Development of an Inclusive Interhospital Resource Allocation to Mitigate States Hospital Capacity during COVID-19

Eman A Toraih¹, Danielle Tatum², Mohammad H Hussein³, Juan Duchesne⁴

ABSTRACT

The severe acute respiratory syndrome coronavirus (SARS-CoV-2), commonly known as COVID-19, has resulted in severe resource shortages in the areas that have become hot spots. A leading area of concern has been hospital bed and intensive care unit bed availability that would leave hospitals unable to treat the most severe cases and which would result in unnecessary additional loss of life. Here, we present a model based on prediction of cases by state to propose resource allocation to alleviate hospital bed shortages.

Keywords: COVID-19, Emergency, Outcomes.

RESUMEN

El coronavirus del síndrome respiratorio agudo severo (SARS-CoV-2), comúnmente conocido como COVID-19, ha provocado una grave escasez de recursos en las áreas que se han convertido en regiones de alta prevalencia (puntos calientes). Una de las principales áreas de preocupación ha sido la disponibilidad de camas de hospital y de unidades de cuidados intensivos que dejan los hospitales sin poder tratar los casos más graves y que daría lugar a pérdidas de vidas adicionales innecesarias. Aquí te presentamos un modelo basado en la predicción de casos por estado para proponer la asignación de recursos para aliviar la escasez de camas hospitalares.

Palabras clave: COVID-19, emergencia, outcome.

Panamerican Journal of Trauma, Critical Care & Emergency Surgery (2020): 10.5005/jp-journals-10030-1281

BACKGROUND

As of April 13, 2020, the United States has surpassed all other countries in number of confirmed novel coronavirus disease 2019 (COVID-19) cases with over 500,000 total, more than 6 times the reported numbers in China.¹ Several states have experienced larger, more severe outbreaks than others, with New York, New Jersey, and Louisiana being among the worst. New York and New Jersey have the highest case numbers per capita in the nation, and Louisiana has second highest number of deaths per capita in addition to the fastest growth rate of cases in the world.^{2,3} Regions such as these are at high risk for soon exceeding their capacity to care for the steadily increasing number of infected and critically ill patients. Conversely, other states such as Mississippi, Wyoming, and the Dakotas have fared better with significantly fewer cases in defined areas as opposed to widespread transmission. Thus, United States began lockdown orders across many states, including schools and business (Table 1).

A recently published (though not yet peer reviewed) article estimated the predicted health service utilization and deaths due to the novel coronavirus in the United States over the next 4 months.⁴ Based on these forecasted estimates and state-level data,⁵ we examined which states would likely exceed hospital capacity and which would not over the coming days and months (Fig. 1 and Table 2). Our main objective was to potentially develop solutions for states with the nearest peak capacity based on an inclusive healthcare model that includes interhospital resource transfers with the less burdened by the pandemic.

¹Division of Endocrine and Oncologic Surgery, Department of Surgery, Tulane University, School of Medicine, New Orleans, Louisiana, USA; Genetics Unit, Department of Histology and Cell Biology, Faculty of Medicine, Suez Canal University, Ismailia, Egypt

²Trauma Specialist Program, Our Lady of the Lake Regional Medical Center, Baton Rouge, Louisiana, USA

³Division of Endocrine and Oncologic Surgery, Department of Surgery, Tulane University, School of Medicine, New Orleans, Louisiana, USA

⁴Trauma/Acute Care and Critical Care, Department of Surgery, Tulane School of Medicine, New Orleans, Louisiana, USA

Corresponding Author: Juan Duchesne, Trauma/Acute Care and Critical Care, Department of Surgery, Tulane School of Medicine, New Orleans, Louisiana, USA, Phone: +1 504-988-5111, e-mail: jduchesn@tulane.edu

How to cite this article: Toraih EA, Tatum D, Hussein MH, et al. Development of an Inclusive Interhospital Resource Allocation to Mitigate States Hospital Capacity during COVID-19. *Panam J Trauma Crit Care Emerg Surg* 2020;9(2):147–154.

