Biomedical Equipment for COVID-19 Case Management

Senegal Facility Survey Report

April 2021

PATH

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The work described in this report was carried out as part of PATH's COVID-19 Respiratory Care Response Coordination project, which is a partnership between PATH, the Clinton Health Access Initiative, and the Every Breath Counts Coalition to support country decision-makers in the development and execution of a comprehensive respiratory care plan to meet the demands of COVID-19. The project is also pursuing strategies to help prioritize and improve access to oxygen therapy and other essential equipment involved in respiratory care as an integral part of health systems strengthening, beyond the pandemic response.

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Abbreviations

CHR	centre hospitalier regional (regional hospital)
COVID-19	coronavirus disease 2019
ECG	electrocardiogram
HDU	high dependency unit
ICU	intensive care unit
LPM	liters per minute
PSA	pressure swing adsorption
WHO	World Health Organization

Executive summary

In response to the COVID-19 pandemic, a biomedical equipment survey was conducted between June and July 2020 in 29 designated COVID-19 treatment centers across 13 of 14 regions in Senegal. The purpose of this survey was to quantify existing oxygen delivery and production equipment, consumables for administering oxygen therapy, bed capacity, and facility infrastructure characteristics that are relevant to providing respiratory care. Primary, secondary, and tertiary health care facilities designated for COVID-19 treatment, as well as newly developed temporary COVID-19 treatment sites, were included in the sample. This report summarizes observations from the collected data and provides a unique resource for understanding COVID-19 treatment capacity in Senegal's health facilities. Information was collected to enable evidence-based decisions on allocation of the limited quantities of respiratory care equipment available to treat patients affected by COVID-19 and other respiratory illnesses. By documenting the current availability of equipment and modeling the requirements in Senegal, the data reported here can enable stakeholders to engage in specific actions to meet the country's needs.

The results indicated that intensive care unit bed capacity was a key constraining factor to oxygen therapy across most COVID-19 treatment centers. **The data also revealed significant scarcity of oxygen delivery equipment across Senegal, with available oxygen equipment often totaling far less than the number of reported beds. Available critical oxygen delivery and production equipment was highly concentrated in the capital, Dakar.** For instance, of 77 functional ventilators reported across all surveyed COVID-19 treatment centers, 84% were held by facilities in Dakar—this despite Dakar making up only 23% of Senegal's current population. **There was also a lack of basic durable and consumable equipment to deliver medical oxygen.** For instance, data showed only 103 adult oxygen masks across all surveyed COVID-19 treatment centers. Additionally, the distribution of delivery equipment and vital signs monitoring equipment was not proportional across regions. This implies that safe oxygen administration and pulse oximetry was limited in many facilities in Senegal.

An immediate next step after quantifying baseline oxygen availability was to compare observed equipment totals to estimated equipment needs for a hypothetical COVID-19 scenario. This gap in oxygen and respiratory equipment is reported as total procurement quantities by product category. Significant shortfalls in respiratory care consumables and durables were estimated for the scenario. For example, we estimated a shortfall exceeding 1,000 units each of oxygen masks, nasal cannulae, and nasal catheters, and more than 100 units each of pulse oximeters and patient monitors. It will be prudent to review these estimates and develop plans to address the shortages in order to meet COVID-19 patient needs.

This report and gap analysis identified specific needs that donors, implementing partners, country governments, and other stakeholders should prioritize through policy and funding decisions that increase availability of respiratory care equipment. The survey data could also enable informed, efficient allocation (and potentially reallocation, post the COVID-19 pandemic) of procured supplies. These findings and recommendations will ultimately help to ensure new equipment is placed in facilities where it can be maximally utilized. It is important to note that since data collection was completed in July 2020, additional equipment has been procured. Information regarding this newly procured equipment has been integrated into an ongoing PATH-led analysis of medical equipment and oxygen device inventory across 164 public health care facilities. This information will also be taken into account when developing policy and procurement recommendations.

