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Research Article

U.S. Field Hospitals: A Study on Public Health Emergency Response to COVID-19

Luorongxin Yuan[1,4], Sherryn Sherryn[2,4], Peter Hu[3] and Fenghao Chen[4,5]*

[1]Department of Biology, Johns Hopkins University, Baltimore, Maryland, USA

[2]Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, USA

[3]Department of Anesthesiology, University of Maryland School of Medicine, Baltimore, Maryland, USA

[4]COVID-19 Research Consortium, the Hopkins Club for Innovation and Entrepreneurship, USA

[5]LINKSciences LLC, 701 E Pratt St, RM 2031, Baltimore, Maryland, USA

***Corresponding Author:** Fenghao Chen, COVID-19 Research Consortium, the Hopkins Club for Innovation and Entrepreneurship, USA.

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Abstract

The outbreak of SARS-CoV-2 rapidly grew into a global pandemic. The rapid growth in cases during the first wave of COVID-19 in the U.S. led to shortage of hospital capacities in many states. In addition to discharging non-critical patients, expanding local hospitals' capacity as well as re-opening closed healthcare facilities, states impacted by the pandemic resorted to build or convert public venues into field hospitals to fill the gap. However, it is unclear how effective these field hospitals were for the response to current pandemic. By studying the timing and utilization rate, we found that the states most severely impacted by the pandemic were fast at responding with the first wave of field hospitals opening around the date of peak demand and the majority ready to use by the end of April. The variation of field hospital utilization rates was wide- ranging from 0% to 100%-depending on the types of patients they were designed to accept (COVID-19 vs. non-COVID-19) and their integration with local healthcare system. This study highlights the importance of evaluating the effectiveness of field hospitals to meet the demand of COVID-19 pandemic and gained insights to guide proper response to outbreaks in the future.

***Keywords:** SARS-CoV-2; COVID-19; non-COVID-19*

Introduction

The first COVID-19 in the U.S. was confirmed on January 21st, but local transmission was not reported until February 26th. From early March, the spreading of COVID-19 began to accelerate and by March 13th, President Donald Trump declared National Emergency, shortly after which COVID-19 cases were reported in all 50 states, District of Columbia and a few territories [1]. To monitor the global spreading of COVID-19 live, the Center for System Sciences and Engineering at the Johns Hopkins University (JHU CSSE) launched the COVID tracking map on January 21st and when the number of accumulative cases became an alarming 467.8K in the U.S., the Institute for Health Metrics and Evaluation at the University of Washington (IHME) released a projection model on March 25th to predict the surge of affected population and accordingly the imminent medical crisis [2,3]. Seeing the rapid growth of confirmed cases in each state and the potential medical supply shortage, almost all state government took the initiative to recruit available beds and seek public venues to build makeshift hospitals. Even though there is mass media coverage on the building and opening of these field hospitals, little is known about how the decision was made and how wise they are-namely, whether the field hospitals are effectively sharing the load with local hospitals. In this study about field hospitals during the first wave of COVID-19 in the U.S., we aim to answer 1) if the field hospitals opened in time ready for the surge, 2) if their capacity met the predicted demand, 3) what particular role they play in the medical system and 4) if they have fulfilled their intended purpose to relieve the stress experienced by local hospitals.

Methods

Information regarding hospital capacities in the U.S. was obtained from American Hospital Directory, Inc. online database through JHU subscription [4]. All data points about field hospitals were collected manually by searching keywords such as "COVID-19", "coronavirus", "field hospital" online. The information collected from the news feeds include the location of field hospitals, construction time, opening date, type of patients they accept (COVID-19 vs. non-COVID-19), affiliation (military vs. non-military) and updates on how they are running. Unless noted otherwise, the operational date is estimated as one day after the construction end date. Information about Army-built field hospital was obtained from Army Corps of Engineers website [5]. Live update on confirmed cases, incidence rate, hospitalization rate, etc. was downloaded from the JHU CSSE COVID GitHub and the COVID-19 estimate dataset was obtained from IHME COVID-19 projection open results [2,3]. The update cutoff date is May 1st.

Results

Two weeks into National Emergency, two United States Naval Ship (*USNS*) medical cruise first docked in Los Angeles and New York City, the two epicenters at the time, followed by the construction of more than 70 field hospitals in 24 states, supplying more than 27K beds in the next 2 months (Table 1). About half of the field hospitals started operating while the rest remained closed until further notice. The majority of the field hospitals take COVID-19 patients with mild symptoms and were built by Army Corps of Engineers, National Guards, and volunteers. The first field batch of field hospitals started receiving patients on April 1st; taking into consideration that it takes 1 - 2 weeks on average to prepare one field hospital, many states have taken actions immediately after the declaration of National Emergency [5].

Hospital Name	Beds	COVID	Military	City	State	Peak Demand	Constr. Start	Constr. End	Operational Date
Oregon Convention Center Shelter	140	No	No	Portland	OR	4/9			3/21
USNS Mercy	1000	No	Yes	San Pedro	CA	4/17			3/27
USNS Comfort	1000	No	Yes	NYC	NY	4/8			3/30
San Diego Convention Center Shelter	400	No	No	San Diego	CA	4/17			4/1
Western Connecticut State University O'Neill Center	200	Yes	No	Danbury	CT	4/10			4/1
Central Park Field Hospital	68	Yes	No	NYC	NY	4/8			4/1
Shorline Soccer Field	200	Yes	No	Shorline	WA	4/19			4/2
Javits New York Medical Station	1000	Yes	Yes	NYC	NY	4/8	3/30	4/8	4/4
Ernest N. Morial Convention Center Medical Center	1000	Yes	No	New Orleans	LA	4/14			4/6
CenturyLink	250	No	Yes	Seattle	WA	4/19			4/6
Colorado Convention Center Shelter	600	No	Yes	Denver	CO	4/28	4/9	4/24	4/7
Saint Francis Field Hospital	25	Yes	Yes	Hartford	CT	4/10			4/7
Santa Clara Convention Center	250	Yes	Yes	Santa Clara	CA	4/17			4/8
Danburry Field Hospital	25	Yes	Yes	Danburry	CT	4/10			4/8
Middlesex Health Field Hospital	25	Yes	Yes	Middletown	CT	4/10			4/8
DCU Center	250	Yes	No	Worcester	MA	4/12			4/9
Southern Connecticut State University Moore Fieldhouse	250	Yes	Yes	New Haven	CT	4/10			4/10