Source of support: Nil

Conflict of interest: None

STATISTICAL MODEL

Data were obtained from The Institute for Health Metrics and Evaluation (IHME) COVID-19 projections developed by the global health research center at the University of Washington School of Medicine (<http://www.healthdata.org/covid>). The analytical

Table 1: Lockdown measures of Unites States

<i>State</i>	<i>Stay at home order</i>	<i>Educational facilities closed</i>	<i>Nonessential services closed</i>
Alabama	Not implemented	18-Mar	18-Mar
Alaska	25-Mar	26-Mar	18-Mar
Arizona	Not implemented	16-Mar	20-Mar
Arkansas	Not implemented	17-Mar	19-Mar
California	19-Mar	19-Mar	19-Mar
Colorado	Not implemented	23-Mar	17-Mar
Connecticut	23-Mar	17-Mar	16-Mar
Delaware	24-Mar	16-Mar	16-Mar
District of Colombia	Not implemented	16-Mar	16-Mar
Florida	Not implemented	17-Mar	20-Mar
Georgia	Not implemented	18-Apr	Not implemented
Hawaii	25-Mar	19-Mar	17-Mar
Idaho	Not implemented	Not implemented	Not implemented
Illinois	21-Mar	17-Mar	21-Mar
Indiana	25-Mar	19-Mar	16-Mar
Iowa	Not implemented	Not implemented	17-Mar
Kansas	Not implemented	17-Mar	Not implemented
Kentucky	Not implemented	12-Mar	16-Mar
Louisiana	23-Mar	16-Mar	17-Mar
Maine	Not implemented	15-Mar	18-Mar
Maryland	Not implemented	16-Mar	23-Mar
Massachusetts	Not implemented	17-Mar	24-Mar
Michigan	24-Mar	16-Mar	23-Mar
Minnesota	27-Mar	18-Mar	Not implemented
Mississippi	Not implemented	19-Mar	Not implemented
Missouri	Not implemented	23-Mar	Not implemented
Montana	26-Mar	15-Mar	26-Mar
Nebraska	Not implemented	Not implemented	Not implemented
Nevada	Not implemented	16-Mar	20-Mar
New hampshire	27-Mar	16-Mar	27-Mar
New Jersey	21-Mar	18-Mar	21-Mar
New Mexico	Not implemented	13-Mar	24-Mar
New York	22-Mar	18-Mar	20-Mar
North carolina	30-Mar	14-Mar	30-Mar
North Dakota	Not implemented	16-Mar	Not implemented
Ohio	23-Mar	16-Mar	23-Mar
Oklahoma	Not implemented	17-Mar	Not implemented
Oregon	23-Mar	16-Mar	Not implemented
Pennsylvania	23-Mar	17-Mar	23-Mar
Rhode Island	28-Mar	16-Mar	28-Mar
South Carolina	Not implemented	16-Mar	Not implemented
South Dakota	Not implemented	16-Mar	Not implemented
Tennessee	Not implemented	Not implemented	Not implemented
Texas	Not implemented	19-Mar	Not implemented
Utah	Not implemented	16-Mar	Not implemented
Vermont	24-Mar	18-Mar	25-Mar
Virginia	Not implemented	16-Mar	Not implemented
Washington	23-Mar	13-Mar	25-Mar
West Virginia	25-Mar	14-Mar	24-Mar
Wisconsin	25-Mar	18-Mar	25-Mar
Wyoming	Not implemented	19-Mar	Not implemented

Figs 1A to D: Density map illustrating areas of: (A) Estimated number and location of surplus hospital beds; (B) Estimated surplus and locations of ICU beds. Density map illustrating (C) Predicted number of additional hospital beds needed by state and (D) Predicted number of additional ICU beds needed by state

platform forecasts daily and cumulative COVID-19 deaths in association with social distancing order information and testing. For each state in the United States, the projected hospital and intensive care unit (ICU) bed needed were subtracted from the available resources to identify the presence of excess and shortage per State (Table 2).

SUPPLY AND DEMAND

As confirmed cases of COVID-19 in the United States continue to increase, the number of beds needed are exceeding what is locally available in many areas. For the whole of the country, an estimated 61,509 hospital beds and 15,103 ICU beds will be required within

14 days in order to meet demand. However, projected demand only significantly exceeds supply in certain states (Fig. 2). For example, New York state has 13,010 total hospital beds but is projected to need a staggering 71,574, nearly 59,000 more than their current capability (Table 2). On March 30, 2020, New York received the US Naval hospital ship, the USNS Comfort, with 1,000 beds to alleviate pressure on overwhelmed hospitals. A similar ship, the USNS Mercy, was deployed to Los Angeles to expand critically needed hospital capacity there. However, the Navy alone cannot solve the bed shortage problem, particularly since much of the country is not accessible by port.