Survey scope and sampling

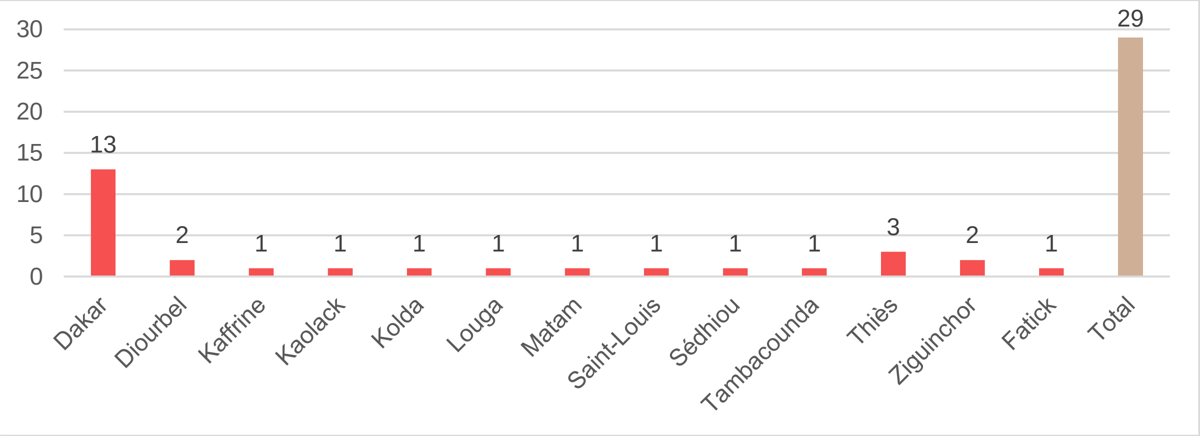
This report begins by describing the design of the facility assessments conducted, key facility characteristics (e.g., intensive care unit [ICU] bed counts) observed in the data, and a discussion of other factors that could constrain COVID-19 treatment capacity. The report then highlights observations of the current availability of oxygen delivery and respiratory care equipment, oxygen production/supply equipment, and consumables within health facilities.[a]

Nationally, 29 COVID-19 treatment centers were surveyed across 13 regions of Senegal. The types of facilities surveyed included existing primary (centre de santé), secondary (hôpital de niveau 1, hôpital de niveau 2), tertiary (hôpital de niveau 3), and specially created new COVID-19-dedicated treatment and observation centers. A full list of the facilities visited is available in Appendix A.

These facilities are expected to treat COVID-19 patients and will require the minimum equipment to care for critically ill patients. Overall, this data collection effort covered approximately 21% of the 137 health care facilities in Senegal (35 tier 1/2/3 hospitals and 102 health centers), as defined in the 2019–2028 *Plan National de Développement Sanitaire et Social* (National Health and Social Development Plan).

Figure 1 shows the number of facilities surveyed per region. More facilities were sampled in Dakar, the national capital, which continues to be the epicenter of COVID-19 cases in Senegal, than in other regions.

Figure 1. Number of facilities surveyed, by region.



Data collection methods

The World Health Organization (WHO) biomedical equipment for COVID-19 case management data collection tool[b] was adapted by PATH for use in Senegal, in collaboration with the Ministry of Health Emergency Operations Center, WHO in Senegal, and the Ministry of Health Direction of Infrastructure, Equipment and Maintenance. The questions included in the survey were informed by the WHO list of priority medical devices for COVID-19 case management.[1]

a. The survey data used to inform these observations can be accessed upon a request to PATH at oxygen@path.org.

b. Essential equipment for COVID-19 treatment was defined by the World Health Organization COVID-19 Essential Supplies Forecasting Tool: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/covid-19-critical-items.

The instrument was hosted on the SurveyCTO platform with data generated from it being used to develop this report.

Data collection was organized and conducted by PATH and the Senegal Ministry of Health Emergency Operations Center.

Data privacy was a priority for survey data collection and has been maintained by encrypting and storing all data in password-protected containers during all data cleaning and analysis.

Study teams

Facility data were collected over a span of 11 days. Data collection was carried out by PATH in partnership with Ministry of Health officers with significant experience in medical oxygen delivery. A two-day training on the survey tool was conducted prior to the field work. All data were collected on a digital survey platform (SurveyCTO) using tablets, and uploaded to the server on each day of the collection period. Analysis and data collection was completed by the PATH team under the supervision of Dr. Abdoulaye Ly of the Ministry of Health Emergency Operations Center.

Limits of the study

Data collection was done in June and July 2020. Since then, additional medical equipment has been purchased to strengthen Senegal's health system and COVID-19 response. Information regarding this newly procured equipment has been integrated into an ongoing analysis of medical equipment and oxygen device inventory across 164 public health care facilities supported by PATH staff in Senegal.