McCormick Place	1000	Yes	Yes	Chicago	IL	4/8	3/29	4/24	4/10
Boston Convention and Exposition Center	1000	Yes	No	Boston	MA	4/12			4/10
Newtown Athletic Club	300	No	No	Newtown	PA	4/17			4/10
TCF Center Field Hospital	1000	Yes	Yes	Detroit	MI	4/8	4/1	4/9	4/11
New Jersey Convention and Exposition Center	500	Yes	Yes	Edison	NJ	4/9			4/11
Sharon Field Hospital	25	Yes	Yes	Sharon	CT	4/10			4/12
Connecticut Convention Center	646	Yes	Yes	Hartford	CT	4/10			4/15
Missouri ACF Quality Inn at Florissant	120	Yes	Yes	Florissant	MO	4/28	4/8	4/11	4/15
Meadowlands Exposition Center	250	Yes	No	Secaucus	NJ	4/9			4/15
Craneway Pavilion	250	Yes	Yes	Richmond	CA	4/17			4/17
Alaska Airlines Center	163	Yes	Yes	Anchorage	AK	4/18	4/9	4/17	4/18
Westchester Community Center	100	Yes	Yes	White Plains	NY	4/8	3/27	4/17	4/18
Wisconsin State Fair	530	Yes	Yes	West Allis	WI	4/14	4/8	4/18	4/19
Miami Beach Convention Center	450	Yes	Yes	Miami Beach	FL	5/3	4/8	4/19	4/20
Atlantic City Convention Center	250	No	Yes	Atlantic City	NJ	4/9			4/20
Miyamura High School	50	Yes	Yes	Gallup	NM	4/25	4/6	4/19	4/20
New Bridge-Bergen Medical Center	40	No	Yes	Paramus	NJ	4/9	4/9	4/22	4/23
Suburban Collection Showplace	250	Yes	Yes	Novi	MI	4/8	4/6	4/20	4/24
East Orange Hospital	250	Yes	Yes	East Orange	NJ	4/9	4/9	4/23	4/24
New Bridge Hospital	40	Yes	Yes	Paramus	NJ	4/9	4/9	4/23	4/24
Metro South Medical Ctr	350	Yes	Yes	Blue Island	IL	4/8	3/30	4/24	4/25
Sherman Hospital	283	Yes	Yes	Eglin	IL	4/8	3/30	4/24	4/25
Westlake Hospital	314	Yes	Yes	Melrose Park	IL	4/8	4/5	4/24	4/25
Hagerstown Correctional Facility	192	Yes	Yes	Hagerstown	MD	4/11	4/13	4/24	4/25
Baltimore Convention Center	250	Yes	Yes	Baltimore	MD	4/11		4/13	4/27
SUNY Old Westbury	1022	Yes	Yes	Old Westbury	NY	4/8	3/31	4/26	4/27
SUNY Stony Brook	1038	Yes	Yes	Stony Brook	NY	4/8	3/29	4/26	4/27
St. Francis Hospital	37	Yes	Yes	Trenton	NJ	4/9	4/14	4/27	4/28
The Ranch Events Complex	1007	Yes	Yes	Loveland	CO	4/28	4/9	4/29	4/30
New Bridge-Bergen Med Ctr Parking Lot	100	Yes	Yes	Paramus	NJ	4/9	4/15	4/29	4/30
Chinle Community Center	50	No	Yes	Chinle	AZ	4/30	4/18	5/1	5/2
Atsa Biyaazh Community Center	40	No	Yes	Shiprock	NM	4/25	4/18	5/1	5/2
Eugene River Facility	42	Yes	Yes	Eugene	OR	4/9	4/18	5/1	5/2

Walter Washington Community	491	Yes	Yes	Washington	DC	4/26	4/18	5/8	5/9
St. Luke's Medical Center	411	Yes	Yes	Phoenix	AZ	4/30	4/16	5/14	5/15
United Medical Center (UMC)	6	Yes	Yes	Washington	DC	4/9	4/9	4/22	5/15
Commercial Appeal Building	170	Yes	Yes	Memphis	TN	4/16	4/9	5/14	5/15
Dulles Expo Center	510	TBD	Yes	Chantilly	VA	5/2			5/15
Van Cortland Park	200	Yes	No	The Bronx	NY	4/8			Canceled
Kay Bailey Hutchison Convention Center Medical Center	1400	Yes	Yes	Dallas	TX	4/18			Canceled
Hampdon Roads Convention Center	580	TBD		Hampton	VA	5/2			Canceled
Los Angeles Convention Center	250	Yes	Yes	Los Angeles	CA	4/17			NA
Miami-Dade County Fairground	250	Yes	No	Miami	FL	5/3			NA
South Florida Fairgrounds	200	Yes	No	West Palm Beach	FL	5/3	4/7		NA
Dalton Convention Center	150		No	Dalton	GA	4/21			NA
Joint Base Cape Cod	150	Yes	Yes	Bourne	MA	4/12			NA
Dayton Convention Center		Yes	No	Dayton	OH	4/16			NA
Sea Gate Convention Center	415	Yes	No	Toledo	OH	4/16			NA
East Stroudsburg Campus			No	Stroudsburg	PA	4/17			NA
Music City Center		Yes	Yes	Nashville	TN	4/16			NA
Richmond Convention Center	758	TBD	Yes	Richmond	VA	5/2			NA
Porterville Dev. Center	246	Yes	Yes	Porterville	CA	4/17	4/8	4/21	TBD
San Mateo Event Center	250	No	No	San Mateo	CA	4/17			TBD
Gibson Medical Center	200	Yes	Yes	Albuquerque	NM	4/25	4/3	4/17	TBD
Case Western Health Education Campus Hope Hospital	327	Yes	No	Cleveland	OH	4/16		4/2	TBD
Covelli Convention Center	200	Yes	Yes	Youngstown	OH	4/16			TBD
Duke Energy Convention Center	500	Yes	No	Cincinnati	OH	4/16		4/16	TBD
Greater Columbus Convention Center	1000	Yes	No	Columbus	OH	4/16		4/14	TBD

