Descriptive data or 'attributes' associated with a specific data item in a given layer are linked to the geographic location on the map so that when the spatial location is queried (left mouse click on map location using identity ('i') tool), the descriptive data associated with that location is displayed at the bottom of the map. More advanced analyses can be performed within a given layer, using a combination of layers or using the intersection of layers, by utilizing the off-line, desktop GIS which contains the data layers available in the web-based mapping application as well as some additional data attributes and layers (e.g., topography).

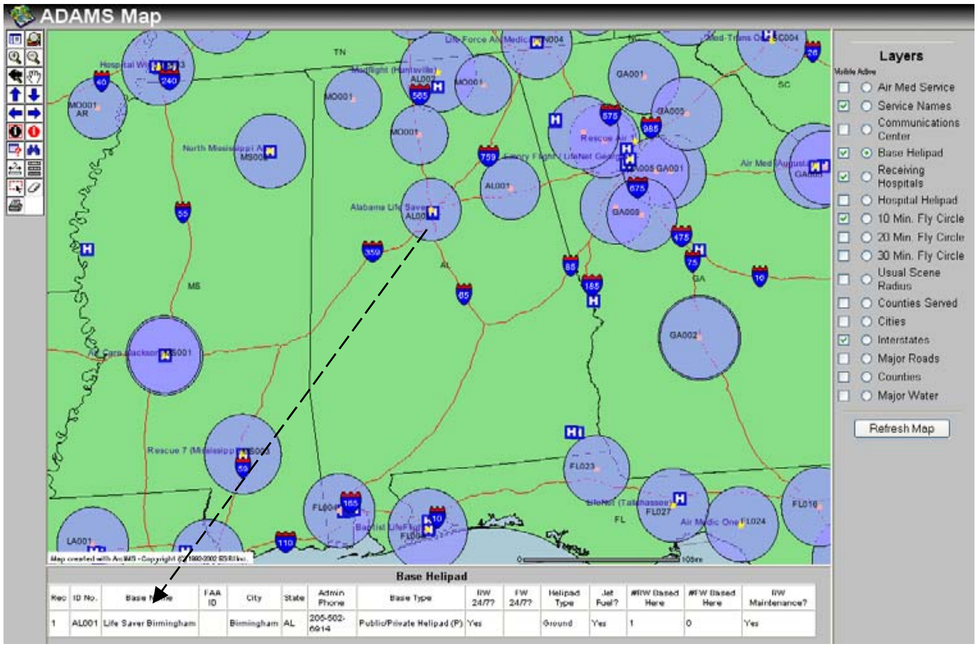

Figure 3 Air Medical RW Base Locations in the Southeast US as Viewed on the ADAMS GIS Website

Assessment of Air Medical Coverage by State

The subject of helicopter trauma transport cost and benefit has provoked significant debate and has produced a sizable body of research on air medical effectiveness (see Ref 16 and references therein). In assessing effectiveness on a national scale however, it is important to establish whether air medical services are truly accessible and how this access might differ in various parts of the country. The ADAMS Geographic Information System provides a tool to support a variety of such studies. Consider again the map in **Figure 3**, which shows the locations of all the air medical rotor wing bases currently in ADAMS. It is apparent that some states have greater geographic coverage than others.

A more quantitative picture of the air medical *geographic* coverage is provided in the first 5 columns of **Table 2** which shows the percent area covered by 10, 20 and 30 minute fly circles around RW bases in the 50 states and D.C. As seen in the table, the state percentages shown for 10 minute fly circles range from 1.5% for Alaska to 98% for Delaware. The other 48 states have values in between. Because of its small territory, D.C. is 100% covered. **Figure 4** provides a bar chart showing the 50 states ranked by percent of geographic area covered by 10 minute fly circles in each state. The inset shows Nevada as an example with its percent area covered (6.5%) highlighted in the plot.

In addition to considering the geographic location and coverage area around RW bases, it is also appropriate to examine what fraction of the *population* is within a given flight time from an air medical base. The last 4 columns in **Table 2** show numerical results of this calculation for all 50 states. The percentage of the state population covered by 10 minute fly circles ranges from a low of 10% (Vermont) to a high of 98% (Maryland and Delaware). Thirteen states have less than 50% of their populations within a 10 minute fly circle (~15 minute response). The high coverage for populations in Nevada (where 91% of the population is within a 10 minute fly circle), is particularly interesting given the low percentage of geographic *area* covered within that state. However, desert, mountains, Air Force bases and test ranges account for most of Nevada's area. Nevada's citizens are therefore concentrated in just a few cities, which explains the high population coverage relative to area coverage. The last row of the table shows that 74.8% of the total U.S. population resides within a 10-minute fly circle (15 minute response) as of Oct. 2004.