For a more comprehensive understanding of oxygen equipment and supplies availability in Senegal, the 2020–2024 health investment plan, *2019–2028 Plan National de Développement Sanitaire et Social*, and the *Plan Sénégal Emergent* (Emerging Senegal Plan, a government reference document) can be consulted in addition to this report.

COVID-19 treatment capacity

Treatment capacity was constrained principally by the number of available beds. ICU beds are especially important for the treatment of critical COVID-19 cases, as they are equipped to provide consistent oxygen therapy at higher flow rates, as well as mechanical ventilation.[c,2] Table 1 shows total and ICU bed counts across health facilities, broken down by region.

Table 1. Bed counts, by region.

Region	Number of facilities surveyed	Total beds per region*	Intensive care beds
Dakar	13	927	26
Diourbel	2	156	9
Fatick	1	23	3
Kaffrine	1	29	7
Kaolack	1	17	2
Kolda	1	43	0
Louga	1	10	0
Matam	1	28	4
Saint-Louis	1	62	12
Sédhiou	1	33	0
Tambacounda	1	60	2
Thiès	3	373	2
Ziguinchor	2	50	4
Grand total	**29**	**1,811**	**71**

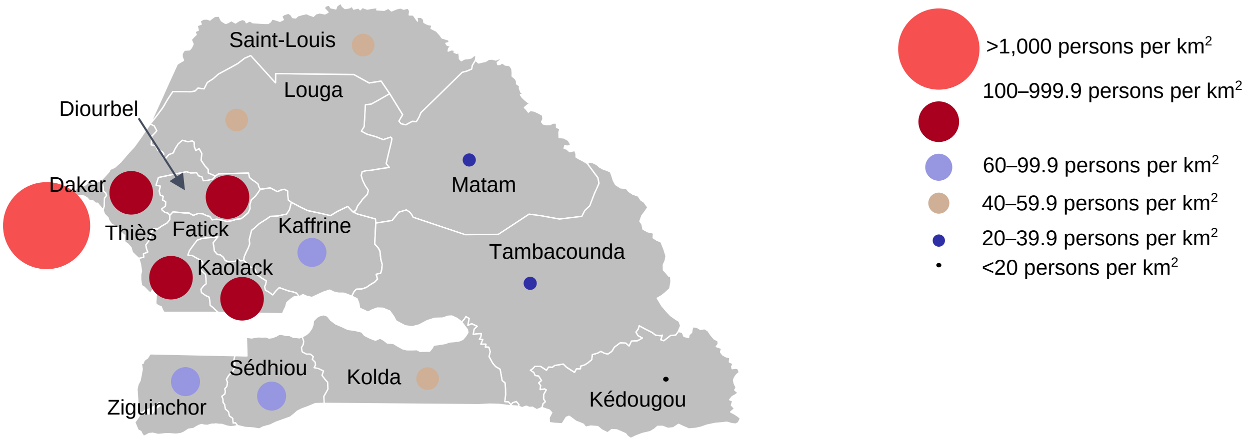
*Note: total beds per region includes both general and intensive care unit (ICU) beds.

The higher-density regions of Dakar, Diourbel, and Thiès (Figure 2 below) had the highest numbers of total available beds and total ICU beds (Table 1). The number of ICU beds was limited in the identified COVID-19 treatment centers in Senegal, accounting for only 4% of total surveyed beds (71 ICU beds/1,811 total beds), or 0.43 beds per 100,000 people. This is in sharp contrast to the Organisation for Economic Co-operation and Development average of 12 ICU beds/100,000 people.[3] Within Dakar, 10 of the 26 available ICU beds were located at Réanimation Cuomo, an ICU-only facility designated for critical COVID-19 cases. Three regions (Kolda, Louga, and Sédhiou), with a total population of 2,382,231 (see Table 2 below), reported no ICU beds.

These findings suggest that overall treatment capacity for severe and critical COVID-19 patients was limited at the time of data collection by both ICU bed capacity and geographic availability of beds.

c. High-flow oxygen therapy requires up to 70 liters per minute.

Figure 2. Senegal population density, by region.



Source: Agence Nationale de la Statistique et de la Démographique, Division des Statistiques Démographiques et Sociales. *Population du Sénégal 2018*. Dakar: Ministère de l'Economie, du Plan et de la Coopération; 2019. http://www.ansd.sn/ressources/publications/Rapport_population_060219%20002%20RECsn%20.pdf.