Table 1: *List of existing and planned field hospital and shelters [20]. All dates are in 2020.*

Field hospitals are concentrated in states with international airports and high population density

First, we mapped the existing and planned field hospitals to visualize their spatial distribution (Figure 1). It was not surprising to see that the field hospitals clustered around major international airports, such as San Francisco, Los Angeles, Seattle, Chicago, Dallas, and New York, that have connections to China-where the first epicenter was-and to Europe-where most transatlantic import occurred-especially before the international travel restriction was published on the 31st of March [5,6]. In addition to imported cases, the coronavirus then spread out to other cities through domestic travels and community-based transmission. Where the field hospitals indexed the most affected states, their distribution highly resembles that of imported measles outbreak predicted according to 1) international travel volume and port of entry, 2) incidence rate at the origin and 3) the population of surrounding count [7,8]. If an international epidemic originating from Europe or Asia occurs in the future, these states should the first ones to start public health emergency response procedures.

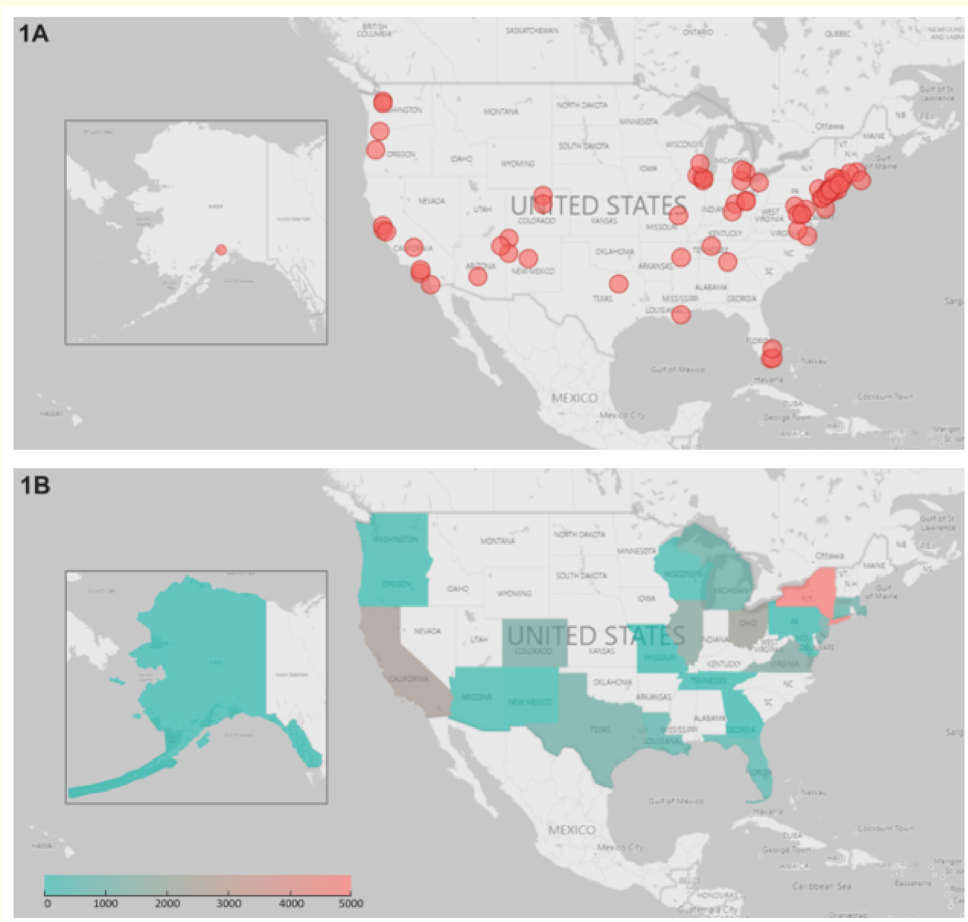


Figure 1: *Visualizing the spatial distribution of field hospitals. 1A: Current and planned field hospitals and shelters mapped to their location using Power BI. Each dot represents one field hospital regardless of its capacity. 1B: Density map indicating total number of field hospital beds in each state.*

Next, the question becomes, when the local epidemics developed into national pandemic, what determined when and where to build field hospitals? While reading through news reports, it was hard to ignore that the building and opening of field hospitals is a very dynamic process to accommodate the evolving curve of existing confirmed cases. Besides the field hospitals affiliated to and staffed by local healthcare system, recruiting staff can be challenging during the pandemic. Therefore, many field hospitals were constructed but remained closed until necessary to reserve medical resources. Similarly, in states where the outbreak was not as urgent, the potential sites were outfitted but no construction would start until situation worsens; alternatively, if the situation improves the construction would be canceled. Therefore, the decision must be dependent on the live feeds of the growing numbers. For convenience, we collected the U.S. COVID-19 statistics on April 15th, the national peak predicted by IHME, shown in table 2.