Table 2. Geographic Areas and Populations Within 10, 20 and 30 Minute Fly Circles Around Air Medical RW Bases (50 States + DC)

State	Geographic Area* (Sq. Miles)	Percent State Area in Fly Circle			Y2000 State Population	Percent State Population in Fly Circle		
		10 min	20 min	30 min		10 min	20 min	30 min
AK	600,523	1.49%	5.66%	11.50%	626,932	63.38%	74.79%	81.10%
AL	49,181	19.03%	47.50%	71.49%	4,447,100	46.59%	70.03%	85.36%
AR	50,078	23.31%	67.67%	90.71%	2,673,400	48.27%	84.94%	95.19%
AZ	107,778	29.13%	68.95%	89.06%	5,130,632	93.53%	97.02%	98.82%
CA	148,862	37.11%	78.18%	93.33%	33,871,648	91.15%	99.31%	99.53%
CO	97,943	14.96%	42.15%	71.22%	4,301,261	85.74%	92.45%	97.31%
CT	4,675	63.83%	100.00%	100.00%	3,405,565	63.80%	100.00%	100.00%
DC	62	100.00%	100.00%	100.00%	572,059	100.00%	100.00%	100.00%
DE	1,933	97.71%	100.00%	100.00%	783,600	97.85%	100.00%	100.00%
FL	53,749	57.95%	95.83%	99.98%	15,982,378	83.20%	98.46%	99.71%
GA	55,775	29.12%	76.89%	99.43%	8,186,453	65.79%	89.55%	99.89%
HI	6,374	20.14%	26.15%	30.08%	1,211,537	77.44%	82.85%	83.43%
IA	52,848	19.50%	64.56%	96.47%	2,926,324	44.66%	74.86%	98.56%
ID	78,380	10.91%	39.35%	68.59%	1,293,953	65.90%	83.74%	92.88%
IL	52,930	35.13%	87.26%	100.00%	12,419,293	81.98%	96.61%	100.00%
IN	34,221	47.62%	97.13%	100.00%	6,080,485	70.05%	99.43%	100.00%
KS	77,366	19.40%	56.30%	77.89%	2,688,418	66.97%	88.21%	94.13%
KY	37,991	49.08%	97.15%	100.00%	4,041,769	69.47%	97.34%	100.00%
LA	43,788	30.54%	76.27%	93.81%	4,468,976	72.35%	89.97%	95.13%
MA	7,677	53.55%	97.37%	100.00%	6,349,097	80.02%	99.67%	100.00%
MD	9,162	95.26%	100.00%	100.00%	5,296,486	97.84%	100.00%	100.00%
ME	30,265	13.58%	42.72%	64.38%	1,274,923	35.96%	86.23%	93.58%
MI	54,446	22.89%	49.25%	66.10%	9,938,444	41.15%	89.71%	95.37%
MN	79,640	19.97%	55.94%	75.00%	4,919,479	72.35%	90.66%	97.66%
MO	65,744	38.61%	88.41%	99.74%	5,595,211	78.23%	97.21%	99.97%
MS	45,290	16.83%	61.19%	90.24%	2,844,658	33.74%	72.00%	90.62%
MT	138,866	5.20%	20.36%	40.81%	902,195	42.80%	53.34%	68.46%
NC	46,359	33.60%	85.50%	99.14%	8,049,313	55.83%	89.02%	99.21%
ND	66,824	3.43%	14.53%	32.80%	642,200	27.83%	34.08%	52.24%
NE	72,647	18.13%	52.79%	77.01%	1,711,263	65.60%	90.12%	97.96%
NH	8,701	17.10%	78.90%	95.56%	1,235,786	26.19%	92.86%	99.63%
NJ	7,056	67.48%	100.00%	100.00%	8,414,350	80.35%	100.00%	100.00%
NM	115,369	11.25%	36.81%	64.02%	1,819,046	64.63%	77.61%	85.53%
NV	104,111	6.50%	15.50%	27.74%	1,998,257	91.39%	93.34%	94.76%
NY	45,624	40.65%	86.86%	99.44%	18,976,457	82.89%	98.40%	99.92%
OH	38,717	63.26%	97.79%	100.00%	11,353,140	85.34%	99.40%	100.00%
OK	66,165	18.56%	54.28%	74.98%	3,450,654	63.54%	87.23%	96.29%
OR	91,243	7.12%	26.19%	51.84%	3,421,399	56.95%	72.77%	84.53%
PA	42,619	77.35%	99.74%	100.00%	12,281,054	95.49%	99.97%	100.00%
RI	981	34.58%	100.00%	100.00%	1,048,319	12.02%	100.00%	100.00%
SC	29,272	22.38%	74.14%	94.00%	4,012,012	50.58%	83.23%	95.42%
SD	72,576	6.98%	26.12%	49.49%	754,844	42.94%	64.59%	77.50%
TN	39,762	48.74%	92.85%	100.00%	5,689,283	76.57%	98.27%	100.00%
TX	252,474	20.18%	55.00%	79.17%	20,851,820	74.12%	91.54%	97.80%
UT	79,835	7.52%	24.03%	49.10%	2,233,169	79.72%	87.12%	90.90%
VA	37,521	40.43%	90.67%	100.00%	7,078,515	77.64%	97.75%	100.00%
VT	9,026	11.88%	58.69%	91.67%	608,827	10.44%	59.15%	95.58%
WA	63,492	19.07%	55.31%	86.28%	5,894,121	78.04%	90.77%	98.48%
WI	52,744	25.62%	71.88%	90.97%	5,363,675	62.86%	93.91%	98.68%
WV	22,800	27.20%	74.49%	100.00%	1,808,344	49.55%	85.43%	100.00%
WY	91,894	2.09%	10.90%	34.52%	493,782	14.03%	24.92%	51.28%
Totals	**3,443,357**	**19.20%**	**46.91%**	**64.19%**	**281,421,906**	**74.81%**	**92.33%**	**96.54%**

*The geographic area used here was extracted from the ArcUSA 1:25M database (where the scale refers to the scale of the hardcopy the map files were digitized from.) The state borders have been generalized. Although generalizing lowers the resolution and reduces positional accuracy somewhat, it improves drawing speed and reduces data storage requirements. Water bodies adjacent to the state are not included in the areas.

