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# Opportunities to Enhance Air Emergency Medical Service Scale through New Vehicles and Operations

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**Air Emergency Medical Service (Air EMS) provides unique and important medical transport capabilities to society. Air EMS can move patients or live organs more rapidly than surface modes over long distances or congested areas. Air EMS also provides unparalleled access to accident scenes in regions where surface transportation is compromised such as in the backcountry or during disaster scenarios. However, despite these unique capabilities, Air EMS is currently provided to only a small minority of the most critical medical cases. This is due to the high historical cost and risk of airborne operations. Air EMS costs are driven primarily by the high level of availability required of these services and their low utilization. The elevated accident rate compared to other forms of aviation is in large part due to the operation of these services to and from off-field landing areas with unmarked and perhaps unknown obstacles. This research investigates opportunities to increase the number of Air EMS operations provided in a region by reducing the cost per operation and increasing the level of care. Significant recent investments in Urban Air Mobility (UAM) systems are maturing a new class of electric aircraft and automation technologies that may provide benefits to Air EMS operations. Furthermore, opportunities to deploy Air EMS assets as part of a UAM system to increase utilization and reduce costs through revenue management are also reviewed. Finally, potential pathways to leverage Air EMS as a proving ground and forcing function to overcome constraints in air traffic control and community acceptance for broader UAM services are discussed. The results of this study suggest that near-term electric aircraft are not expected to meet the requirements of the Air EMS mission and also provide little cost reduction potential for the industry. However, new operational models that leverage UAM markets and airline revenue management systems show promise to enhance Air EMS scale. Finally, flight automation technologies in development for UAM aircraft show potential to increase Air EMS safety.**

## I. Introduction

**A**ir Emergency Medical Services (Air EMS), and more specifically Helicopter Emergency Medical Services (HEMS), operate as current-day example of Urban Air Mobility (UAM) that provides high quality medical services and on-demand transportation to a small percentage of patients. Air EMS comprises an important element of the medical transport system that assists in shuttling patients, equipment, supplies, and medical personnel throughout the medical network for time-critical emergency transportation as well as long-distance scheduled transfers.

Despite the significantly higher cost per transfer relative to surface ambulance options, Air EMS services persist because of the unique value air transport brings to hospitals and first responders. Helicopter and fixed-wing transports are associated with the perception of elevated levels of care for emergency scene-response, more rapid inter-facility transport over long distances, and unparalleled access to areas with poor roads (such as the backcountry or in disaster scenarios). Furthermore, Air EMS also often brings the most critically injured and high-value patients to hospital facilities for treatment; these are patients who may have experienced a less effective medical outcome if a surface trip to the hospital had been their only option.

Emergency scene response and patient or organ facility-to-facility transport are two categories of transport that characterize a majority of current HEMS operations. Air EMS operates on the principle of high availability (often 24 hours a day), on-demand transportation. Providing such a high level of availability requires continual staffing of pilots and medical teams. Due to current low utilization of these resources, this required level of availability imposes a

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significant financial burden on the hospitals and patients (through usage fees) to maintain the service and infrastructure. Furthermore, the on-demand nature and high priority of Air EMS operations also burdens Air Traffic Control (ATC), especially for pop-up operations near airports.

Recent investments in novel electric Vertical Takeoff and Landing (eVTOL) and Short Takeoff and Landing (STOL) aircraft for commercial UAM missions may provide a means to address the cost and safety challenges of Air EMS. Electrification of these aircraft is expected to reduce total operating cost per seat mile by 26% compared to helicopters [1]. The development of simplified flight controls, advanced sense and avoid technologies, and even fully autonomous aircraft may also increase the safety of Air EMS operations. Furthermore, increased safety could reduce Air EMS operating costs through the removal of second pilots or a reduction of insurance costs.

Beyond flight technologies, new service models for Air EMS may also help to reduce costs through increased utilization. Over the past decades commercial airlines have realized significant revenue gains through the use of revenue management systems. These systems, simply speaking, seek to distribute a limited number of seats on a flight to the variety of potential customers in each class so as to maximize the revenue of the flight [2]. Air EMS operators have traditionally only provided service to the most severe medical cases (i.e. the highest fare class) so as to ensure that their aircraft was available in case another more severe case came about. The use of revenue management ideologies and Air EMS product expansion, perhaps as part of a commercial UAM system, is investigated as a means to increase asset utilization and ultimately provide expanded Air EMS at a larger scale with the same or better availability to patients.

Finally, emerging UAM systems have been found to be constrained by numerous operational challenges including ATC scalability, ground infrastructure availability, and community acceptance [3]. This paper proposes and reviews how the implementation of Air EMS services at a larger scale may be a means by which to avoid these constraints for near-term operation of new aircraft and services, and ultimately enable the removal of these constraints for commercial UAM services.

For example, the implementation of Air EMS operations at a larger scale may pose a number of challenges for safe and effective ATC. These challenges were shown by [4] [5] to include managing a significantly increased number of vehicles operating at high densities in low altitude airspace. While ATC may simply deny commercial UAM operations access to saturated airspace, the high priority afforded to Air EMS operations means that ATC would be stimulated to adapt to the increased density of Air EMS flights by creating new means to accommodate the operations.

Similarly, while commercial helicopter operations have often received significant public backlash for noise emissions over communities [6], the noise generated by HEMS operations have mostly (though not always the case [7]) been deemed permissible by local communities due to the high societal value their service provides. Therefore, increasing the number of Air EMS operations in an area may help to build community acceptance at the outset in a manner commercial operations could not.

This paper investigates if the scale of Air EMS provided to society could be enhanced by leveraging new opportunities emerging from the UAM sector. Specifically, this research focuses on improvements to the Air EMS vehicle capabilities and the services' operational model. By improving the cost/benefit ratio for current operations, and by examining the strain these helicopters place on ATC and communities, it may be possible to both improve the Air EMS operational model and support the implementation of future UAM systems.

## **II. Current Air EMS Operations**

Air EMS is a critical support system for emergency medical care. It exists to connect a complex healthcare service to patients when timing and level of care are critical factors in the successful outcome of the patient. This section presents an overview of the current structure and operation of the Air EMS ecosystem. The purpose of the review is to define the fundamental requirements of the Air EMS mission and identify where current vehicles and operations are lacking in these requirements. The Air EMS market is first presented followed by a review of vehicle medical and transport capabilities, the service interoperability with a variety of support systems, and finally a cost breakdown of current services.