In contrast to these areas of crises, other areas are projected to have a surplus of thousands of beds, including those for ICU

Table 2: Projected needs and resource availability

State	Projected peak	Days left to peak	All beds needed	All beds available	bed shortage	Excess hospital beds	ICU beds needed	ICU beds available	ICU bed shortage	Excess ICU bed	Invasive ventilators needed	Daily death at peak	Time Max daily death	Total death till 4-Aug
Alabama	24-Apr	25	3,628	5,743	0	2,115	553	474	79		299	37	24-Apr	1,732
Alaska	26-Apr	27	524	682	0	158	78	54	24		42	5	24-Apr	129
Arizona	19-Apr	20	5,342	6,017	0	675	808	508	300		436	58	18-Apr	1,613
Arkansas	25-Apr	26	2,183	5,005	0	2,822	328	394	0	66	177	22	23-Apr	762
California	24-Apr	25	15,242	26,654	0	11,412	2,292	1,993	299		1,238	148	25-Apr	4,306
Colorado	28-Apr	29	2,260	4,851	0	2,591	337	554	0	217	182	21	25-Apr	2,151
Connecticut	10-Apr	11	3,341	1,738	1,603		521	99	422		281	36	10-Apr	378
Delaware	24-Mar	-6	725	696	29		110	41	69		59	7	20-Apr	827
District of Columbia	24-Mar	-6	408	1,093	0	685	62	66	0	4	33	4	19-Apr	132
Florida	14-May	45	5,576	20,184	0	14,608	836	1,695	0	859	451	56	12-May	6,766
Georgia	21-Apr	22	10,436	8,322	2,114		1,566	589	977		846	98	21-Apr	2,777
Hawaii	25-Apr	26	1,070	956	114		160	45	115		86	11	22-Apr	390
Idaho	25-Apr	26	1,206	1,718	0	512	181	151	30		98	12	22-Apr	84
Illinois	16-Apr	17	8,855	14,552	0	5,697	1,335	1,131	204		721	88	16-Apr	2,454
Indiana	14-Apr	15	10,458	8,485	1,973		1,582	706	876		854	110	14-Apr	2,440
Iowa	24-Apr	25	2,250	4,297	0	2,047	341	246	95		184	24	23-Apr	742
Kansas	24-Apr	25	2,036	4,810	0	2,774	310	278	32		167	21	23-Apr	669
Kentucky	5-May	36	1,172	6,210	0	5,038	175	448	0	273	95	11	29-Apr	585
Louisiana	8-Apr	9	9,217	7,204	2,013		1,436	477	959		775	97	9-Apr	2,081
Maine	24-Apr	25	1,086	1,061	25		164	64	100		88	11	21-Apr	334
Maryland	30-Apr	31	0	3,961	0	3,961	0	266	0	266	0	11	21-Apr	
Massachusetts	14-Apr	15	7,503	4,848	2,655		1,171	277	894		937	81	16-Apr	1,782
Michigan	10-Apr	11	13,944	10,154	3,790		2,162	742	1,420		1,730	158	11-Apr	2,862
Minnesota	21-Apr	22	6,863	4,983	1,880		1,049	355	694		839	70	21-Apr	2,146
Mississippi	22-Apr	23	8,984	5,733	3,251		1,356	340	1,016		1,085	92	23-Apr	2,292
Missouri	11-May	42	2,055	7,933	0	5,878	308	558	0	250	247	20	8-May	1,055
Montana	30-Apr	31	877	1,669	0	792	133	85	48		106	9	28-Apr	282
Nebraska	30-Apr	31	1,278	3,130	0	1,852	195	232	0	37	156	13	28-Apr	424
Nevada	20-Apr	21	1,941	2,247	0	306	293	183	110		234	19	21-Apr	568
New Hampshire	30-Apr	31	1,127	1,018	109		170	83	87		136	11	28-Apr	351
New Jersey	9-Apr	10	9,502	7,815	1,687		1,453	465	988		1,163	104	10-Apr	2,096
New Mexico	30-Apr	31	1,588	1,752	0	164	240	117	123		192	16	28-Apr	514
New York	9-Apr	10	71,574	13,010	58,564		11,070	718	10,352		8,855	798	10-Apr	15,546
North Carolina	22-Apr	23	5,588	7,125	0		845	567	278		676	56	22-Apr	1,721
North Dakota	1-May	32	507	1,545	0	1,038	76	86	0	10	61	5	26-Apr	171