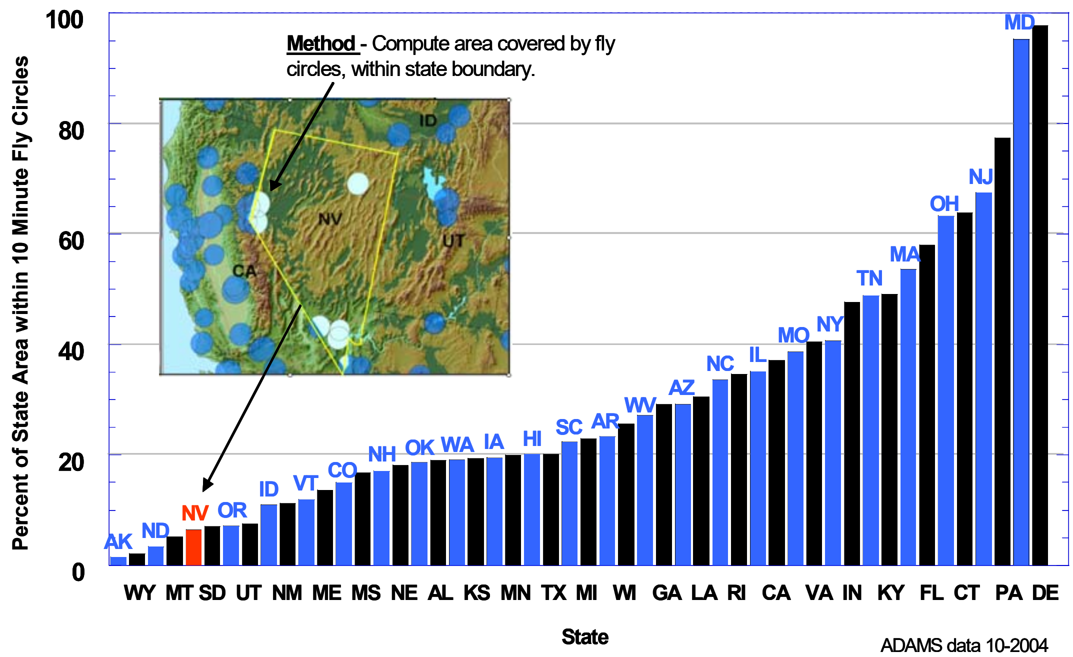

Figure 4. Ranking of Percent State Geographic Area in 10-Minute Fly Circles

Figure 5 provides a bar chart showing the states ranked by percent of the population covered by 10 minute fly circles in the state. The difference in state rankings (by population covered) relative to state rankings (by area covered in Figure 4) is apparent. For an integrated, national look at population and geographic coverage, **Figure 6** shows fly circles overlaid on a national map. Each small gray dot represents a population of 10,000.