State	Confirmed	Ranking	Deaths	Active	Incidence Rate	Ranking	Field Hospital Bed	Population	Land Area	Population Density	Available Bed	Bed Rate
Alaska	293	50	9	284	49.0	47	163	731545	570641	1.3	683	93.4
Arizona	3964	23	142	3822	54.5	44	461	7278717	113594	64.1	6018	82.7
California	26686	6	860	25826	68.1	35	2646	39512223	155779	253.6	26654	67.5
Colorado	7956	16	328	7628	140.4	16	1607	5758736	103642	55.6	4852	84.3
Connecticut	14755	12	868	13887	413.9	5	1196	3565278	4842	736.3	1818	51.0
Florida	22511	8	596	21915	106.0	21	900	21477737	53625	400.5	20184	94.0
Georgia	14987	11	552	14435	147.8	14	150	10617423	57513	184.6	8323	78.4
Illinois	24593	7	949	23644	209.6	10	1947	12671821	55519	228.2	14552	114.8
Indiana	8960	15	436	8524	136.9	17	0	6732219	35826	187.9	8485	126.0
Louisiana	21951	9	1103	20848	477.5	3	1000	4648794	43204	107.6	7205	155.0
Maryland	10032	14	311	9721	168.8	12	442	6045680	9707	622.8	3961	65.5
Massachusetts	29918	3	1108	28810	435.9	4	1400	6892503	7800	883.7	4849	70.4
Michigan	28059	4	1921	26138	352.2	6	1250	9986857	56539	176.6	10155	101.7
Missouri	4791	21	153	4638	81.8	29	120	6137428	68742	89.3	7933	129.3
New Jersey	71030	2	3156	67874	799.7	2	1467	8882190	7354	1207.8	7815	88.0
New Mexico	1484	39	36	1448	89.0	23	290	2096829	121298	17.3	1753	83.6
New York	214454	1	11617	202837	1271.9	1	4428	19453561	47126	412.8	13011	66.9
Ohio	7794	17	362	7432	69.8	33	2442	11689100	40861	286.1	14291	122.3
Oregon	1663	36	58	1605	41.5	49	182	4217737	95988	43.9	2658	63.0
Pennsylvania	26753	5	779	25974	212.5	9	300	12801989	44743	286.1	14395	112.4
Tennessee	5827	19	124	5703	88.8	25	170	6829174	41235	165.6	7812	114.4
Texas	15907	10	375	15532	69.2	34	1400	28995881	261232	111.0	28634	98.8
Virginia	6500	18	195	6305	82.2	28	1848	8535519	39490	216.1	6581	77.1
Washington	10942	13	552	10390	144.9	15	450	7614893	66456	114.6	4907	64.4
Washington DC	2197	32	72	2125	311.3	7	497	702455	68.34	10278.8	1094	155.7
Wisconsin	3721	24	183	3538	71.9	32	530	5822434	97093	60.0	5365	92.1

Table 2: *Logistics and JHU CSSE COVID-19 updates of states that have existing or planned field hospitals. All COVID-19 data below reflect the outbreak on April 15th, the average peak date nationwide. Incidence rate is the number of confirmed cases per 100,000 persons. The ranking number is assigned to each state when either accumulative confirmed cases or incidence rate of all 50 states and Washington DC are ranked from largest to smallest. Land area is measured in mi^2, and population density in $persons/mi^2$. Available bed counts reflect hospital capacity in each state before the COVID-19 outbreak. Bed rate is calculated as number of beds available per 100,000 persons.*

The field hospital opening is more influenced by accumulated confirmed cases in each state

The timeline histogram shows that the greatest number of field hospitals opened during the 5th week, where most state met bed demand peaks (Table 1 and figure 2A). Intuitively, the more urgent the COVID-19 outbreak was in the state, the earlier the field hospitals would be built. For COVID-19, the recovery time is calculated from the first day showing symptom or having tested positive to the last day of testing negative for two consecutive days [9,10]. During the early phase of highly contagious disease with doubling time of 5 days and recovery time of 10 days, the recovery and death rate is almost negligible, and it is essential to contract trace, identify and isolate the infected individuals to slow down the spreading [11]. Therefore, the confirmed cases and the incidence rate, defined as number of infected individuals per 100,000 persons, should be more correlated with the opening time of field hospitals. Because larger population will produce larger number of confirmed cases, it is perceived that the population-independent infected rate would be a more accurate indicator of when to build the field hospitals. However, when we indexed each state with a ranking number, where either accumulative confirmed case number or incidence rate of all 50 state and Washington DC on April 15th was ranked from largest to smallest, and plotted against the opening date of the field hospitals, a stronger correlation was observed between ranking of accumulative confirmed cases and the field hospital opening date (Figure 2B and 2D). For example, California had an alarming number of accumulative confirmed cases of 26,686, ranking 6th in the nation; however, by incidence rate it was ranked 35th, indicating that the outbreak in the state was not as bad as it appeared even though the incidence rate was exceptionally high in certain cities. At the state level, the additional field hospital beds seemed unnecessary but at city level, they were essential. Consequently, a more case-specific micro-scale analysis is required to describe the discrepancy between the ranking of accumulative confirmed cases and of incidence rate. This observation could also be contributed to the fact that JHU CSSE did not publish the county-level population-corrected COVID-19 outbreak until April 12th. Even though the incidence rate could be calculated with simple math and more reliable, the mounting number of accumulative confirmed cases may have had a heavier impact on decision-making psychologically.