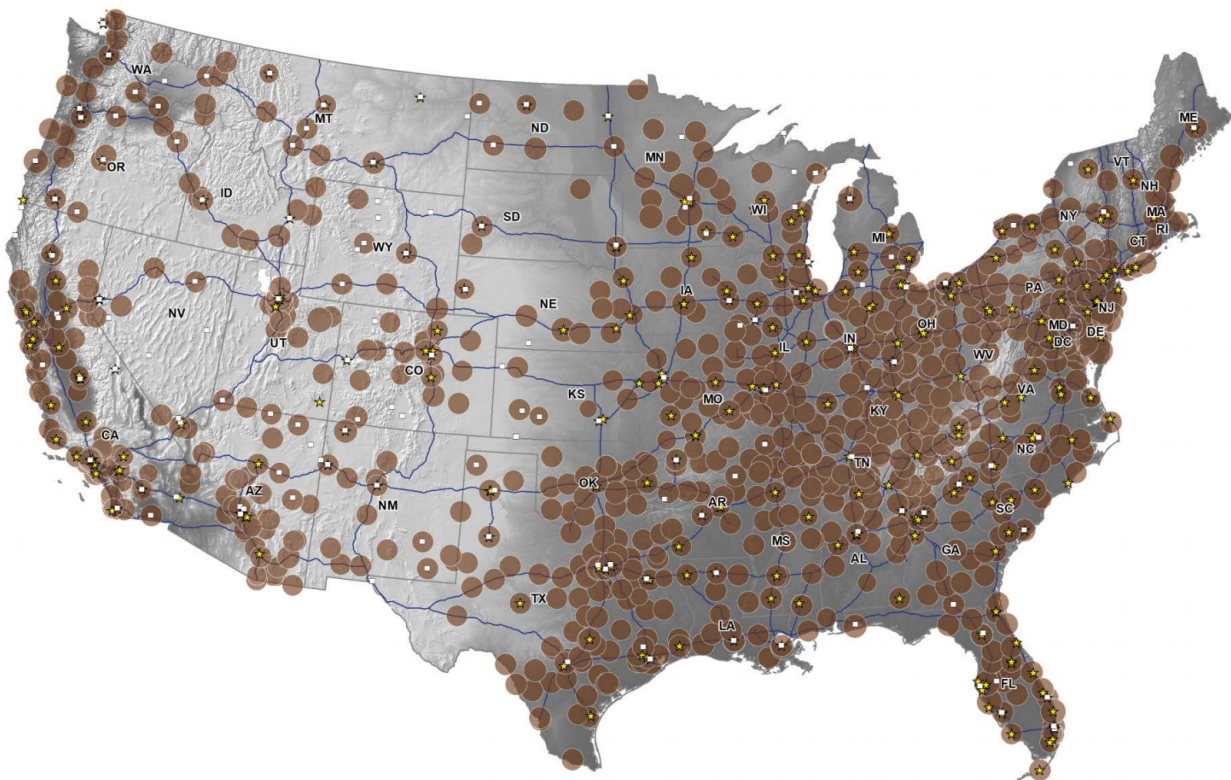
### **A. Description of Air EMS Operations and Markets**

Air EMS provides benefit through the fast transportation of patients whose medical outcome may depend on speed of access to appropriate care and through the provision of highly trained EMS and equipment. Air ambulance transport can be broken down into three categories of missions, with 54% consisting of interfacility transport, 33% scene response, and 13% organ transport [8].

Interfacility transports occur when a patient at an existing medical facility is transported to another facility that is

able to provide more appropriate care. In some cases, critical patients are first stabilized at the nearest hospital prior to transfer to the most appropriate facility where definitive care will be provided [9]. In other cases, a patient already at a facility appropriate for his or her current condition may experience decompensation and unexpectedly require an intervention not available at the current facility. The medical team may then request an air ambulance for an emergency transport to a more advanced facility. During scene response missions, the helicopter travels to the scene of injury, providing advanced life support capabilities through personnel and equipment, as well as fast transportation from the scene to the appropriate hospital. Air ambulances are used for organ transport to facilitate the timely transport of organs from the site of procurement to the transplant facility.

Air ambulances transport approximately 400,000 patients by rotary-wing and 150,000 by fixed-wing aircraft each year in the US, compared to 36 million transports by ground [10]. Geographically, Air EMS services are currently located within a 10 minute flight radius of 85% of the continental US population [11], as shown in Fig. 1. The gaps in coverage within the 10-minute fly radii are primarily located in rural areas. In these regions advanced EMS services, hospital infrastructure, and even ground ambulances are often limited in availability due to the challenging economics of providing service in such demand poor areas. As a result, typical rural healthcare facilities are able to treat a narrower set of health issues, and are also less able to commit medical transport resources for extended periods of time. This means that many rural facilities cannot dedicate their sole ground ambulance for transporting patients to region's primary hospital which may be over an hour away in some cases.



**Fig. 1 Air EMS providers in the continental United States. Circles represent areas within a 10-minute fly radius of a vehicle. Image adapted from Ref. [11].**

Air ambulances compensate for this lack of medical transport capability by serving as a faster link between these rural facilities and major metropolitan trauma facilities. However, in some regions even Air EMS operations are limited from providing effective transport by range limitations. Furthermore, long trips to rural treatment facilities may not be taken by an air ambulance if the time required to complete the trip reduces the availability of the Air EMS service in the primary city center. This suggests that new vehicles with longer ranges and faster cruise speeds than existing helicopters may provide additional capabilities to Air EMS operators in some rural areas.

Besides being allowed to operate, the service must also be financially viable and accessible. The high costs to operate current air ambulance services has resulted in extremely high per-transport prices, often upwards of \$11,000, that financially strain patients and also create pressure for air ambulance services to cut costs or take higher risks during missions in order to generate revenue. Having extremely high prices for transport may prevent the use of air EMS services, or alternatively create undue financial burden for patients who are transported. However, setting prices too much lower than the costs incurred is unsustainable. Air EMS operations should be sufficiently low cost in order to be useful to the population it is trying to serve.

While the total number of rotary-wing air ambulances in the US has risen dramatically since 2004, the number of vehicles has plateaued and stayed roughly constant in the last three years. At the same time, the utilization of the vehicles has been slowly decreasing. Current utilization is around 400 transports per vehicle per year on average [11], with a large variance in the distribution of missions per vehicle. This may indicate that the increasing marginal costs of adding coverage to underserved areas has become an inhibiting barrier, especially to extend coverage further into rural areas.

Furthermore, the expansion in number of providers and helicopters in certain regions, without expanding coverage, results in reduced per-vehicle utilization and thereby increased costs for each transport. Increased costs further discourage use of the service, creating a negative cycle. Therefore current vehicles and operations may be too costly to operate and new systems or operation models are needed that can significantly reduce operating costs in order to and increase vehicle utilization and achievable geographic coverage. A significant reduction in costs would assist in expanding coverage to rural, underserved areas, as well as potentially increasing utilization to some degree in urban areas, where ground transports currently are dominant.

## **B. Medical Service Capabilities**

Air EMS is valued for both the medical treatment capabilities and the transportation capabilities it brings. In current operations, each flight includes two highly trained medical personnel, generally a paramedic and a flight nurse, as well as advanced life support equipment. This quality of medical service often exceeds what is available in a typical surface ambulance. Particularly in rural areas, where local emergency medical technicians may be trained to a lesser degree or have less experience with particular kinds of injuries, Air EMS can be especially valuable for the advanced training and experience that is brought to the patient.

For on-scene responses, the medical personnel must stabilize the patient and prepare the patient for transport, which may include accounting for potential risks and complications that may arise in flight. For inter-hospital transports, the patient is generally already stabilized but may still need preparation for transport. The goal of the preparations is to maximize the likelihood of a positive outcome for the patient and to minimize the risk of decompensation or other complications arising during the flight.

During transport, the aim is to get the patient safely to the destination hospital. Occasionally, the patient condition deteriorates or complications arise, and the medical personnel onboard may need to respond with treatment en route. Conducting medical treatment while airborne creates set of concerns that are not present when transporting by ground. Many helicopters currently being used for medical transport are limited in space and may make it difficult to access certain areas of the patient. Poor lighting, high noise, potentially severe vibrations, and the inability to easily stop the vehicle also challenge the ability of the medical personnel to respond to decompensation of the patient and provide effective treatment. These challenges of flight in current helicopters and fixed-wing aircraft represent potential opportunities for new vehicles.

