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A National Strategy for Ventilator and ICU Resource Allocation During the Coronavirus Disease 2019 Pandemic



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Clinicians across the country have watched the coronavirus disease 2019 (COVID-19) pandemic unfold with very different local experiences. While some in “hot spots” like New York have found their resources rapidly depleted, others have found themselves managing largely empty ICUs waiting for an inevitable surge of patients critically ill with COVID-19. We, the authors, practice in health systems covering the spectrum of these situations. Some of us are focused on aggressive

ABBREVIATIONS: COVID-19 = coronavirus disease 2019; EMAC = Emergency Management Assistance Compact; IHME = Institute for Health Metrics and Evaluation; SNP = Strategic National Stockpile

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preparations without significant current strain (North Carolina and Syracuse, New York), others are managing steadily rising cases and rapidly expanding staffing (Boston, Massachusetts, and Chicago, Illinois), while others are battling an overwhelming and disastrous surge (New York City). Left to their own devices, individual hospital systems and perhaps even states will likely plan for the needs they’ll be facing in the near future. We suggest that a coordinated nationwide response may be more effective and agile as the pandemic moves across the country.

As the COVID-19 pandemic reaches its peak in the United States over the next several weeks, the Institute for Health Metrics and Evaluation (IHME) has projected that demand for critical care beds and ventilators will outstrip supply in numerous locations.¹ There are not enough ventilators in the Strategic National Stockpile (SNP) to meet demand, nor can we build enough ventilators quickly enough to meet the surging demand over the next month over widespread geographical locations. This situation has led to discussions in the medical community revolving around the triage of patients so that ventilators are allocated to patients in the most logical and ethical way possible. Most of these discussions assume that there is a national shortage of ventilators and other ICU resources. However, our review of IHME projections show that although 20 states will exceed their ICU capacities and 15 of those by > 50%, 28 states and the District of Columbia are not projected to meet their maximum ICU capacity (Table 1). Viewed through this lens, the problem is not so much a ventilator shortage as it is a ventilator distribution problem. This presents a tangible opportunity for collaborative allocation; the best way to meet excess demand is by reallocating scarce supplies from areas with excess supply to areas with need.

The best estimate of the number of ventilators in the United States is approximately 160,000 based on a 2010 survey of hospitals.² The actual number of ventilators at the present time is not known. To properly allocate this life-saving resource, we need an immediate and accurate count of all ventilators in the country. Upon defining this number, in conjunction with projected ICU utilization, we must move quickly to reallocate resources from areas where need is projected to be low to areas

TABLE 1] States Projected to Have > 50% ICU Bed Deficit vs No Deficit IHME Projection as of April 4, 2020

> 50% ICU Bed Deficit	No Deficit	No Deficit
Connecticut	Alabama	New Hampshire
Alaska	Arkansas	North Carolina
Georgia	Arizona	Ohio
Hawaii	Idaho	Oklahoma
Illinois	California	Oregon
Maryland	Colorado	Pennsylvania
Massachusetts	Delaware	South Carolina
Michigan	District of Columbia	South Dakota
Nevada	Iowa	Tennessee
New Jersey	Kansas	Texas
New Mexico	Maine	Utah
New York	Minnesota	Vermont
North Dakota	Mississippi	Washington
Rhode Island	Missouri	West Virginia
Wisconsin	Montana	

IHME = Institute for Health Metrics and Evaluation.

with an acute shortage. This is an issue that could have two competing approaches. In one approach, the responsibility rests with the federal government; in the other, it rests upon states to act on their own behalf.

Given the interstate scope of this disease, a federal model is the most ideal. The federal government's current focus remains on distribution of resources from the SNP. Distribution of SNP resources generally parallels population estimates based on the most recent census data.³ This is inherently inefficient, as COVID-19 does not strike populations in a uniform manner. Further federal activities include construction of field hospitals by the Army Corp of Engineers, and removing restrictions in the current hospital chain, so that hospitals can procure their own supplies. However, the federal government could do significantly more. By deploying military assets, the federal government could quickly obtain an inventory of ICU resources (including ventilators), determine need, and redistribute them faster than any other national organization or the state government machinery. Those supplies could then be rapidly redeployed to the next area of need. By quickly identifying unused resources, the federal government can help states reallocate resources both within and between their borders. Data for local disease activity from the Centers for Disease Control and Prevention and local health departments should be used

to guide reallocation of resources. For states with relatively small resource deficits, a reallocation of their own resources may be adequate to meet demand, whereas those with relatively large deficits will require resources from other states. In a federally led model, the federal government would have an inventory of ICU resources throughout the country and thus be in the best position to objectively reallocate resources while minimizing risk of harm.