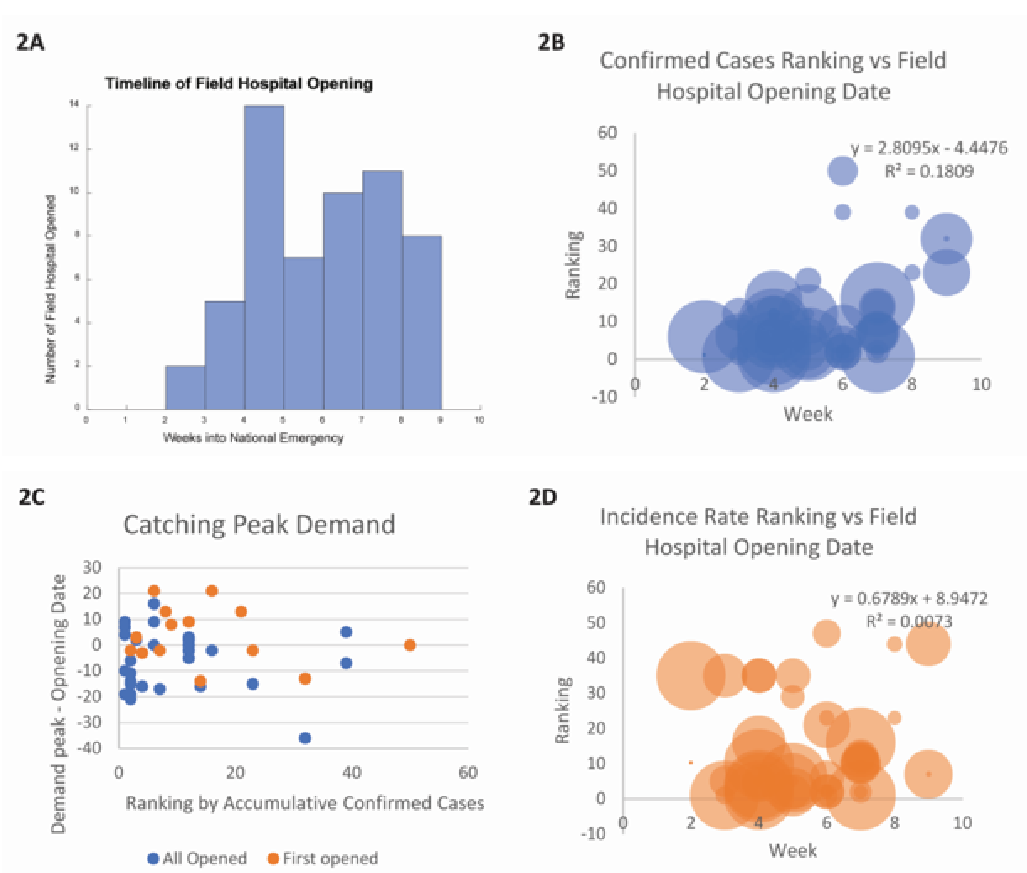


Figure 2: *The accumulative confirmed cases is a more important factor determining when and where to build the field hospitals. 2A: Histogram of field hospital opening time, binned to weeks into National Emergency. 2B and D: Urgency level, approximated by accumulated confirmed cases or incidence rate ranking, against opening date of field hospitals with linear fit. Radii of circles indicate the capacity of each field hospital. 2C: Most opening dates of field hospitals are clustered around y=0 or the date of predicted peak demand in the state they belong to. The first field hospital in each state on average opened before or by peak demand date. Each dot represents one field hospital. All field hospitals shown in blue, the first field hospital to open in each state shown in orange.*

Field hospitals in each state opened promptly to meet peak demand

Then we ask the question-were the field hospitals built by the date of peak demand? Knowing that the accumulative confirmed number is the determining factor of building these field hospitals, we plotted the difference between peak demand peak and field hospital opening date against the ranking of accumulative confirmed cases (Figure 2C). A positive y-value indicates that the field hospital opened before demand peak arrived, whereas a negative value suggests otherwise. From the scatter plot, we could conclude that most hospitals were opened around the day of peak demand. When the first hospital in each state to open was highlighted in orange, we could see that on average they were put to service well before or around the day of peak demand. It is noteworthy that some larger field hospitals, such as the Javits New York Medical Station, opened before construction ended to account for the imminent bed shortage (Table 1). In general, field hospitals in each state opened promptly to meet peak demand.

The total number of beds in field hospitals is most correlated to the difference between incidence rate and bed rate in each state

In parallel to the question when and where to build the field hospital is how many additional beds are needed? The classic SIR (Susceptible-Infected-Recovered) model of infectious disease suggests that the maximal infected rate I_{max}/N can be estimated as

$$I_{max}/N \;=\; 1 - \frac{1}{R_0}(1 \;+\; log\; R_0)$$

Where I_{max} is the maximal number of infected individuals, the population in the defined area, and R_0 the basic reproduction number of the infectious disease [12]. At first R_0 was estimated to be 3.65, which means that on average, 2.55 individuals will be infected by any given infected person, however after the implementation of social distancing, the effective R_0 is estimated to be 2.55 for COVID-19 in the U.S. [12]. Because the number of available hospital beds is directly proportional to population (Figure 3A), and the hospitalization rate (number of patients hospitalized over number of confirmed cases) is known to each state, the maximal number of additional beds required should be more or less proportional to the difference between maximal infected rate and bed rate, calculated as the number of beds per 100,000 persons. When the total number of field hospital beds was plotted against (infected rate - bed rate) (Figure 3B), indeed the correlation is stronger than that against any other statistics, followed by state population and accumulative confirmed cases (Supplemental figure 3). This phenomenon should be largely credited to the IHME projection model, which provided state-specific guidelines in preparing for the upcoming surge.