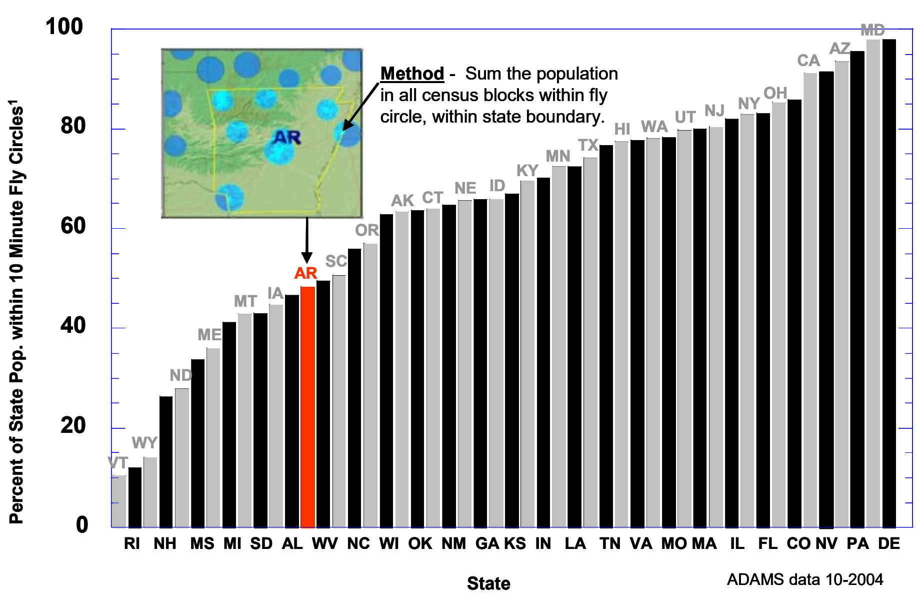

Figure 5. Ranking of Percent State Populations in 10-Minute Fly Circles

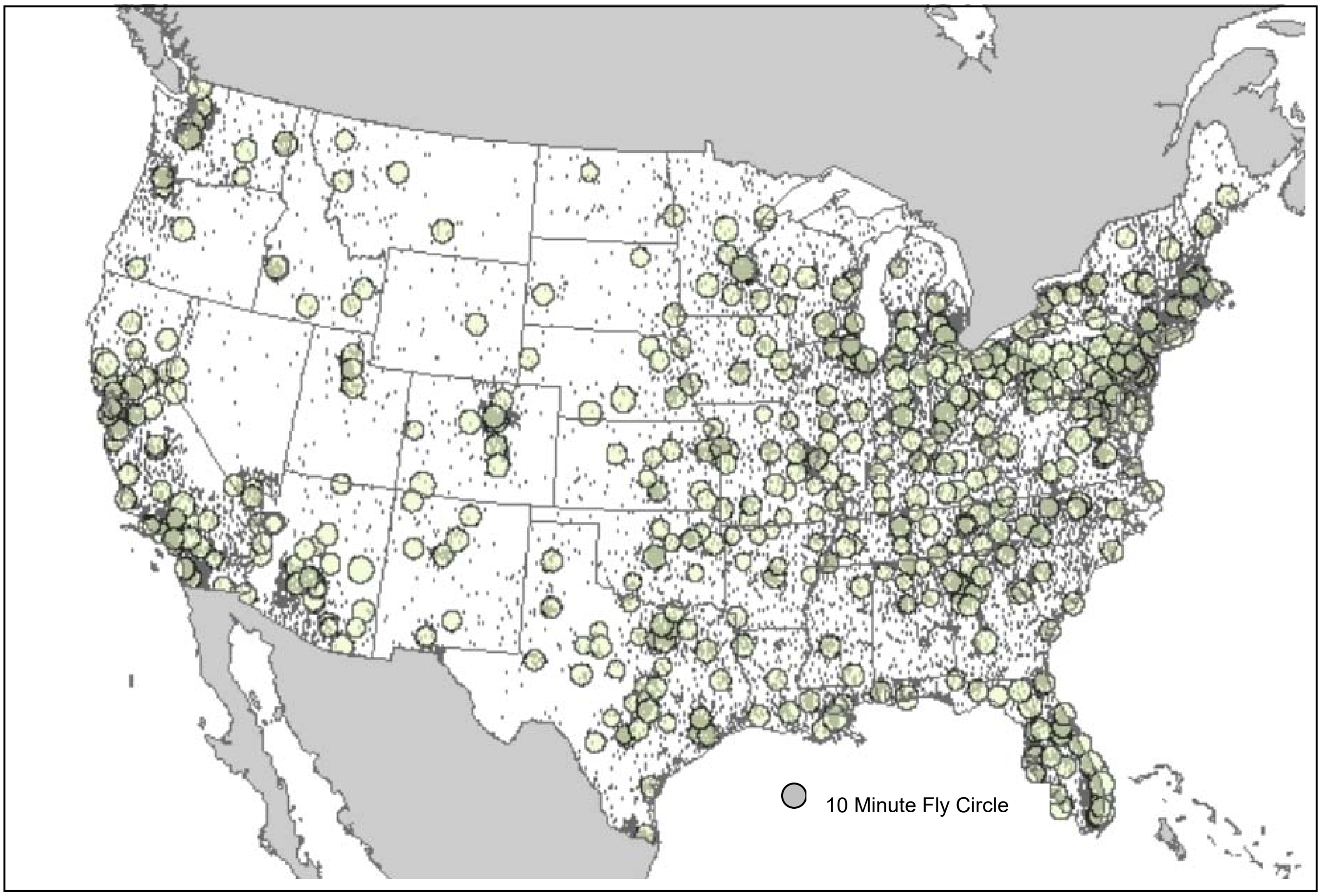

Figure 6. Air Medical RW Bases (with 10 Minute Fly Circles) Overlaid on National Map with State Boundaries. Gray Dots Indicate 10,000 People.

Analysis

Motor Vehicle Crash Fatality Rates and Air Medical Coverage Patterns

Air medical services play an important role in providing access to high level pre-hospital care, especially in rural areas. Data indicates that in 2001, about 39 percent of vehicle miles traveled occurred along rural roads, yet approximately 61 percent of all crash fatalities occurred along rural roads[17]. Furthermore, the number of people who die at the crash scene (i.e., are not transported to a hospital for medical treatment) along rural roads is more than double the number of people who die at the scene along urban roads. There are many reasons identified to account for the higher rural crash mortality rates. Many of the rural fatalities are due to single vehicle run-off-the-road crashes. About 17,000 single vehicle, run-off-the-road, crash-related fatalities occur each year with 12,000 (70%) along rural roads and 5,000 (30%) along urban roads. Delays in crash notification are frequently associated with these crashes because the crashes were unobserved. About 62 percent of run-off-the-road fatalities occur at night and/or in poor visibility conditions.

Table 3 lists FARS traffic fatality data, along with the standard FARS fatality rate metrics provided by NHTSA (headings highlighted in gray) for the 43 states for which injury data was readily available. The minimum and maximum fatality rate in each column are shown in bold type.