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State	Projected peak	Days left to peak	All beds needed	All beds available	bed shortage	Excess hospital beds	ICU beds needed	ICU beds available	ICU bed shortage	Excess ICU bed	Invasive ventilators needed	Daily death at peak	Time Max daily death	Total death till 4-Aug
Ohio	19-Apr	20	3,854	14,290	0	10,436	585	1,238	0	653	468	39	19-Apr	1,203
Oklahoma	17-Apr	18	4,879	5,457	0	578	752	467	285		602	52	18-Apr	1,149
Oregon	3-May	34	984	2,657	0	1,673	147	210	0	63	118	10	2-May	469
Pennsylvania	15-Apr	16	6,182	14,395	0	8,213	949	1,043	0	94	759	67	16-Apr	1,579
Rhode Island	19-Apr	20	975	795	180		147	41	106	65	117	10	16-Apr	306
South Carolina	24-Apr	25	3,240	4,679	0	1,439	492	404	88		394	32	24-Apr	1,043
South Dakota	1-May	32	611	1,805	0	1,194	92	74	18		73	6	26-Apr	204
Tennessee	26-Apr	27	3,494	7,812	0	4,318	525	629	0	104	420	35	26-Apr	1,067
Texas	2-May	33	10,956	28,633	0	17,677	1,640	2,259	0	619	1,312	102	2-May	4,150
Utah	27-Apr	28	1,606	2,771	0	1,165	242	170	72		194	16	27-Apr	502
Vermont	9-Apr	10	330	533	0	203	50	34	16		40	3	23-Mar	95
Virginia	17-May	48	3,696	6,581	0	2,885	552	329	223		442	35	17-May	2,053
Washington	24-Apr	25	3,030	4,907	0	1,877	451	341	110		361	29	24-Apr	1,670
West Virginia	1-May	32	1,665	3,032	0	1,367	251	196	55		201	17	29-Apr	543
Wisconsin	26-Apr	27	3,758	5,364	0	1,606	562	172	390		450	37	25-Apr	1,309
Wyoming	1-May	32	420	1,069	0	649	64	44	20		51	4	26-Apr	132

Analysis was performed on March 30. [Data source: <https://covid19.healthdata.org/united-states-of-america>].

Figs 2A and B: Density map illustrating the total number of: (A) Estimated available hospital beds and predicted number needed; (B) Estimated available ICU beds and predicted number needed

Figs 3A to D: (A) Timeline of days remaining until exceeding capacity; (B) Estimated number of daily deaths at peak of crisis; (C) A census of total hospital beds by the states; (D) A census of total ICU beds by the states

care. As depicted in Figure 3, Pennsylvania is forecast to have nearly 8,000 available hospital beds, Ohio a surplus of more than 10,000, and Texas nearly 18,000 unused beds throughout the next 4 months of this crisis. Ohio and Texas are also expected to each have approximately 600–650 available ICU beds, while several other states will potentially have between 100 and 260 that remain unused (Figs 3C and D). Outbreaks are not uniform throughout the country, and different regions are beginning to see decreased numbers of new cases daily, while other regions are expected to not reach their peak for several more weeks or are developing fewer cases than originally predicted (Fig. 3A).

There current number of hospital beds in the United States is sufficient to meet demand; therefore, overall supply is not the problem. Rather, it is distinct areas of high demand which are rapidly approaching and exceeding hospital capacity (Fig. 2). Several places have begun to address this by repurposing existing structures such as dormitories and hotel rooms into makeshift hospital rooms. New Orleans, one of the hardest hit cities in the nation, has re-outfitted its large convention center, which was used to house victims of Hurricane Katrina as a stepdown facility for patients who do not require ICU care. While these structural transformations are helpful, they are also time intensive, costly, and alone may not be sufficient to meet demand.