The transportation process should ideally minimize the risk of decompensation, allow for the accurate recognition and diagnosing of the patient condition when decompensation occurs, and facilitate treatment in those cases to maximize the probability of positive patient outcome. A survey of medical practices and challenges in air EMS operations was conducted and uncovered a range of challenges which are summarized in Table. 1. The most significant challenges involved securing a patient's airways, starting IV lines, and the ability to hear patient sounds and speech or medical personnel commands. When transporting a patient using an air ambulance, the medical personnel currently take precautions unique to flight by implementing redundancies in their care for the patient to ensure the flight does not need to be terminated halfway to the destination because of a problem caused by the ride quality or lighting of the vehicle. This most often entails EMS personnel starting two IVs instead of one and intubating before take-off if there is a good chance the patient will need it en route [12]. The motion and vibrations of the vehicle make intubation and starting an IV difficult in flight, and the addition of the helicopter noise decreases the medical personnel's abilities to monitor the patient. The lighting conditions in the vehicle also make seeing the patient's veins difficult.

**Table 1 Challenges experienced by operators in current Air EMS vehicles.**

<b>Primary Challenges</b>	<b>Secondary Challenges</b>
Limited ability for in-flight intubation/securing an airway	Limited ability to accommodate specialized procedures such as capnography, invasive monitoring for arterial, central venous, or intracranial pressure
Limited ability to start an IV in flight	Limited ability to deliver neonates
Limited ability to hear heart or breath sounds and patient communications (such as identifying an arrhythmia)	Inability to transport patients with pneumothorax due to pressure differences in flight
	Complications from aircraft vibrations
	Inability to maintain temperature and humidity of patient surroundings
	Most Air EMS aircraft are unable to accommodate more than one patient

### **C. Transport Capability**

The transport capability a vehicle provides is characterized by the vehicle's range, cruise speed, and take-off and landing requirements. Current air EMS helicopters normally transport medical personnel from staging areas at medical or airport facilities to the patient, who may be located at a medical facility or near an injury scene. The patient is then transported to an appropriate care facility, for example a Trauma Level 1 or 2 facility, characterized by its 24-hour doctor and specialist presence onsite. These facilities are located almost entirely within dense urban populations because of the high patient volume requirements necessary to sustain the continual onsite care.

Most current vehicles are only capable of transporting one patient at a time, although some helicopters are able to carry two patients. While most cases do not require the transportation of more than one patient, the ability to transport multiple patients can be useful for multiple-casualty events. Additional volume and payload requirements come from the equipment onboard the helicopter and the amount of space needed to accommodate the medical personnel's movement.

While helicopters are valued for their vertical lift capabilities, helicopters still face some constraints in terms of landing sites. Hospital landing pads will have maximum vehicle weight limits and sometimes rotor diameter restrictions. First responders must survey and mark out improvised landing zones with sufficient area, no obstacles, and with limited slopes. Current helicopters may reject improvised landing zones because of obstacles, uneven terrain, or poor visibility. This then necessitates first-mile transportation to a suitable landing zone for the patient so he or she can board the helicopter. Some Air EMS crews are outfitted with night-vision goggles to enable nighttime operations, however landings in the presence of obstacles or uneven terrain is an unmet challenge for existing helicopters.

Patient loading and offloading is required to be streamlined and accessible in order to be able to load critically injured patients as quickly and safely as possible. Main rotors and unshrouded tail rotors pose a danger to people on higher ground relative to the helicopter and behind the helicopter, requiring careful procedures during loading and unloading. The alternative of shutting down and restarting rotors requires significant additional time. A vehicle with a faster cruise speed or lower spin-up time may enable the operator to service a larger coverage area, in addition to reducing transport time. A vehicle that is more capable of landing in unfamiliar terrain would also improve availability or decrease the need for the first-mile transport of injured patients.

### **D. Interoperability with Aviation Ecosystems**

In order to provide this service, air EMS must operate within the constraints imposed on them from various sources, both regulatory and practical, including air traffic control, local communities, regulations, and financial considerations.

Air traffic control has been identified as one of the leading constraints for UAM, as current separation standards, procedures, and controller workload generally enable operations for only a handful of helicopters within specified corridors around major cities and airports [13]. Air EMS, however, is handled as an exception to usual controller

strategies, with air traffic controllers giving priority status to MEDEVAC flights [14]. Since Air EMS landing locations at major trauma hospitals are often co-located in urban areas with large airports, the controllers for those major airports must deal with unscheduled helicopter operations in both VFR and IFR conditions. Helicopter movements are dealt with on a case-by-case basis and usually have a major impact on traffic flow at major airports during operations because medical flights have priority over other aircraft. In Boston, for example, when Logan Airport is operating in particular runway configurations, it must delay departure and arrival operations on impacted runways to allow helicopters to transport patients to and from Mass General Hospital when IFR conditions are present in the city. Although an increase in Air EMS operations may force action from ATC operators to revise their strategy of controlling those helicopter operations to avoid a significant impact on the local air traffic, Air EMS will still need to operate within the air traffic control structure and constraints that are present at the time.

Community complaints about noise and perceived safety are one of the dominant factors that has shaped the current operational landscape for helicopter operations in the US, with significant pressure to scale back the number of helicopter operations around New York City, for example [15]. As such, community perception poses a major hurdle for UAM concepts, which envision hundreds of vehicles operating in and around major cities at low altitudes. Community perception of aircraft operations has the ability to directly influence UAM operations, including air EMS services, often through imposing restrictions when a community becomes continually disturbed from noisy or frequent operations. Quieter operations and improved safety would lower the potential opposition from local communities. However, air EMS may also have the potential to influence community acceptance. One might propose that a community familiar with frequent HEMS operations might be more accepting of a future UAM service because they have already become acclimated to the regular presence of EMS aircraft. Nevertheless, although Air EMS operations are more insulated from potential noise restrictions because of the high social value of transporting patients, they still must consider the noise and risk perceived by the community.

Air EMS operations are also subject to various regulations, besides the ones that may arise from residents' concerns about noise or perceived safety, as previously discussed. Regulations concerning helicopters operations for medical transport missions have recently increased in stringency, involving greater necessary pilot certification, onboard equipment, and IFR minimums, following a spate of accidents involving air ambulances. The vehicles themselves are governed by certification requirements, which remain a current challenge when considering new eVTOL concepts. Air EMS must conduct its services within the constraints of such operational and certification requirements.

## E. Air EMS Cost Breakdown

Air EMS Services are high-cost, low-utilization and have a very large fixed cost for operations needed to sustain 24/7 staffed medical and pilot services. Costs associated with insuring the operations, the facilities cost, and staffing the aircraft are all fixed costs. Variable costs for each transport depend on the mission duration and consist of aircraft maintenance costs, depreciation, and fuel. Fig. 2 shows the breakdown of fixed and variable costs of the operation. Fixed costs account for between 75% to 85% of the total costs, which means the relative cost of operating the vehicle compared to the spending on establishing the support for the service is low enough to warrant a look into increasing operations.