Table 3. Data Employed in Fatality Rate Calculations (43 States)

State	Year	Fatalities *	Injuries[18] **	Fatalities Per 1000 Injuries	FARS Fatalities			
					Per Million VMT	Per 100K Drivers	Per 100K Reg'd Vehicles	Per 100K Population
AL	2001	994	42909	23.2	1.75	27.92	23.17	22.27
AK	2001	89	6543	13.6	1.8	18.01	13.82	13.90
AZ	2001	1048	73962	14.2	2.06	29.52	25.20	19.75
AR	2001	611	47003	13.0	2.08	31.14	32.28	22.70
CA	2001	3956	305907	12.9	1.27	18.29	13.52	11.47
CO	2001	741	49363	15.0	1.71	22.38	15.19	16.66
FL	2001	3011	234600	12.8	1.93	23.63	20.56	18.36
GA	2001	1615	132306	12.2	1.5	27.68	21.83	19.26
ID	2001	259	14021	18.5	1.84	28.87	19.00	19.61
IL	2001	1414	124631	11.3	1.37	18.10	13.98	11.33
IN	2000	886	70678	12.5	1.27	22.08	15.80	14.87
IA	2000	445	35529	12.5	1.49	22.59	12.93	15.29
KS	2001	494	28828	17.1	1.75	26.40	20.73	18.33
KY	2001	869	52952	16.4	1.83	30.65	23.01	20.78
ME	1998	606	15303	12.5	1.33	20.36	18.29	14.92
MD	1998	606	60757	10.0	1.27	19.12	16.52	12.28
MA	2002	459	56555	8.1	**0.9**	**10.34**	**8.98**	**7.48**
MI	2001	1328	112292	11.8	1.34	19.03	15.35	13.29
MN	2001	568	42223	13.5	1.06	19.18	12.07	11.42
MS	1996	811	27784	29.2	2.18	42.17	**39.58**	27.43
MO	2001	1098	73629	14.9	1.62	28.43	25.70	19.50
MT	2001	230	8982	25.6	**2.3**	33.67	21.70	25.43
NE	2001	246	26751	9.2	1.36	19.42	14.85	14.36
NV	2001	313	29287	10.7	1.71	22.03	23.86	14.86
NJ	1998	743	158103	**4.7**	1.09	13.07	11.14	8.80
NM	2001	463	27536	16.8	1.99	37.58	31.78	25.31
NY	2001	1554	259143	6.0	1.18	14.05	15.01	8.14
NC	2001	1533	134238	11.4	1.67	26.00	24.41	18.69
ND	2001	105	4608	22.8	1.45	23.03	14.46	16.55
OH	2001	1378	138847	9.9	1.29	17.81	12.73	12.12
OK	2001	676	45275	14.9	1.55	31.12	20.13	19.54
OR	2001	488	26976	18.1	1.42	19.26	15.68	14.05
PA	2000	1530	131471	11.6	1.49	18.60	15.50	12.45
SC	2001	1059	52350	20.2	2.27	37.16	33.10	26.06
SD	2001	171	7118	24.0	2	31.38	20.48	22.60
TN	2001	1307	76910	17.0	1.85	29.87	23.95	21.79
TX	2000	3724	285255	13.1	1.72	28.55	25.56	17.46
UT	2001	292	29699	9.8	1.25	19.52	16.30	12.86
VT	2001	92	2628	**35.0**	0.96	17.86	16.49	15.10
VA	2001	935	80187	11.7	1.27	19.00	14.99	13.01
WV	2001	386	25797	15.0	1.91	28.55	25.41	20.87
WI	2001	763	58279	13.1	1.33	20.81	16.30	14.12
WY	2001	186	5759	32.3	2.16	**50.13**	31.31	**37.62**

* FARS Fatality data and fatality rate metrics are from *NCSA Traffic Safety Facts* for indicated year (column 2). Target year is 2001.
**Year 2001 injury data available for 34 of the 43 states listed. Injury data for other 9 states derived from closest year available. Injury data not readily available for 7 states not listed (i.e., CT, DE, HI, LA, NH, RI and WA).

Figure 7 (left) shows a plot of 'fatalities per 100K registered vehicles' in each state vs 'percent state population in a 10 minute fly circle'. The red line in the plot represents a linear least squares fit to the data. The correlation coefficient R, associated with the fit is shown in the upper right corner. The value of the correlation coefficient (R = -0.33) shows that the correlation of these quantities is weak. (Perfect correlation would give R= -1.0). However, the fit in **Figure 7** (right) which shows 'fatalities per 100K population' vs 'percent population in a 10 minute fly circle' produces a correlation coefficient of R= -0.55. This indicates that reduced fatality rates (by population) are somewhat correlated with increased air medical coverage.