A state-led model would require that states take stock of their own ventilator inventory. States that are expected to have a large deficit (> 50%) of ICU beds and ventilators, while additionally seeking unused supplies from within their borders, should also seek to partner with other states for help. The Emergency Management Assistance Compact (EMAC) provides a legal and financial framework allowing any state under an emergency declaration to formally request aid from other states. EMAC enabled the deployment of > 66,000 personnel to the Gulf States following the hurricanes of 2005. Under this agreement, a state such as Massachusetts, for example, whose ICU bed deficit is projected to be 2,745 beds, could request assistance from California and Texas, who together are projected to have an excess capacity of 2,769 ICU beds. It is vitally important in such cases that both the requesting and donor states carefully scrutinize available data to ensure that any potential surge does not coincide.

Although the current article's primary consideration is ventilator reallocation, the principles discussed could be applied to other aspects of the ICU supply chain. Medications, protective equipment, and personnel would also fall under the purview of EMAC. Reciprocal states could request and agree to movement of health-care supplies and workers between them without relicensing requirements, while assuring workers that they would not lose their job by volunteering in the reciprocal state.

The looming question is whether reallocation of ventilators would be adequate to meet the expected tremendous shortage. There are several reasons why the deficit of ventilators may not be as large as initially projected. First, the best estimate of ventilator supply is now 10 years old, and it is likely that hospitals will have increased their supplies since that time. Indeed, hospitals have been acquiring ventilators since the beginning of this crisis, and these numbers may not be reflected in current ventilator inventory estimates. Many physicians have been innovative in dealing with the shortage, by repurposing bilevel devices⁴ and even splitting

ventilators between multiple patients. The federal government's deployment of military assets, including field hospitals and military ships, may help to ameliorate the shortage in some areas. In addition, significant progress seems to have been made on "flattening the curve," as the newest projections of the IHME showed a decrease in projected hospital admissions and deaths. It is also possible that treatments currently under trial will have some success in reducing the number of patients that may need ventilators. Finally, the pandemic may urge clinicians and families to have appropriate and timely in-depth conversations about end-of-life wishes and goals of care, which may also result in reduced ventilator demand.

Logistical challenges notwithstanding, there are tremendous ethical, political, economic, and social implications to consider when taking lifesaving equipment from one group of people and giving it to another. We strongly caution any group to consider these implications carefully before carrying out a redistribution of life-saving resources. One such issue is trust. If Missouri lends supplies to Alabama, Missourians must be assured that they will receive their supplies back when they are needed, no matter how bad things get in Alabama. Transparency will also be needed. Citizens who lend their supplies to another region must be shown data, either from testing or projections, that disease activity in their area is low and that they are not expected to have a shortage of ventilators in the near future. Officials must take into account the natural history of COVID-19, including the proportion of patients who may develop ARDS and thus require a

mechanical ventilator for a prolonged period. If Louisiana agrees to return ventilators to Oregon by a certain date, will they need to take patients off life support to accommodate them? These are the types of questions that officials will need to consider before performing such an undertaking. With any strategy, there will be estimates that fall short, and even the best-laid plans will result in some health systems lacking capacity when it is needed most due to planned exchanges. Despite this, the net benefits will likely outweigh these individual losses.

Although there are numerous challenges to the reallocation of ventilators, in times of crisis, Americans have always overcome such barriers by putting our nation's needs above our own. We are currently a nation at war. Many will die from this disease. As health-care providers, there is frustratingly little that we can do to prevent that. However, people will also die from lack of supplies and lack of political will. That is inexcusable.

References

1. Institute for Health Metrics and Evaluation (IHME). Seattle, WA: IHME, University of Washington, 2015. <https://covid19.healthdata.org/projections>. Accessed April 6, 2020.
2. Rubinson L, Vaughn F, Nelson S, et al. Mechanical ventilators in US acute care hospitals. *Disaster Med Public Health Prep*. 2010;4(3):199-206.
3. Huna A, Raghu TS, Vinze A. Resource allocation for demand surge mitigation during disaster response. *Decision Support Systems*. 2010;50(1):304-315.
4. Repurposing bi-level ventilators for use with intubated patients while minimizing risk to health care works during insufficient supply of conventional ventilation for patients with COVID-19. <https://inside.mountsinai.org/wp-content/uploads/sites/14/2020/04/NIV-to-Ventilator-Modification-Protocol-v1.02-for-posting.pdf>. Accessed April 4, 2020.