Component	Mean	Median <sup>a</sup>
<b>FIXED COSTS</b>	<b>\$9,095</b>	<b>\$7,741</b>
Vendor Costs <sup>b</sup>	\$372	\$0
Aircraft Ownership/Lease <sup>c</sup>	\$812	\$202
Safety Enhancements <sup>b</sup>	\$111	\$7
Insurance	\$203	\$215
Payroll	\$4,985	\$4,711
Training <sup>c</sup>	\$126	\$88
Supplies and Equipment	\$241	\$218
Facility	\$238	\$242
Marketing <sup>c</sup>	\$68	\$57
Travel <sup>b</sup>	\$132	\$115
Overhead	\$1,806	\$770
<b>VARIABLE COSTS</b>	<b>\$1,991</b>	<b>\$2,145</b>
Aircraft Maintenance <sup>c</sup>	\$975	\$973
Depreciation <sup>c</sup>	\$672	\$659
Fuel	\$344	\$298
<b>TOTAL COSTS</b>		
<b>Total Cost per Transport</b>	<b>\$11,086</b>	<b>\$10,199</b>

**Fig. 2 Cost breakdown for an Air EMS flight. Reprinted from Ref. [17].**

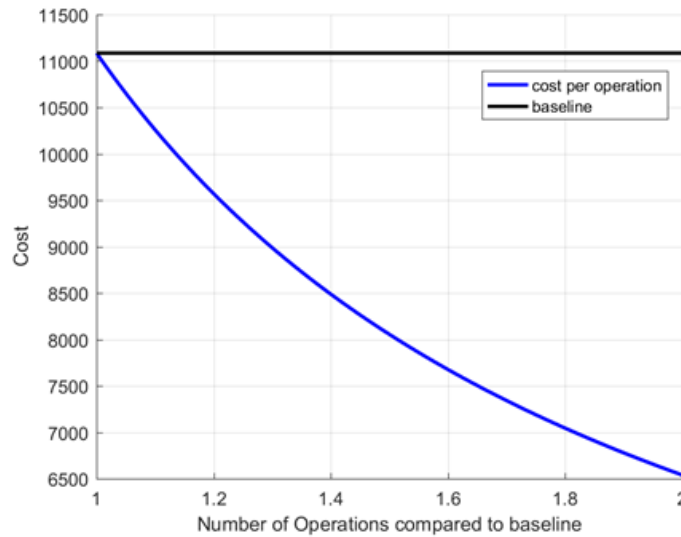
This imbalance in costing is driven by the high staffing and facility needs of the service. Each aircraft generally is



staffed with four crews, each with a pilot, paramedic, and flight nurse.

Costs of the airframe [16], however, only make up 6% of the per-operation cost for services [17]. The vehicle purchasing power of an Air EMS service is somewhat price-insensitive because of this. An investment in a new, more expensive vehicle itself may raise variable costs and the fixed aircraft ownership cost, but a new vehicle may provide the operator more mobility to spread out the fixed costs over more diverse operational cases.

With the average transport in 2016 costing \$11,000, there is significant benefit in spreading the fixed cost over a larger number of missions to decrease the fixed cost per transport for operators which extends those savings to the patients. If the number of operations could be increased with constant fixed costs, doubling the number of operations would reduce the cost per trip by 40%, as seen in Fig. 3. This serves as strong motivation to investigate how an operations model can be developed around the idea of increasing the number of operations when the vehicle may otherwise just be sitting around with a fully-funded crew in order to push a lower fixed to variable cost ratio.



**Fig. 3 Potential average mission cost impacts of increasing the utilization (number of operations) for Air EMS operators.**

### III. Opportunities to Enhance Air EMS through new Vehicles

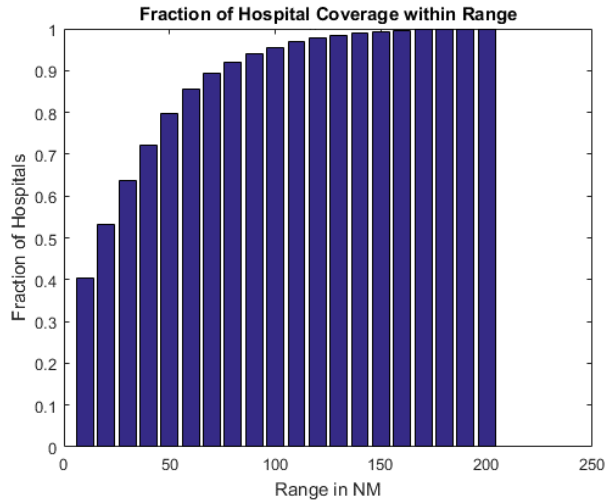
A set of desired requirements for a new Air EMS vehicle was developed by considering current operations and identifying constraints on the services provided. This gave insight into possible requirements for new vehicles to improve Air EMS services. The potential for eVTOL aircraft to bring improvements to air EMS services was specifically examined by comparing the potential capabilities of these emerging vehicles with those of current helicopters in use for the Air EMS mission.

In order to determine an appropriate range requirement for an Air EMS vehicle, a study was conducted of inter-hospital distances in the US. In addition to the fact that most transports are interfacility, the location distribution of hospitals is also expected to be a proxy for population distribution to first order. The distribution of distances from each hospital to its nearest Level 1 or 2 trauma center was computed, as shown in Fig. 4. A one-way range of 100 NM results in coverage of 95% of the hospitals in the US. Therefore, a total range requirement of 200 NM plus reserves was selected which considered the assumption that Air EMS bases are likely to be located near level 1 and 2 trauma centers. Fig. 5 shows the inter-hospital flight time in the US. The blue cross indicates level 1 and 2 trauma centers, green indicating hospitals within 100 NM of a level 1 or 2 trauma center, and red indicating hospitals farther than 100 NM.

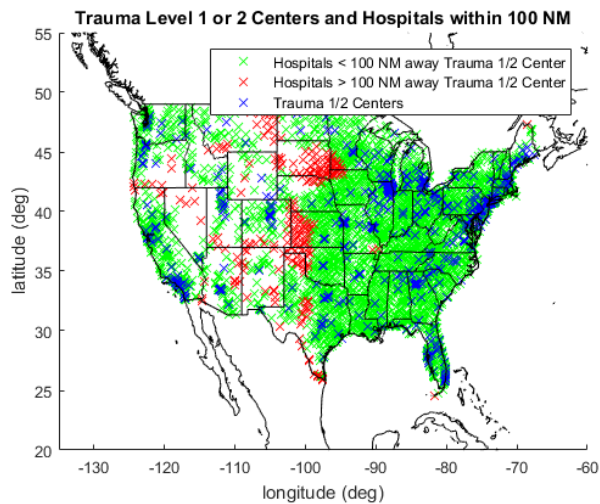
For comparison, Fig. 6 compares the distribution of expected inter-facility travel time for an air vehicle traveling at an average speed of 140 knots and a ground vehicle traveling at an average speed of 40 MPH. The differences in these distributions reveal the regions where air transportation provides significant benefits in terms of accessibility to Level 1 or 2 trauma centers compared to surface transportation.

As warm up and cool down times for current helicopters are significant, reduction of required spin up and shut down





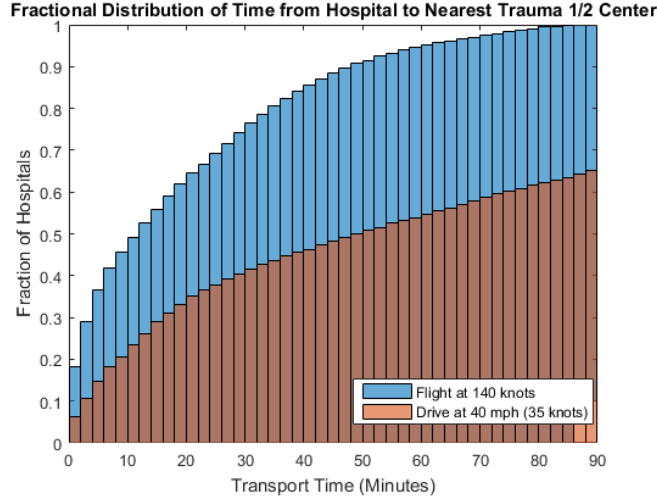
**Fig. 4 Fractional Hospital Coverage with Range.**



**Fig. 5 Hospitals within 100 NM of Level 1 or 2 Trauma Centers.**

time would reduce the transportation time for patients and is desired. A new vehicle would also need to be capable of operating from the same landing sites as current helicopters. Landing zone requirements for undeveloped sites are generally on the order of 100 ft by 100 ft areas clear of obstructions, with up to a ten degree slope. Hospital landing pads will have maximum vehicle weight and sometimes rotor diameter restrictions. Patient compartment layout and vehicle payload weight requirements were derived from the advanced life support equipment requirements and the traditional crew configuration of one pilot, two medical personnel, and one patient. Based on the identified medical challenges faced in current Air EMS operations, it would be desirable for new vehicles to provide improved capabilities for dealing with intubation, starting IV s and hearing various aspects of the patient. As the high costs of the service have been identified as a major issue, a vehicle that results in lower costs would be desired.