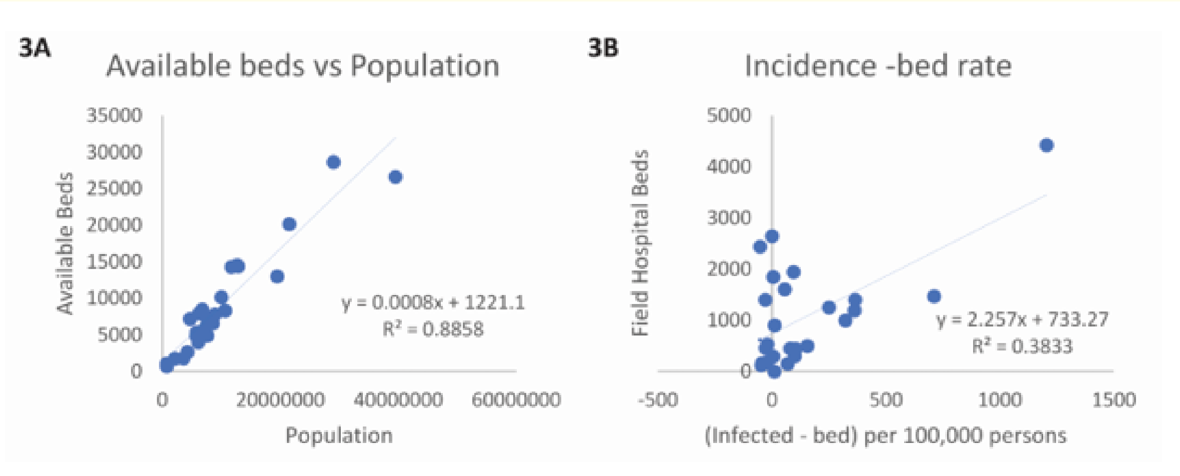


Figure 3: *The number of field hospital beds is mostly correlated to incidence minus bed rate, a proxy for the additional beds required predicting using SIR model. 3A: The number of available beds before COVID-19 is proportional to the population in each state. 3B: The number of field hospital beds in each state is mostly correlated to incidence minus bed rate.*

Different types of field hospitals were utilized differentially

When the field hospitals had been constructed with the right capacity and ready to receive patients around demand peak, the final question came down to: what purpose should they serve? Should they treat routine non-COVID-19 patients-such as those with kidney failure, heart disease, or cancer-to restore normal operation of the healthcare system, or should they take up COVID-19 patients when there is not enough space in the local hospitals? Should there be intensive care units or for mild-symptom and recovering patients only? While the local hospitals have been toiled by the flood of COVID-19 patients, it seemed like a cost-effective plan to designate field hospitals as overflow facilities to care for mild and recovering COVID-19 patients, where neither extra medical equipment, such as ventilators, nor specially trained staff were required. However, the follow-up news coverage may suggest otherwise (Table 3).

Hospital Name	COVID	Military	Beds	Opening Date	Utilized well	COVID tested	Low admission	Strict transfer	Closed
Central Park Field Hospital	Yes	No	68	4/1	x				
Boston Convention and Exposition Center	Yes	No	1000	4/10	x				
USNS Mercy	No	Yes	1000	3/27		x	x		x
USNS Comfort	No	Yes	1000	3/30		x	x		x
San Diego Convention Center Shelter	No	No	400	4/1		x			
Javits New York Medical Station	Yes	Yes	1000	4/4			x	x	
CenturyLink	No	Yes	250	4/6			x		x
TCF Center Field Hospital	Yes	Yes	1000	4/11			x	x	

***Table 3**: News coverage on opened field hospitals [21]. Positive reports are marked in green and negative in red. Checkmarks indicate the commentaries the field hospitals received. Blank indicates no news coverage.*

As of end of April, among the 75 surveyed field hospitals, 43 opened, 29 remained closed or under construction, and 3 was canceled; out of the 43 opened field hospitals, 2 had positive news reports, 6 negative, and the rest with no additional follow-up news coverage (Figure 4A). The major concerns included 1) COVID-19 outbreak in a non-COVID-19 facility, 2) low admission rate, and 3) strict transfer rules to accept patients from local hospitals. When the field hospitals were not required any more or could not contain the outbreak, patients would be discharged, and hospital shut down. The relationship between the negative commentary categories is depicted in the Venn diagram (Figure 4B).