Table 2. Population statistics for all 14 regions of Senegal.

Region	Population (2019)	Percentage of total population
Dakar	3,732,282	23%
Diourbel	1,801,999	11%
Fatick	870,361	5%
Kaffrine	703,560	4%
Kaolack	1,155,433	7%
Kolda	796,581	5%
Louga	1,032,644	6%
Matam	706,042	4%
Saint-Louis	1,063,539	7%
Sédhiou	553,006	3%
Tambacounda	841,512	5%
Thiès	2,105,711	13%
Ziguinchor	662,179	4%
Kédougou*	184,276	1%

*Note: no facilities in Kédougou were surveyed for this study.

Source: Agence Nationale de la Statistique et de la Démographique, Division des Statistiques Démographiques et Sociales. *Population du Sénégal 2019*. Dakar: Ministère de l'Economie, du Plan et de la Coopération; 2020. https://www.ansd.sn/ressources/publications/Rapport%20population_final%2006mai2020.pdf.

Facility infrastructure and staffing

While bed counts are important for evaluating health facility treatment capacity, additional health facility characteristics can impact effective utilization of beds. Characteristics such as the type of electricity source can limit treatment capacity if using oxygen delivery devices that require power, such as oxygen concentrators. ICU beds that rely on piped medical oxygen may be constrained by the number of wall units installed in that ward. Furthermore, oxygen therapy and patient ventilation require trained clinical staff, including specialized training to safely intubate patients. Tables 3 through 5 summarize collected data on electricity sources, use of piped oxygen, and health facility staff.

Table 3. Electricity sources across facilities.

Electricity source	Number of facilities
Both central grid and generator	23
Central electricity grid only	6

Table 4. Use of piping systems in Senegal.

Piping system	Number of facilities
No piping system	13
Piping system for oxygen	10
Piping system for oxygen, air	1
Piping system for oxygen, air, vacuum	4
Unknown	1

Table 5. Health facility staff with experience in mechanical ventilation and/or intubation.

Staff training	Number of facilities that reported trained staff
Staff with experience in invasive mechanical ventilation and/or intubation	16

Most health facilities surveyed rely on electricity from a central grid with generator backup. About half of the facilities surveyed reported having a piping system for medical oxygen. Among the subset of 19 facilities with a pressure swing adsorption (PSA) plant, four facilities—Centre Hospitalier Régional de Kolda, Centre Hospitalier Régional de Tambacounda, Centre Hospitalier de l'Ordre de Malte, and Centre Hospitalier Régional de Ziguinchor—lacked piping systems.

Just more than half of facilities (16/29, 55%) reported having staff with experience with mechanical ventilation or intubation; however, the number of trained staff per facility was not quantified. Subsequent data collection, using the WHO assessment of human resources for health[d] to understand human resources constraints, could be deployed to learn more about these needs. This survey could also assess the skills capacity for each facility to effectively assess the quality of the management, maintenance, and installation of the equipment.

[d] WHO Assessment of Human Resources for Health: https://www.who.int/hrh/tools/hrh_assessment_guide.pdf?ua=1