In light of these desired requirements, the potential advantages of eVTOL were considered and compared with a typical helicopter in current use, as shown in . Reductions in noise are often cited as potentially attainable by eVTOL vehicles using a larger number of smaller rotors with reduced tip speeds. However, this has not been shown characterized experimentally yet. Electric motors are also expected to allow for shorter warm-up and cool-down times compared to current engines, which can potentially facilitate faster response times, as well as the ability to load and unload patients without the presence of spinning rotors . It is also postulated that electric vehicles will have reduced operating costs, as a result of simplified maintenance of electric motors and exchanging fuel for electricity costs. However, eVTOL



**Fig. 6 Flight and Drive Time to Trauma Centers.**

is expected to have significant challenges in range, with the specific energy of batteries currently being orders of magnitude below that of fuel. Hybrid vehicles may provide sufficient range, but increase the complexity of the vehicle. In comparison, the EC-135 [18], estimated to account for 25% of all air ambulances, has a range of 340 NM and already fulfills the other requirements. Furthermore, the operating costs of current air EMS vehicles is currently a very small fraction of the total costs of the service, so a reduction in operating costs does not represent a significant benefit. While the potential medical improvements in Table. 2 are not currently realized in the current generation of helicopters, the potential advantages that a new eVTOL or hybrid vehicle may bring are limited. Because medical personnel have methods for working around the main operational difficulties, the medical improvements listed are not seen as being major factors in patient outcome. Therefore, the potential benefits are not sufficiently large to warrant an investment at this time in a new eVTOL or hybrid vehicle, especially in light of the challenges that face development and certification of this new class of vehicles.

#### **IV. Opportunities to Enhance Air EMS through new Operational Models**

The potential for new operational models is now examined. As a result of maintaining 24/7 availability of a vehicle, there are large fixed costs compared to the variable costs of flying the vehicle. Utilization of vehicles is currently low, as discussed previously, and results in very large per-mission costs. Consequently, an increase in the number of missions performed by the air EMS vehicles would reduce the per-mission cost significantly. A new business model is therefore proposed that enables vehicles to produce value by performing secondary, non-emergency missions and deploying revenue management to maintain high availability for emergency calls while increasing vehicle utilization.

As shown in Fig. 7, the traditional Air EMS business model has the aircraft and crew stationed at the base whenever they are not performing an emergency mission. Even though there is no value being produced while waiting, the vehicle and crew are still incurring costs during standby. As a result, the costs of the idle periods must be covered by the few missions where an emergency call is served, often resulting in very high charges billed for each emergency transport. However, by conducting non-emergency missions during the idle periods, the vehicle is able to produce value at low marginal costs—essentially the additional operating costs of fuel and maintenance—while waiting and spread out the fixed costs over a greater number of missions. This increases the utilization of the vehicle and brings down the per-mission cost.

As the primary purpose of the air EMS vehicles is to provide emergency transport when needed, it is absolutely critical for the vehicle to maintain the same availability or greater for the emergency mission. A lower availability resulting in the potential death of critically injured patients would not be acceptable, even if costs were lowered. The challenge then is to schedule worthwhile secondary missions without reducing the availability of the current network of air ambulances and without knowledge of exactly when the next emergency call will arise.

**Table 2 Air EMS vehicle requirements.**

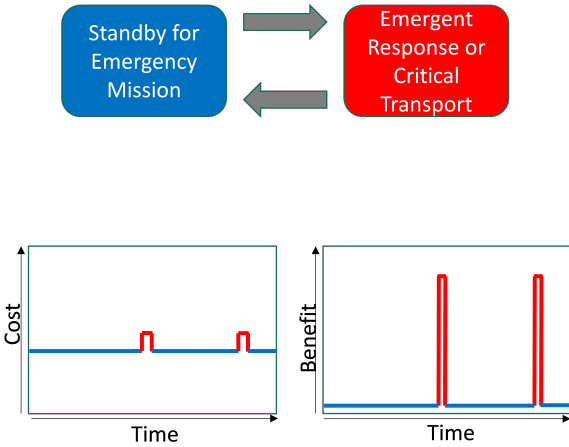
	<b>New Vehicle Requirements</b>	<b>eVTOL</b>	<b>Existing Helicopter (E-135)[18]</b>
<b>Medical</b>	<ul style="list-style-type: none"> <li>- Ride quality sufficient for intubation and starting IVs</li> <li>- Sufficient light to see veins</li> <li>- Decreased cabin noise or increased signal strength to hear patient, heart, breath</li> </ul>	<ul style="list-style-type: none"> <li>- Ride quality sufficient for intubation and starting IVs</li> <li>- Sufficient light to see veins</li> <li>- <b>Decreased cabin noise</b> or increased signal strength to hear patient, heart, breath</li> </ul>	
<b>Range</b>	200 NM + reserves	<b>Significantly less than 200 NM + reserves</b>	340 NM
<b>Payload</b>	<ul style="list-style-type: none"> <li>- ALS equipment</li> <li>- 3 crew + 1 patient</li> <li>- 1350 lbs</li> <li>- 80" x 54" compartment</li> <li>- Streamlined and safe patient load/unload</li> </ul>	<ul style="list-style-type: none"> <li>- ALS equipment</li> <li>- 3 crew + 1 patient</li> <li>- 1350 lbs</li> <li>- 80" x 54" compartment</li> <li>- Streamlined and safe patient load/unload</li> </ul>	<ul style="list-style-type: none"> <li>-ALS + specialized equipment</li> <li>- 3 crew + 2 patients</li> <li>- 3200 lbs</li> <li>- 108" x 59" compartment</li> <li>- Clamshell loading from back with shrouded tail rotor</li> </ul>
<b>TO/Land</b>	<ul style="list-style-type: none"> <li>- Existing hospital helipads</li> <li>- 100 x 100 ft undeveloped areas</li> <li>- Slopes of up to 10 degrees</li> </ul>	<ul style="list-style-type: none"> <li>- Existing hospital helipads</li> <li>- 100 x 100 ft undeveloped areas</li> <li>- Slopes of up to 10 degrees</li> <li>- <b>Decreased warm-up/cool-down time</b></li> </ul>	<ul style="list-style-type: none"> <li>- Existing hospital helipads</li> <li>- 100 x 100 ft undeveloped areas</li> <li>- Slopes</li> </ul>
<b>Cruise Speed</b>	140 kts	140 kts	136 kts
<b>Regulations</b>	Decreased noise	<ul style="list-style-type: none"> <li>- Decreased noise</li> <li>- Certification challenges</li> </ul>	
<b>Cost</b>	Decreased cost	Marginally decreased cost	Baseline

In order to conduct secondary missions, an increase in the number of vehicles is necessary to some degree to ensure the availability and response time for EMS missions is not decreased. Although increasing the number of vehicles will increase total costs, there may exist a point at which economies of scale allow the resulting increase in revenue to more than offset the additional cost while providing equal or better EMS availability. An increase of even one additional vehicle would allow air EMS services to start accepting secondary missions. With the current vehicle numbers, some calls with significantly injured patients are rejected in order to preserve the vehicle for a future case that could be extremely urgent, but may not even occur. Having one more vehicle available would relax the stringent triage considerations and allow for the acceptance of the less-critical secondary missions, whereas before, no secondary missions could be accepted at all.