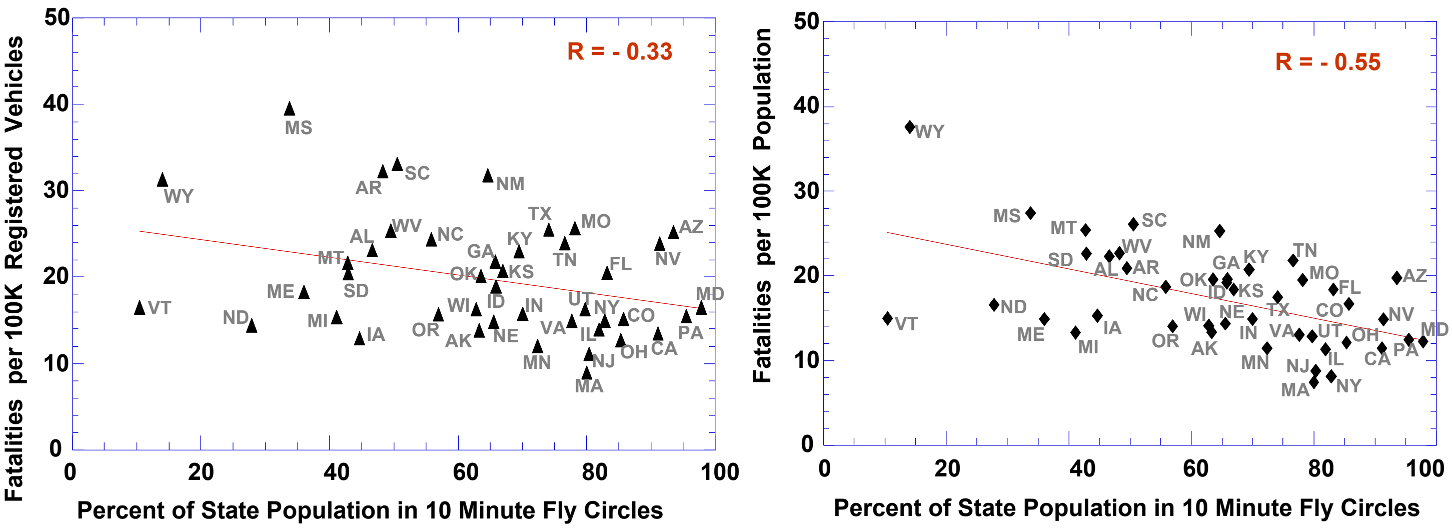

Figure 7. NHTSA Fatality Rates (Per 100K Registered Vehicles and per 100K Population) versus Percent of the State Population in 10 Minute Fly Circle

Let us now consider a different fatality rate, one that is calculated by looking at the number of traffic deaths relative to the number of *traffic injuries*. This is similar to the fatality rate metric devised by Dr. Donald Trunkey who looked at the number of deaths per number wounded during wars over the last 50 years.[19] His research on war related fatalities showed the positive effect an improved trauma care system can have on fatality rates. Intuitively, assessing the number of motor vehicle deaths per number of motor vehicle injuries (requiring hospital care) provides some measure of the effectiveness of the trauma system response. **Table 3** (column 4) shows the injury totals from motor vehicle crashes obtained from individual state sources[12]. The crash fatality/injury rate (calculated as fatalities/1000 injuries) is provided in column 5 of the table for the 43 states and ranges from 4.7 to 35.0 for the various states. (For reference, the ratio of total fatalities per 1000 injuries for the 43 states was 12.4.)

Figure 8 provides a plot of the Fatalities/1000 Injuries versus percent population within a 10 minute fly circle for each of the 43 states. The correlation coefficient in this case is R= -0.74 which is stronger than the previous fatality rates examined. One possible interpretation of this result is that when a high percentage of a state's crash injured victims have access to timely air medical response, the survival rate among the injured is higher. However, it is clear that other factors also must be considered (e.g., different nature of urban and rural crashes) and more analyses are required to explore this relationship. Work is in progress to collect traffic injury data for the remaining 7 states so that a more complete analysis for the entire country, with appropriate statistics, can be completed.

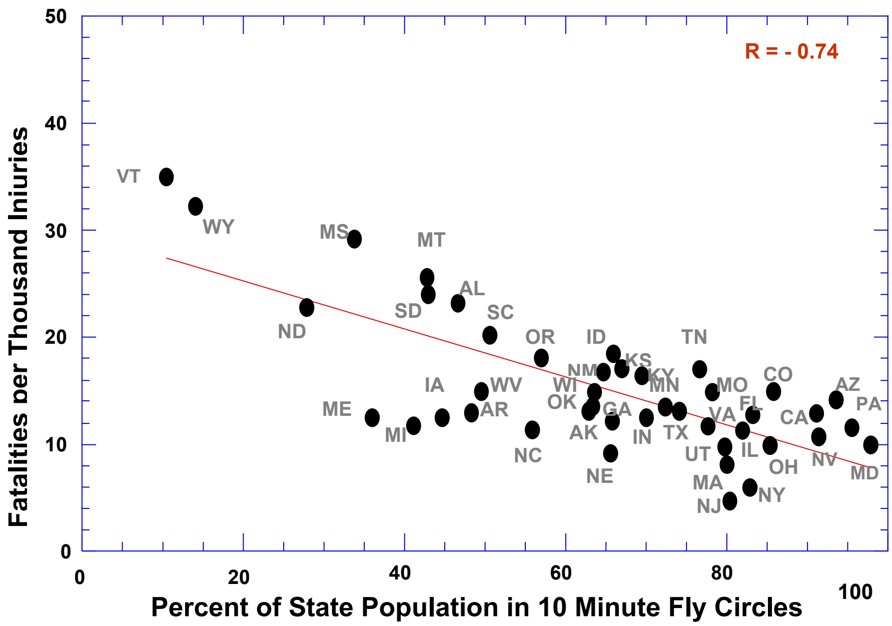

Figure 8. Fatality Rates Per 1000 Injuries versus Percent of the State Population in 10 Minute Fly Circle

Table 4 summarizes the correlation coefficients for all the fatality rates listed in Table 3.