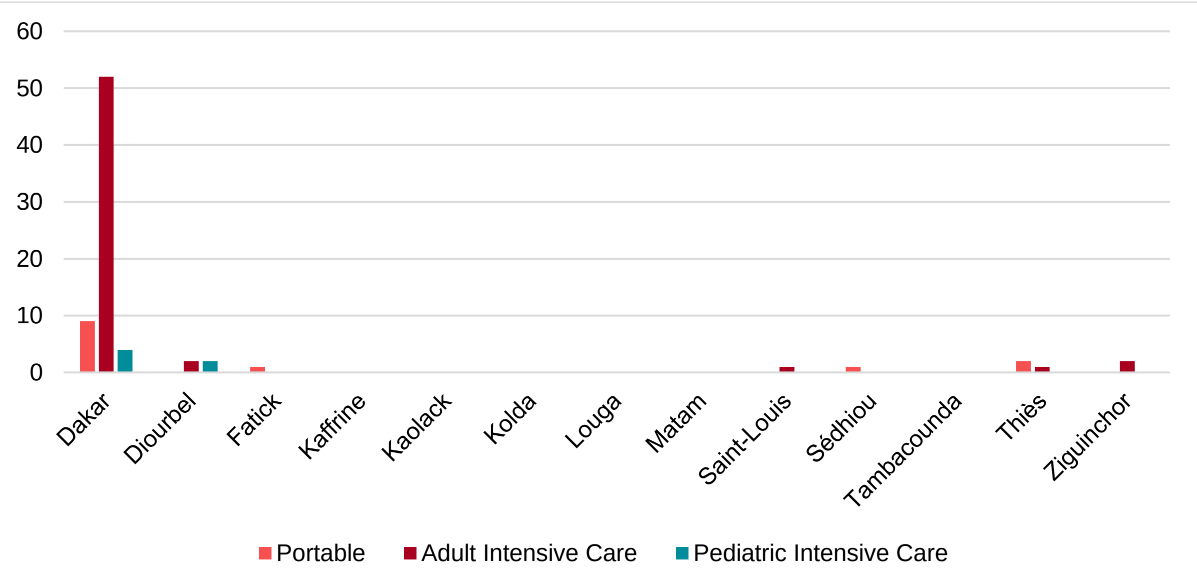
Oxygen delivery equipment

The facility survey quantified existing functional and nonfunctional respiratory care equipment of various device types. The following types of equipment facilitate the delivery of oxygen therapy to the patient, and include ventilators, pulse oximeters, and patient monitors.

Ventilators

Ventilators pump air with supplemental oxygen into a patient's airways in cases of severe respiratory distress during which they are unable to breathe on their own.[4] Ventilators require a patient to be intubated. They have been instrumental in keeping critically ill patients alive. The survey team collected data on various types, including portable ventilators, pediatric intensive care ventilators, and adult intensive care ventilators. Figure 3 quantifies functional ventilators by type, across the surveyed regions. It is important to note that proper intubation and operation of a ventilator requires a high level of training and patient supervision.

Figure 3. Functional ventilators, by type and region.



Only 77 functional ventilators were reported across all 29 surveyed COVID-19 treatment centers. Thirteen facilities reported carrying functional ventilators with the remaining 16 possessing none. Additionally, ventilators were unequally distributed across the regions: 84% (65/77) of all reported ventilators were deployed at facilities in Dakar. Facilities surveyed in six regions (Kaffrine, Kaolack, Kolda, Louga, Matam, and Tambacounda) reported no functional ventilators. This finding implies that none of the 15 reported ICU beds across those regions had mechanical ventilation capabilities.

Five additional ventilators, all located in Dakar, were reported to be nonfunctional.

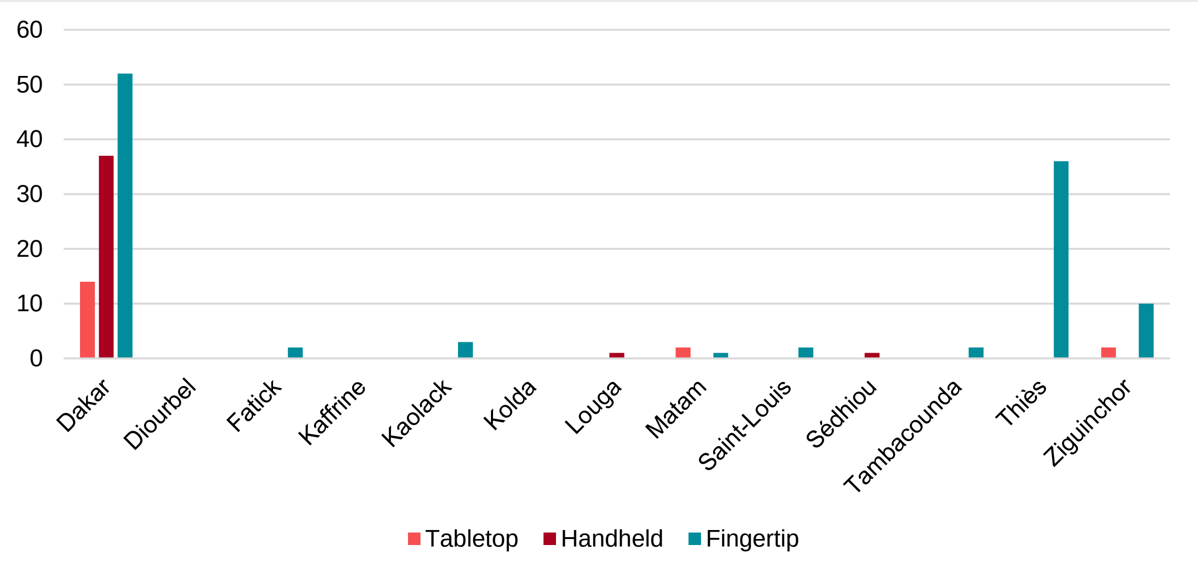
Procuring additional ventilators may allow more critically ill patients to be treated; however, it is important to note that these devices are expensive and require significant staff training and maintenance. Among the 13 facilities with ventilators, 9 reported having staff trained on invasive ventilation techniques. Hence, even if ventilators are available in the remaining 4 facilities, there may not be appropriate staff to use them. Moreover, patient monitors and pulse oximeters should be procured and paired with these devices for safe oxygen administration. Increasing the number of staff trained in invasive mechanical ventilation and intubation would increase the number of patients with access to this critical potentially lifesaving treatment.