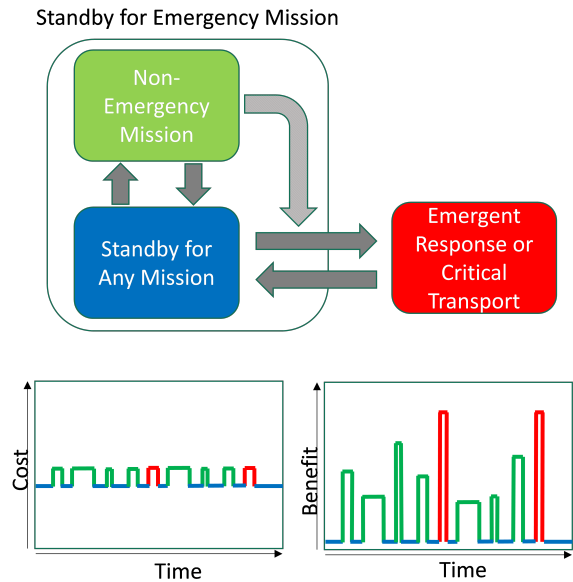
However, the financial viability of increasing vehicle numbers does hinge on the availability of sufficient quantity and value of potential secondary missions, which will be discussed later. Furthermore, availability within the vehicle network can also be augmented by dynamically dispatching and re-allocating vehicle resources based on the current status of available assets and the forecast demand across geography and time. Certain secondary missions may allow vehicles to be re-dispatched in the middle of the mission, and vehicles standing by at bases may also be repositioned to cover areas where increased demand is expected or where coverage is currently missing.

With the increase in the number of vehicles in the network, the new business model poses a scheduling problem where decisions must be made on how much availability of the air EMS network to allocate to various missions. The first objective is to maintain a certain amount of availability for the emergency mission, while the second objective is to