Table 4 - Correlation Coefficient Describing the Relationship between Various Fatality Rates and Percent of State Population within 10 Minute Fly Circle(s)

(ADAMS October 2004 Fly Circles)

Fatality Rate Definition	Correlation Coefficient R
Fatalities per 1K Injuries	-0.74
Fatalities per 100K Population	-0.55
Fatalities per 100K Drivers	-0.45
Fatalities per 100K Registered Vehicles	-0.33
Fatalities per Million VMT	-0.25

Future efforts using ADAMS will focus on examining actual geocoded fatal crash locations relative to air medical coverage. Ideally, the availability of geo-coded information on all crashes (not just fatal crashes) along with crash specific information (i.e., numbers of injured victims, nature and extent of injuries, transport mode, event timelines, transport destination, outcomes, etc.) will permit more complete characterization and analysis of EMS and trauma care system performance.

Limitations of Study

The air medical coverage assessments made here assume that at least one RW aircraft is available at each reported base of operation. Therefore, the results reported represent an upper limit to the air medical coverage pattern.

There are also some limitations related to the accuracy and completeness of state injury data. Injury data is not readily available for 7 states. In states where it is readily available, police reported injury classifications are the primary source of the data. There is some uncertainty as to the accuracy of the police reported data for fatalities that did not occur at the scene or shortly after the crash.

Another limitation is the less-than-perfect concurrency of the air medical coverage data and the injury, fatality and population data. The most recent state injury data available for most states is Y2001. The first national ADAMS dataset of RW bases was not available until October 2003. The ADAMS data from 2003 likely does not exactly reflect the status of the air medical coverage in the year 2001. However, some insight into the sensitivity of the fit to changes in ADAMS data is known. The assessments described here use ADAMS data from October 2004 because this dataset is believed to be more complete and a better snapshot in time. (Specifically, the October 2004 dataset was verified over a 3 month period as compared to the initial Oct 2003 ADAMS dataset collected over a 21 month period from Jan 2002 to Sept 2003). Initially, the fit in **Figure 8** was calculated using fly circles extracted from an interim ADAMS dataset which was very similar in content to the October 2003 dataset and with (about) 19% fewer RW bases relative to the Oct 2004 dataset. This initial plot showed a correlation coefficient of R=-0.75, virtually identical to the correlation coefficient of R=-0.74 using the Oct 2004 dataset in **Figure 8**. This suggests that the correlation will likely hold even with some variations in the ADAMS dataset. This will be confirmed in the future when this correlation is revisited as more recent injury data (closer in time to the ADAMS 2004 dataset) becomes available.

There is some temporal difference between ADAMS data and the population data in the GIS which is based on the Y2000 census. U.S. population is estimated to have increased 1.3% by Y2001 and by 3% by 2003.

Many control factors for the effectiveness of air medical services can be taken into account as part of a multivariate statistical analysis. For instance, the geographic distribution of vehicular traffic and vehicle miles traveled would provide better measures of the population at risk for being involved in a crash. The effectiveness of ground ambulance response is also intimately linked to the benefits of air medical services. More meaningful relationships may be developed by examining Air Medical coverage of actual crash locations rather than resident population locations. This is planned in coming months using geocoded FARS data. However, it may be a while before the locations of non-fatal injury crashes become available. Ultimately, looking at *utilization* (rather than coverage) of air medical services versus ground-based services is of great interest.

Summary & Conclusions

The Atlas and Database of Air Medical Services (ADAMS) is a web-based Geographic Information System originally developed to support emergency response to Automatic Crash Notification (ACN) alerts received from motor vehicle crash scenes. To support ACN message routing, the locations of all air medical bases with Rotor Wing aircraft must be known to enable real-time identification of the nearest air medical emergency responders to an ACN crash site. As of October 2004, there were 256 Air Medical RW Services included in ADAMS, with 658 RW aircraft stationed at 546 helipad bases. We estimate that this includes 95% of the RW services that provide scene response.

This paper has examined the status of air medical coverage in this country. The numbers of base helipad and RW aircraft in each state have been summarized and estimates of the geographic areas and populations covered by air medical services have been calculated for each state. In addition, the benefits of air medical services have been examined by looking at motor vehicle crash fatality rates by state. Using the ratio of 'fatalities per 1000 injuries' as a metric, we have found a moderately strong correlation (R= -0.74) between increased air medical service coverage and reduced fatality rates (based on data from 43 states). One possible interpretation of this result is that when a high percentage of a state's crash injured victims have access to timely air medical response, the survival rate among the injured is higher. The strength of this conclusion will be examined in future studies as more injury data becomes available. With the growing use of ACN technologies and ADAMS, the effectiveness and efficiency of air medical services is expected to be increased.

Finally, the ADAMS GIS provides for the first time, the data and software tools needed to enable users to view the air medical resources in this country on national, state and local levels. In the near future, ADAMS will be used to support development of new software tools for automatically routing ACN alert messages. In addition to supporting ACN applications, ADAMS is expected to support a variety of trauma system research studies as well as mutual aid, disaster response planning and homeland security efforts.