Pulse oximeters

Pulse oximeters and multimodal devices (patient monitors equipped with functions such as electrocardiogram [ECG], oxygen saturation, etc.) are critical to safe oxygen administration.[e] These devices help to monitor the level of oxygen in a patient's blood and alert the health care worker if the oxygen level drops below a safe threshold. This allows for timely identification of hypoxemia and an opportunity for a health care worker to intervene and prevent a patient from decompensating further and risking vital organ damage. These devices are essential in any setting in which a patient receives oxygen—surgery, emergency and intensive care, treatment, and recovery—and for treatment of respiratory diseases, including but not limited to COVID-19.

The survey team collected data on three types of pulse oximeters: fingertip, tabletop, and handheld. Fingertip and handheld devices were the most common across facilities; however, the total count of devices was low, considering it is recommended that pulse oximetry be available when administering oxygen therapy.[5] Similar to ventilators, pulse oximeters were unequally distributed across facilities, with 62% (103/165) being held by facilities in Dakar (Figure 4). Facilities in the regions of Diourbel, Kaffrine, and Kolda reported no inventory of pulse oximeters.

Figure 4. Functional pulse oximeters, by type and region.

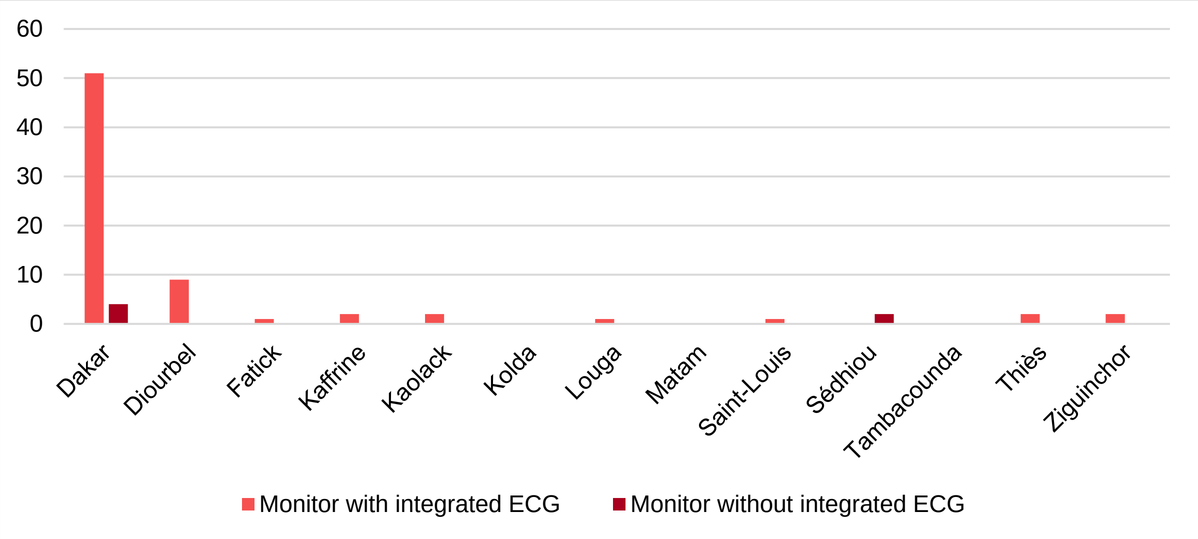


Patient monitors

Similar to pulse oximeters, patient monitors provide measurements of patient vital signs that are critical for health care workers to make effective decisions on patient care, including delivery of oxygen therapy. There were two types of patient monitors surveyed: monitors with integrated ECG and monitors without ECG. Figure 5 compares counts of patient monitors by type across regions and nationally.

e. Recent studies have suggested that clinical guidance should include consideration of the effect of skin pigmentation on pulse oximetry measurement accuracy. As pulse oximetry is expanded, efforts should be made to identify and disseminate the most recent clinical recommendations for patient care, to effectively treat all patients: https://www.nejm.org/doi/full/10.1056/NEJMc2029240.