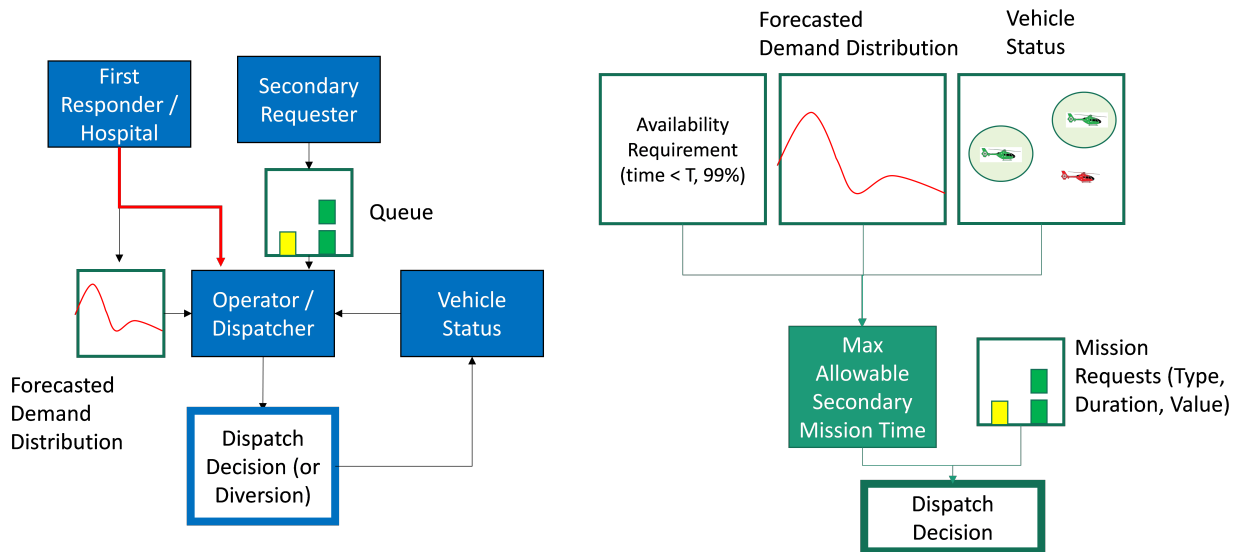
## Old Business Model



## New Business Model



**Fig. 7 Legacy business model compared to potential new business model.**

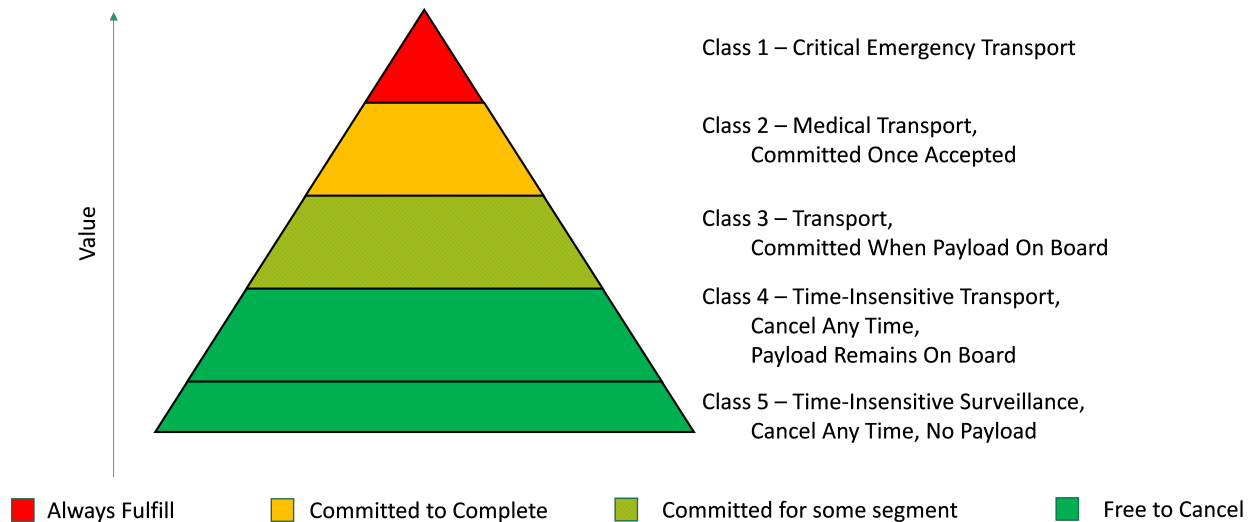


**Fig. 8 Dynamic dispatch and scheduling concept.**

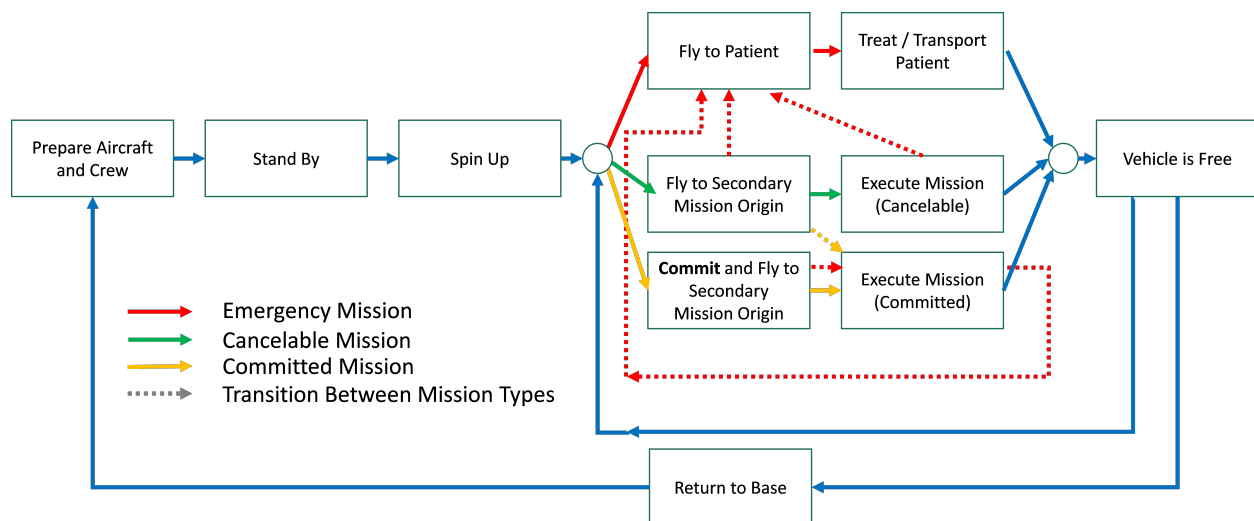
maximize revenue. The availability requirement may be set by what is achieved currently with the current system, or set by policymakers to a selected level.

The decision to dispatch a vehicle to a secondary mission can be made based on a forecast of the geographic and temporal distribution of demand, current vehicle locations and statuses, and the types, durations, and value of current mission requests in queue, as shown in Fig. 8. The availability requirement—for example responding within a certain time for 99% of cases—allows for a determination of the maximum allowable time an additional vehicle in the network can be committed to a secondary mission based on expected demand. Secondary missions within that duration are

then accepted in a way that maximizes expected revenue. If an emergency call comes in, a vehicle is dispatched to that primary mission. This may be dispatching a vehicle that is standing by at base or re-dispatching a vehicle that is performing, but is not committed to, its secondary mission. The scheduling is recomputed online as the situation evolves over time.



**Fig. 9 Levels of urgency for transportation assessment.**



**Fig. 10 Operational Concept for New Business Model.**

In order to maintain availability and increase revenue, missions are categorized into a set of five possible types, shown in Fig. 9. The height of the mission class corresponds to value, while the size of each section indicates the volume of such missions. Emergency transports, Class 1, are the highest in value and must be fulfilled, but are few in number. The second class involves missions that must be fulfilled once accepted, such as non-critically urgent medical transports. For example, it would not be desirable to cancel and therefore delay the transportation of a non-critical patient with broken bones to a hospital after accepting the mission. Class 3 involves missions that are committed once the payload is picked up, but can be cancelled any time before that. Samples for clinical lab testing from a rural hospital will need to arrive at the clinical lab once picked up by the air ambulance. However, the sample may potentially be sent via ground vehicle in the event that the air ambulance is forced to divert to an emergency mission before it picks up the sample. Class 4 involves time-insensitive transport missions that may be diverted at any time. However, considerations

must be taken for whether the payload on board will take up needed space onboard the aircraft, or if it will be necessary to land and offload the package temporarily before transporting the patient. The secondary mission would then be resumed and finished after the emergency call is taken care of. Class 5 includes missions that do not involve transport and can be diverted at any time, such as non-critical aerial surveillance.

A diagram illustrating how a vehicle moves through operations with the new business model is shown Fig. 10. Multiple paths are shown depending on the mission that is accepted. The solid red path shows the standard air EMS mission and is unchanged from the old business model. The green path is for a vehicle that is dispatched to a cancelable mission, such as Class 4 or Class 5 mission. At any point during the mission, the vehicle is able to divert and transition to emergency response, as indicated by the red dotted lines that show transition paths that occur if the vehicle is already flying to the secondary mission or executing the cancelable secondary mission. In contrast, once a vehicle has committed to a secondary mission (yellow path), it is unable to divert and respond to an emergency call until it finishes the committed secondary mission, as illustrated by the red dotted lines connecting the yellow path back to the solid red path.

As this new operational model depends on the number and value of available secondary missions, a preliminary search for potential markets was conducted. Secondary missions must meet the minimum requirement of providing greater value than the cost of operating the vehicle, which is generally on the order of \$500/hour to \$1000/hour, depending on the vehicle. They should ideally also produce high value with minimal cost to vehicle availability for emergency missions. For example, missions that take the vehicle far from its area of responsibility may not be most suitable. Table. 3 presents a partial list of example missions, as well as the reasons for and challenges to their potential viability. Further work needs to be done in assessing the extent of their viability and the logistical details involved at higher fidelity, as well as finding other secondary missions. Ultimately, the new operations model must continue to prioritize its primary medical mission.

**Table 3 Potential opportunities for expanded secondary missions for Air EMS.**

<b>Secondary Mission</b>	<b>Reason for Potential Viability</b>	<b>Frequency</b>	<b>Potential Challenges to Viability</b>	<b>Examples</b>
<b>Medical Equipment Sharing</b>	- Equipment-sharing savings estimated in millions [23]	Low	- Generally not urgent - Transported by ground vehicle - Requires calibration	- Portable CT scanners, surgery equipment
<b>Blood Supply Logistics</b>	- \$200 per unit of blood [24] - Blood is perishable [24]	Low-Medium	- Transported by ground vehicle - Amount of wasted blood already low	Blood supply management, especially during summer and winter shortages
<b>Clinical Lab Specimens</b>	- Shorter emergency test turn around time may decrease emergency department stay time [25]	Low - Medium	- Hospitals often have own clinical lab for common tests	Esoteric chemical tests from smaller hospitals
<b>Electronic News Gathering</b>	- \$1000 - \$1500 / hour to lease 100 120 new helicopters in US [26] - News stations looking to reduce costs	Low - Medium	- Increasing use of drones instead for certain cases	Aerial footage of events
<b>Passenger Transport</b>	- Urban Air Mobility market	Medium - High	- Difficult to redispach	On-Demand mobility

## V. HEMS as a Proving Ground and Forcing Function

HEMS operates as a current-day urban air mobility concept that experiences a greater level of insulation from external constraints, compared to other forms of UAM. The rapidly available, high-quality transport capability continues to have demand, but the growth of the system is limited by the medical market it serves at the price point the service offers. Additionally, restrictive factors such as ATC capacity limitations, available takeoff and landing infrastructure, and community reaction to operations constitute potential constraints to urban mobility operations. Modifying the business operations of Air EMS has the potential to lower costs and increase the availability and quantity of air medical transports, thereby requiring the refinement of controller procedures and technologies to support higher density operations without impacting regular air traffic. Similarly, if operated with a safe track record, more frequent Air EMS operations may also partially assist with encouraging community acceptance of new vehicles or increased frequencies of operations by demonstrating reliability and safety in frequent operations.