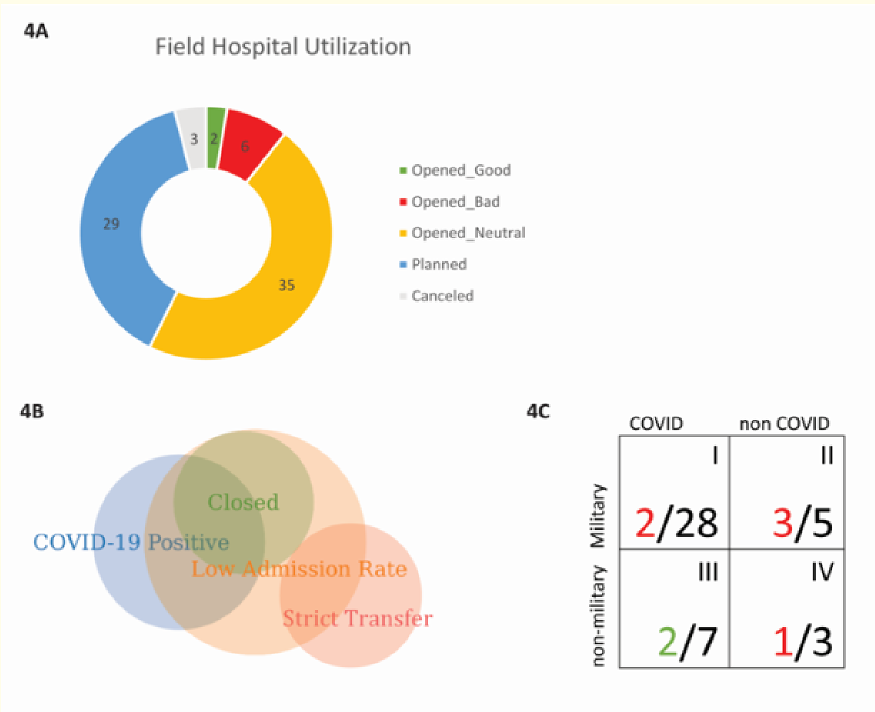
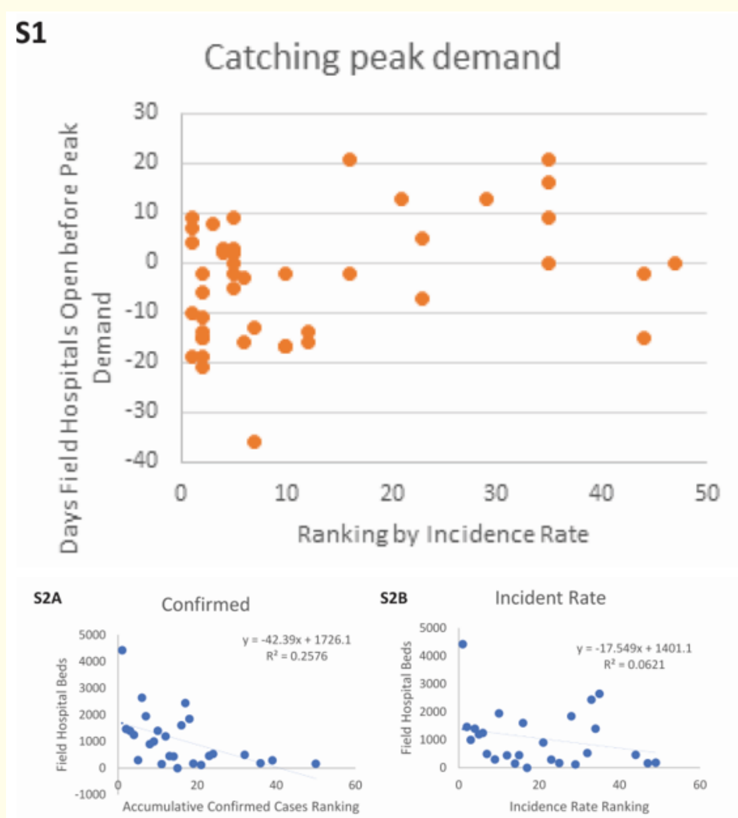


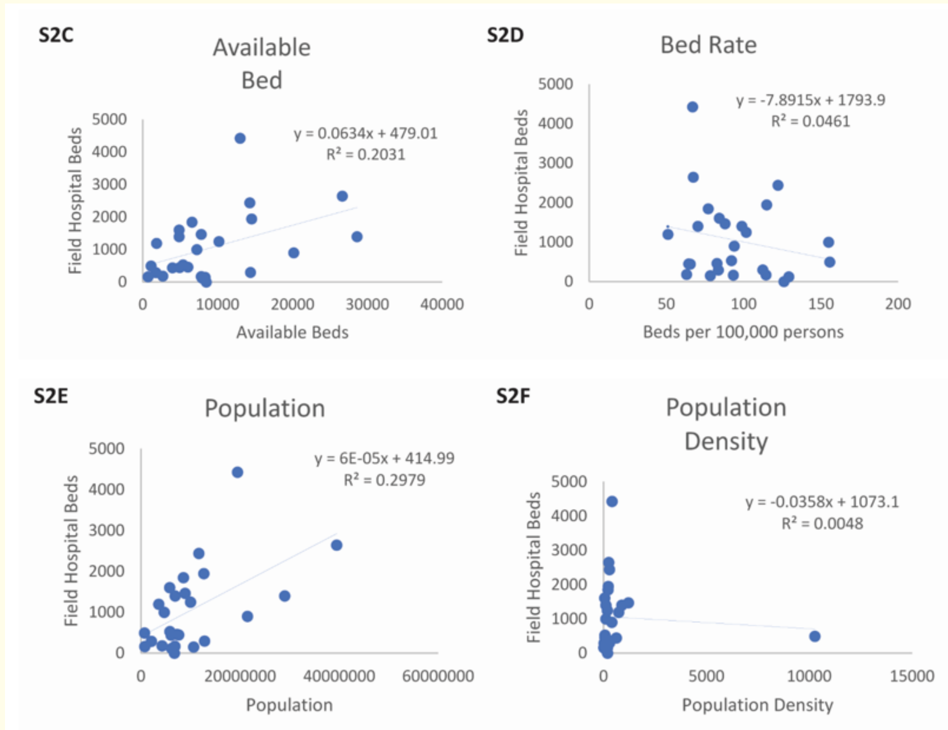
***Figure 4:** The effectiveness of decision making and the utilization of resources. 4A: The status of all field hospitals. 4B: Reasons of negative news report on the opened field hospitals. No conflicting reports were found. 4C: Positive and negative news coverage assigned to different quadrants of opened field hospitals. Red indicates negative commentaries and green positive. The numerator is the number of reported field hospitals, and denominator the total number of opened hospitals in each category. Each quadrant is labeled with Roman numerals on the upper right corner.*

When looking at the table 3 more closely, a pattern could be found between the property of field hospitals and the commentary they received. Therefore, we divided up the opened field hospitals into four quadrants depending on the patients they received (COVID-19 vs non-COVID-19), and the affiliation (military vs non-military). Then the reported field hospitals are assigned to each quadrant (Figure 4C). The non-military-built field hospitals are mostly affiliated or sponsored by local healthcare systems and receive direct transfers whereas the larger scaled military-built field hospitals are mostly freestanding facility accepting patients from the entire region. Therefore, it is an indicator of how well the field hospitals are integrated into the local healthcare system.