Figure 5. Functional patient monitors, by type and region.



Abbreviation: ECG, electrocardiogram.

Patient monitors with integrated ECG were significantly more prevalent in health facilities than monitors without ECG. This is helpful to note, as it might demonstrate that ECG is a desired device feature. Similar to pulse oximeters and ventilators, the majority of patient monitors (71%) were held by facilities in Dakar—despite the survey showing Dakar as having only 45% of facilities and 51% of beds. This shows patient monitors were unequally distributed across facilities and that there was a significant need to procure both pulse oximeters and patient monitors to increase the ability to safely administer oxygen therapy. Such increases would, however, need to be paired with the requisite staffing and training.

The survey team also collected data on several other device types that facilitate oxygen therapy, including bilevel positive airway pressure, high-flow nasal cannula, and suction devices. Observations on these devices are not included here but can be requested from PATH.

Oxygen production equipment and supply

This section quantifies equipment that can produce and store oxygen for patient care. This includes oxygen concentrators and PSA plants, which can purify atmospheric oxygen for medical use, as well as oxygen cylinders, which store medical oxygen.

With the exception of Sédhiou, where a PSA plant is planned for construction, all surveyed regions have at least one PSA oxygen plant. Dakar, the national capital, has eight plants.

Liquid oxygen is not available in any of the COVID-19 treatment centers in Senegal.

Table 6 summarizes the availability of oxygen equipment in the surveyed regions.

Table 6. Availability of oxygen equipment, by region.

Region	Number of facilities surveyed	Liquid oxygen tanks	Pressure swing adsorption oxygen plants	Oxygen cylinders (liters available weekly)	Oxygen concentrators
Dakar	13	–	8	8,500	12
Diourbel	2	–	1	0	0
Fatick	1	–	1	0	0
Kaffrine	1	–	1	1,360	0
Kaolack	1	–	1	1,700	3
Kolda	1	–	1	0	0
Louga	1	–	1	0	0
Matam	1	–	1	0	0
Saint-Louis	1	–	1	0	0
Sédhiou	1	–	–	0	5
Tambacounda	1	–	1	0	0
Thiès	3	–	1	1,360	2
Ziguinchor	2	–	1	0	1
Total	**29**	**–**	**19**	**12,920**	**23**

While oxygen is available in at least one COVID-19 treatment center per region, it does not necessarily mean that oxygen can be safely delivered to patients. Safe delivery of oxygen is highly dependent on availability of equipment such as flowmeters and humidifiers, as well as consumables such as nasal cannulae and oxygen masks.

Oxygen concentrators

Oxygen concentrators are devices that take in ambient air, compress the air, and filter out nitrogen to supply purified oxygen. These devices allow for provision of oxygen to patients in wards without centralized piping systems and can be easily moved. However, concentrators require a reliable source of electricity to function. Oxygen provided via concentrators in certain circumstances can be shared between multiple patients depending on concentrator model, output volume, and patient type. Although concentrators provide a reliable source of oxygen, they are dependent on electricity and require regular maintenance to provide quality oxygen, which often pose challenges for their use in facilities as these devices age.

The survey team collected data on oxygen concentrators of various sizes, including 3, 5, 8, 10, and greater than 10 liters per minute (LPM). Table 7 shows the number of functional and nonfunctional oxygen concentrators by region, as well as the national total. Table 8 shows the distribution of functional oxygen concentrators by type, by region.

Table 7. Availability and functionality of oxygen concentrators, by region.

Region	Functional concentrators	Nonfunctional concentrators
Dakar	12	3
Diourbel	0	0
Fatick	0	0
Kaffrine	0	0
Kaolack	3	0
Kolda	0	0
Louga	0	0
Matam	0	0
Saint-Louis	0	0
Sédhiou	5	0
Tambacounda	0	0
Thiès	2	0
Ziguinchor	1	0
National	**23**	**3**

Table 8. Availability of functional oxygen concentrators by type, by region.