## VI. Conclusion

Current operations for Air EMS services were examined to identify opportunities for improvement through the introduction of new vehicles, technologies, or operating models. The greatest benefit from Air EMS services exist in rural areas, where healthcare services are limited and distances travelled are large. Coverage gaps remain in very rural areas due to high marginal costs to expand coverage in these areas. However, improvements that reduce costs for air EMS services may enable future service expansion into these rural areas. After an assessment of potential benefits of eVTOL aircraft to Air EMS vehicles, it was concluded that the benefits were not sufficient to justify investment at this time into this new class of vehicle for the Air EMS mission. The performance capabilities of near-term eVTOL aircraft were not perceived to match the needs of the air EMS mission, especially in terms of range. However, future investigations should consider the potential of eSTOL vehicles for Air EMS operations [27].

While eVTOL aircraft did not appear to meet the requirements of the Air EMS mission in the near-term, the associated development of advanced pilot autonomy and sense and avoid technologies in the UAM sector may potentially increase the safety and reduce the cost of Air EMS operations with current vehicles.

Finally, a new operational model, where vehicles conduct secondary missions while a modified revenue management system preserves their availability for emergency calls, shows promise for increasing utilization and reducing per-mission costs. As the new operational model depends on the number of viable and valuable secondary missions available, further work is still needed for assessing the viability of specific secondary missions. In the new operational model, vehicle availability for the primary objective of emergency response must be maintained at current levels or better. Increases in the number of vehicles in the network, dynamic scheduling, and revenue management strategies for secondary missions may enable increased utilization and decreased costs while providing the same or improved vehicle availability for emergency response missions.

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## References

- [1] M. J. Duffy, S. R. Wakayama, R. Hupp, R. Lacy, and M. Stauffer, "A Study in Reducing the Cost of Vertical Flight with Electric Propulsion," in *17th AIAA Aviation Technology, Integration, and Operations Conference*, 2017.
- [2] T. Fiig, K. Isler, C. Hopperstad, and P. Belobaba, "Optimization of mixed fare structures: Theory and applications," *J. Revenue Pricing Manag.*, vol. 9, no. 1–2, pp. 152–170, 2010.
- [3] P. D. Vascik and R. J. Hansman, "Constraint Identification in On-Demand Mobility for Aviation through an Exploratory Case Study of Los Angeles," in *17th AIAA Aviation Technology, Integration, and Operations Conference*, 2017.
- [4] P. D. Vascik, H. Balakrishnan, and R. J. Hansman, "Assessment of Air Traffic Control for Urban Air Mobility and Unmanned Systems," in *International Conference on Research in Air Transportation*, 2018.
- [5] E. R. Mueller, P. H. Kopardekar, and K. H. Goodrich, "Enabling Airspace Integration for High-Density On-Demand Mobility Operations," in *17th AIAA Aviation Technology, Integration, and Operations Conference*, 2017, no. June, pp. 1–24.



- [6] Federal Aviation Administration, "Los Angeles Helicopter Noise Initiative," Washington, DC, 2013.
- [7] K. R. Antcliff, M. D. Moore, and K. H. Goodrich, "Silicon Valley as an Early Adopter for On-Demand Civil VTOL Operations," in *16th AIAA Aviation Technology, Integration, and Operations Conference*, 2016, no. June, pp. 1–17.
- [8] "Fact Sheet – FAA Initiatives to Improve Helicopter Air Ambulance Safety." Federal Aviation Administration. 2014. [Online]. Available:  
[https://www.faa.gov/news/fact\\_sheets/news\\_story.cfm?newsId=15794](https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=15794)
- [9] "Trauma Field Triage and Statewide Point of Entry Plan." Massachusetts Health and Human Services, 1 Sept. 2011. [Online]. Available:  
<http://www.mass.gov/eohhs/docs/dph/quality/hcq-circular-letters/trauma-hospital-destinations.pdf>
- [10] "National EMS Assessment." National Association of State EMS Officials. 2011. [Online]. Available:  
[https://www.nasemso.org/documents/National\\_EMS\\_Assessment\\_Final\\_Draft\\_12202011.pdf](https://www.nasemso.org/documents/National_EMS_Assessment_Final_Draft_12202011.pdf)
- [11] "The Atlas & Database of Air Medical Services." Association of Air Medical Services. 2017. [Online]. Available:  
[http://www.adamsairmed.org/pubs/atlas\\_2017.pdf](http://www.adamsairmed.org/pubs/atlas_2017.pdf)
- [12] Sethi D, Subramanian S. When place and time matter: How to conduct safe inter-hospital transfer of patients. *Saudi Journal of Anaesthesia*. 2014;8(1):104-113. doi:10.4103/1658-354X.125964.
- [13] P. D. Vascik and R. J. Hansman, "Air Traffic Control, Ground Infrastructure, and Noise Constraints for Urban Air Mobility Operations," in *18th AIAA Aviation Technology, Integration, and Operations Conference*, 2018.
- [14] "JO7110.65X." Federal Aviation Administration. 2017.
- [15] "Deal Restricts Tourist Helicopter Flights Over New York," New York Times. 2017. [Online]. Available:  
<https://www.nytimes.com/2016/02/01/nyregion/deal-restricts-tourist-helicopter-flights-over-new-york.html>
- [16] "An Economic Analysis of the U.S. Rotary Wing Air Medical Transport Industry." Economic and Planning Systems. August 2014. [Online]. Available:  
<http://medevacfoundation.org/wp-content/uploads/2014/08/Rotary-Wing-AMT-Economic-Benefit-Study-EPS-082114.pdf>
- [17] "Air Medical Services Cost Study Report." Association of Air Medical Services. 2017. [Online]. Available:  
<http://aams.org/wp-content/uploads/2017/04/Air-Medical-Services-Cost-Study-Report.pdf>
- [18] "Eurocopter EC135 Technical Data." Eurocopter. [Online]. Available:  
<https://www.helistar.eu/sites/default/files/2017-01/ec-h135-brochure.pdf>
- [19] "AIR MED '101'." Association of Air Medical Services. [Online]. 2014. Available:  
<http://aams.org/wp-content/uploads/2014/01/AIRMED101.pdf>
- [20] "Air Ambulance Services in the US." IBISWorld. 2017. [Online]. Available:  
<http://clients1.ibisworld.com/reports/us/industry/default.aspx?entid=5969>
- [21] "Fact Sheet and FAQs." Association of Air Medical Services. [Online]. Available:  
<http://aams.org/member-services/fact-sheet-faqs/>
- [22] "Hospitals are learning how to share and it's saving them millions." Fortune. Dec 2014. [Online]. Available:  
<http://fortune.com/2014/12/16/hospitals-are-learning-how-to-share-and-its-saving-them-millions/>
- [23] Toner RW et al. "Costs to hospitals of acquiring and processing blood in the US: a survey of hospital-based blood banks and transfusion services." *Appl Health Econ Health Policy*. 2011. 9(1): 29-37.
- [24] "Manual on the management, maintenance and use of blood cold chain equipment." World Health Organization. 2005.
- [25] Keith E. Volmar, David S. Wilkinson, Elizabeth A. Wagar, and Christopher M. Lehman (2013) "Utilization of Stat Test Priority in the Clinical Laboratory: A College of American Pathologists Q-Probes Study of 52 Institutions." *Archives of Pathology & Laboratory Medicine*: February 2013, Vol. 137, No. 2, pp. 220-227.

- [26] "TV News Choppers Flying High Once Again." TVNewsCheck. Aug 2013. [Online]. Available:  
<http://www.tvnewscheck.com/article/69563/tv-news-choppers-flying-high-once-again>
- [27] C. Courtin, M. Burton, P. Butler, A. Yu, P. Vascik, and R. J. Hansman, "Feasibility Study of Short Takeoff and Landing Urban Air Mobility Vehicles using Geometric Programming," in *18th AIAA Aviation Technology, Integration, and Operations Conference*, 2018.