Javits Medical Center and TCF Center fell into quadrant I (COVID-19, military) and they both had low admission rate due to strict transfer rules. Even though many patients requested transfer, only a small portion was granted admission. The two *USNS* cruises and CenturyLink belong to quadrant II (non-COVID-19, military) and they all had low admission rate. Both *USNS* cruises had staff or patients tested positive for COVID-19. *USNS* Comfort discharged all patients and left New York after 3 weeks of service and *USNS* Mercy dispatched crew members to assist local healthcare facilities. CenturyLink in Seattle received 0 patients 3 days after opening and was soon closed. San Diego Convention Center Shelter in quadrant IV also had 2 confirmed COVID-19 cases among the homeless. The two well utilized field hospitals-Central Park Field Hospital and Boston Convention Center-both fall into quadrant III (COVID-19, non-military). Central Park Field Hospital, especially, is more like an overflow ward of Mt. Sinai Hospital with full capacity to provide intensive care. It admitted 142 patients one week after opening and hospitalized at least 50 patients at all time.

In general, the non-COVID and/or military-build field hospitals appeared less utilized than planned. However, from the perspective of public health, the low utilization rate can have mixed implications.





Supplementary Figures

Discussion

Low utilization rate of field hospital could be due to various factors

In response to the COVID-19 pandemic, many countries have built makeshift hospitals. Like many field hospitals in the U.S., the NHS (National Health Service) Nightingale Hospitals in the UK also treated very few patients. The Nightingales are also designed as overflow hospitals when the surge does occur. Therefore, the underutilization demonstrate that the local health systems had coped with the extra pressure COVID-19 brought [13]. Similarly, the low utilization rate in the U.S. field hospitals, which are also built as the last resort during the medical crisis, could be due to that public health interventions, such as social distancing and wearing masks, are effective to "flatten the curve" and the infected population did not grow to the predicted value. According to the IHME model, the estimated maximal daily infections in the U.S. were 260K on March 29th, however the actual number peaked on April 8th with 32K confirmed cases [4]. Consequently, the field hospitals prepared for the surge were no longer needed.

On top of the lowered number of infected cases, procedural and socioeconomic factors further decrease the utilization of field hospitals. CDC encourages patients with mild symptoms to practice self-isolation and recover at home, which decreases the proportion of infected cases entering the medical system [16]. In addition, loss of health insurance due to unemployment and confusion of coverage also discourage patients to seek medical attention when symptoms are mild [16,17]. When patients are hospitalized but do not need intensive care, the transfer qualification, specifically in Javits Medical Station and TCF Center Field Hospital, again strictly limits the number of patients admitted to the field hospital even though large volume of patients requested for transfer.

COVID-19 intensive care should be prioritized in the epicenter

The most significant difference between the U.S. and UK field hospitals is that the NHS prioritized the COVID-19 patients needing critical care over mild and recovering patients, with the non-COVID-19 patients coming last. The most important medical center, the ExCel Nightingale, specifically was commissioned with a purpose to take up unconscious, ventilated patients who could not take direct referrals from the community. It was not a "step down" facility, but rather an alternative. Whereas in the U.S., most COVID-19 field hospitals only take mild and recovering patients and had low admission rate. In contrast, the Central Park Field Hospital, equipped with intensive care unit have filled the beds with patients and are running around the clock. Comparatively speaking, it may be a better idea to accentuate the resources on smaller number of intensive care beds instead of on large amount of non-intensive care beds, when most patients can recover without hospitalization [18].

Non-intensive COVID-19 field hospitals can serve as entry instead of step-down facilities

The FangCang field hospitals built in Wuhan, China were also designed for mild and recovering COVID-19 patients but had high occupancy. The major difference is that instead of taking patient outflow, FangCang field hospitals triage and quarantine COVID-19 positive patients before the more severe individuals are transferred to designated healthcare facilities [19]. Not only can this workflow free up the space in local hospitals, the confirmed cases can be properly quarantined to prevent further in-person transmission. Whereas many COVID-19 patients with mild symptoms were self-quarantined at home and may not strictly follow the rules, group quarantine patients in field hospital appears a more effective way to utilize the resources.

Conclusion

When the accumulative confirmed cases surged immensely in mid-March, the affected states have properly responded to the COVID-19 outbreak by promptly building field hospitals to supply additional beds predicted by the IHME model. While many hospitals remained closed to reserve resources, 43 field hospitals opened from late March to May 1st. The number of follow-up news report on the operation of field hospitals is low, so the conclusion may not be definitive. From what we have gathered, low utilization rate is common. It could be due to a combination of factors, such as non-COVID-19 patients reluctant to seek medical assistance and the outbreak being contained.

By comparing the field hospitals across different categories in the U.S. as well as those in other countries, there could be multiple ways to improve the utilization of medical resources during the pandemic. First, more resources could have been concentrated on intensive care. These field hospitals can be paired with local healthcare systems to allow efficient transfer. Next, non-critical COVID-19 field hospitals can triage confirmed patients and group quarantine them to prevent further transmission. Last but not the least, the non-COVID-19 field hospitals can be kept to minimum and strict screening must be followed to prevent cross-transmission.

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