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References

1. Blincoe L, Seay A, Zaloshnja E, .Miller T, Romano E, Luchter S, Spicer, R. The Economic Impact of Motor Vehicle Crashes, 2000, NHTSA Technical Report DOT HS 809 446, U.S. Department of Transportation, National Highway Traffic Safety Administration, May 2002.
2. Nathens AB, Jurkovich GJ, Cummings P, Rivara FP, Maier RV. The Effect of Organized Systems of Trauma Care on Motor Vehicle Crash Mortality, JAMA. 2000;283:1990-1994.
3. Nathens AB, Jurkovich GJ, Rivara FP, Maier RV. Effectiveness of state trauma systems in reducing injury-related mortality: a national evaluation., J Trauma. 2000 Jan;48(1):25-30. General Trauma System Agenda for the Future, coordinated through the American Trauma Society, Supported by the US DOT, NHTSA, October 2002.
4. Funke D, Bellis E, Donnelly B, Blatt A, McClellan R, Wilson G, Automated Collision Notification (ACN) Field Operational Test Final Report, National Highway Traffic Safety Administration, U.S. DOT HS 809 303, October 31, 2000.
5. Bachman LR, Preziotti GR, Automated Collision Notification (ACN) Field Operational Test (FOT) Evaluation Report, National Highway Traffic Safety Administration, U.S. DOT HS 809 304, February 2001, page 6-7.
6. Champion HR, Augenstein JS, Blatt AJ, Cushing B, Digges KH, Hunt RC, Lombardo LV, Siegel JH, Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Vehicles in Crashes to EMS, Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles, May 19-22, 2003, available at http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv18/cd/files/18ESV-000406.pdf
7. Trunkey DD, Trauma, Scientific American, August 1983, Vol. 249, No. 2, pp. 28-35. This paper by Dr. Trunkey was the original inspiration for the ADAMS project. Subsequently, other researchers reinforced the life-saving value of air medical services.
8. These include membership lists of professional air medical organizations such as AAMS, AMPA, NEMSPA, NFPA, ASTNA as well as supporting organizations such as CAMTS, FlightWeb, etc. and magazines such as Air Ambulance/Helicopter World.
9. Flanigan, M, Blatt, A (Editors), ADAMS - Atlas and Database of Air Medical Services; A Compilation of National and State Maps Showing Air Medical Coverage (Main and Satellite Base Locations), 1st Edition (Oct 2003), Buffalo: CenTIR/AAMS/NHTSA.

10. Flanigan M, Blatt A, Miller M, Pirson H, Lombardo L, Mancuso D, The Atlas and Database of Air Medical Services; A Timely Safety and Security Link, Proceedings of the Intelligent Transportation System Safety & Security Conference, Miami Beach, FL, March 24-25, 2004.
11. ADAC Stationatlas; Luftrettungsstationem in Deutschland, ADAC Luftrettung GmbH, Munchen, 2000.
12. Hwang J, Thill JC, Air Medical Services GIS Data Processor Software and Report, Department of Geography, University at Buffalo, August 2003.
13. Flanigan M, Blatt A (Editors), ADAMS - Atlas and Database of Air Medical Services; A Compilation of National and State Maps Showing Air Medical Coverage (Main and Satellite Base Locations), *2nd Edition (0ct 2004)*, Buffalo: CenTIR/AAMS/NHTSA. (2004 Edition also available at http://ADAMSairmed.org)
14. U.S. Census Bureau, http://www.census.gov/popest/datasets.html
15. Traffic Safety Facts 2001, A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System, DOT HS 809 484, U.S. DOT, NHTSA, National Center for Statistics and Analysis, December 2002.
16.Thomas S, Harrison, T, Buras, Ahmed W, Cheema F, Wedel S, Helicopter Transport and Blunt Trauma Mortality: A Multicenter Trial, Journal of Trauma Injury, Infection and Critical Care Volume 52(1), Jan 2002, pp 136-145.
17.Traffic Safety Facts 2001, Rural/Urban Comparison, NHTSA, NCSA, DOT HS 809 524.
[18] Alabama Department of Public Safety, Alaska Department of Transportation and Public Facilities, Arizona Governor's Office of Highway Safety, Arkansas State Police, NHTSA (CA, CO, MI, MO, WV), Georgia Governors Office of Highway Safety, Idaho Transportation Department, Illinois DOT, Governor's Council on Impaired and Dangerous Driving (Indiana), Iowa Dept of Public Safety, Kansas DOT, Kentucky State Police, Maryland DOT, Massachusetts Registry of Motor Vehicles and Crash Data System, Michigan Criminal Justice Information Center, Minnesota Dept of Public Safety, Governor's Highway Safety Association (MS, NJ), Montana Traffic Safety, Nebraska Department of Roads, New Mexico State Highway and Transportation Department, NYS DMV, Univ of North Carolina Highway Safety Research Center, North Dakota DOT, Ohio Dept of Public Safety, Oklahoma Dept of Public Safety, Oregon DOT, Pennsylvania DOT, South Carolina DOT, South Dakota DOT, Tennessee DOT, Texas DOT, Utah DOT, Vermont DOT, Virginia DOT, Wisconsin DOT.
[19] Trunkey D, History & Development of Trauma Care: The U.S. Experience, Clinical Orthopedics, 2000;374.