HISTORY LESSONS

During World War II, the nation witnessed massive scales of repurposing and reassigning resources. Car factories began making war planes seemingly overnight. Scores of women left the household for the first time to fulfill factories jobs left vacant by men going to war. Wartime required (what was then) radical thinking in order to adapt, and we again find ourselves in a war, albeit a different sort, and must engage in outside-the-box thinking. If America was a supermarket and facing supply shortages in some regions but surplus in others, the supply chains would be reconfigured and resources redistributed in order to meet demand in all stores. Indeed, we have already observed a sort of reallocation of resources in the form of medical personnel. Pleas from overburdened hospitals for additional medical personnel to treat COVID-19 patients have been made and are being answered in large numbers. In addition to the Navy hospital ship, approximately 80,000 healthcare providers have arrived in New York to volunteer and alleviate the strain on frontline staff.

Adding together the excess numbers from each state, there are projected to be roughly 120,405 available hospital beds and 3,580

Table 3: Proposed national transfer of resources across states

Allocation flow of hospital beds		Excess hospital beds	Needed beds	Still spare at the source
From	To			
Texas	LA	17,677	2,000	15,677
Texas	NY	15,677	15,000	677
Florida	NY	14,608	12,000	2,608
Ohio	NY	10,436	10,000	436
California	NY	11,412	8,000	3,412
Illinois	NY	5,697	8,000	213
Pennsylvania	NY	8,213	5,000	697
Missouri	Indiana	5,878	2,000	3,878
Missouri	Michigan	3,878	3,000	878
Nebraska	Minnesota	1,852	1,500	352
Kentucky	Georgia	5,038	2,000	3,038
Kentucky	Mississippi	3,038	3,000	38
Maryland	Connecticut	3,961	1,600	2,361
Maryland	New Jersey	3,961	1,700	661

available ICU beds nationwide. Estimated projections predict that 61,509 hospital beds and 15,103 ICU beds will be needed. While it is currently not feasible to redistribute patients to hospitals with capacity for various reasons, we *can* reallocate our resources in order to get them to patients (Fig. 4). Such an approach could significantly alleviate strain on cities and hospitals that are nearing their breaking points. Proposed reallocation of resources is demonstrated in Table 3.

TIME IS OF THE ESSENCE

There is little time to act if lives are to be saved. Several states are projected to exceed their capacity in a matter of just days. Based on projected state-level timelines of days to reach capacity and the points at which estimated daily deaths will peak, the number of unused hospital beds in less affected areas can be a tool for mobilizing resources to where they are most needed. The approach is also fluid, as regions that are currently inundated will reach a peak in cases and begin to decline, thus freeing up resources which could then be allocated to new or developing areas of need. Although specific numbers are not included in the present discussion, the same approach could be applied to address the critical shortage of ventilators in overwhelmed areas. The country has ample infrastructure via railways, cargo planes, and cross-country trucking to allow rapid mobilization and redistribution of equipment to any of our states and territories in need.

LIMITATIONS

There are limitations to the data upon which our proposal is based, which, by extension, are limitations of our output as well. Age was not considered when the original forecast models were created. This may miss important and unique features in populations of states such as Florida with a significant proportion of geriatric patients. It has been well demonstrated that older COVID-19 patients have worse outcomes, and thus the real number of beds needed may exceed the estimated values. Additionally, these values are based on artificial intelligence projections based on available state data of licensed capacity and average annual occupancy rates and may not be 100% accurate as with any model.

Fig. 4: Illustrated schematic of potential resource allocation maneuvers to alleviate resource shortages. Red circles represent areas of need, and green ones represent areas of surplus. K—1,000

Finally, the proposed approach does not fully solve the forecast shortage of ICU beds. However, it does represent a meaningful start to address the issue.

CONCLUSION

In conclusion, we present an argument for a resource sharing/re-allocation approach in order to mitigate future, but preventable, deaths due to regional lack of resources. This proposed approach is not intended to be a directive to be undertaken immediately. We recognize that there may be hesitancy to loan equipment based on a fear of the unknown in terms of future, not yet diagnosed cases. We further recognize that this may not be a feasible endeavor for every facility with available beds and that what we suggest is a complicated solution to a complicated problem. However, it is urgent that, at a minimum, we do due diligence and rapidly begin to assess the feasibility of sharing resources. When combating a virus which shows no concerns for borders or boundaries, can we afford to place such restrictions on ourselves at the expense of thousands of lives?

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