Region	3 LPM	5 LPM	8 LPM	10 LPM	>10 LPM
Dakar	0	10	0	0	2
Diourbel	0	0	0	0	0
Fatick	0	0	0	0	0
Kaffrine	0	0	0	0	0
Kaolack	0	3	0	0	0
Kolda	0	0	0	0	0
Louga	0	0	0	0	0
Matam	0	0	0	0	0
Saint-Louis	0	0	0	0	0
Sédhiou	0	5	0	0	0
Tambacounda	0	0	0	0	0
Thiès	0	2	0	0	0
Ziguinchor	1	0	0	0	0
National	**1**	**20**	**0**	**0**	**2**

Functional concentrators were located in only five of the regions surveyed (Dakar, Kaolack, Sédhiou, Thiès, and Ziguinchor), with more than half of those located in Dakar. Oxygen concentrators of size 5 LPM, which are suitable for most patients, were the most prevalent across all surveyed regions. For severe and critical COVID-19 patients, WHO recommends high flow rates (upward of 10 LPM). Dakar is the only region to report concentrators with more than 5 LPM capacity (2/12). Overall, high-flow concentrators (>5 LPM) were reported in short supply across all regions.

Oxygen cylinders

Oxygen cylinders are metal canisters that require regular refills at a centralized depots or facility-based plants with cylinder filling capacity, and require routine distribution, often over long distances. They require minimal maintenance and no electricity, making them a suitable oxygen source in some settings with insufficient infrastructure (e.g., access to reliable electricity). However, to be of any value in providing oxygen therapy, a reliable, consistent supply chain and logistics system should be in place to provide refills. Like other oxygen delivery and production devices, they depend on availability of oxygen consumables, such as masks, tubing, and cylinder assembly units to facilitate oxygen delivery.

The facility assessment established that the total number of cylinders in Senegal among surveyed facilities was limited, with only 25 cylinders reported nationwide. Moreover, a majority of the cylinders (13/25) were located at facilities in Dakar. Given low cylinder and concentrator counts, it is possible that facilities relied primarily on oxygen generated by the co-located PSA plant to meet oxygen needs.

It is important to note, however, that 13 facilities reported no piping infrastructure and thus would require concentrators or cylinders to supply oxygen to patients. Table 9 shows quantities of cylinders by size and connection type in each region.

Table 9. Counts of oxygen cylinders, by size and connection type, in each region.

Region	Size D (340 L) pin-index	Size D (340 L) bullnose	Size E (680 L) pin-index	Size E (680 L) bullnose	Size F (1,360 L) pin-index	Size F (1,360 L) bullnose	Size G (3,400 L) pin-index	Size G (3,400 L) bullnose	Size J (6,800 L) pin-index	Size J (6,800 L) bullnose
Dakar	–	13	–	2	–	2	–	–	–	–
Diourbel	–	–	–	–	–	–	–	–	–	–
Fatick	–	–	–	–	–	–	–	–	–	–
Kaffrine	–	–	–	–	1	–	–	–	–	–
Kaolack	5	–	–	–	–	–	–	–	–	–
Kolda	–	–	–	–	–	–	–	–	–	–
Louga	–	–	–	–	–	–	–	–	–	–
Matam	–	–	–	–	–	–	–	–	–	–
Saint-Louis	–	–	–	–	–	–	–	–	–	–
Sédhiou	–	–	–	–	–	–	–	–	–	–
Tambacounda	–	–	–	–	–	–	–	–	–	–
Thiès	–	–	2	–	–	–	–	–	–	–
Ziguinchor	–	–	–	–	–	–	–	–	–	–
National total	**5**	**13**	**2**	**2**	**1**	**2**	**0**	**0**	**0**	**0**

Size “D” cylinders were the most common, although all observed size “D” cylinders were concentrated in facilities in Dakar and Kaolack. There was a mix of other sizes across regions. Overall, bullnose assemblies were more common than pin-index in Senegal.

Pressure swing adsorption plants

Pressure swing adsorption plants are health facility–based factories that use pressure to separate oxygen from the atmosphere and purify it to medical grade oxygen. They operate using the same technology as oxygen concentrators but at a much larger scale. In all, 19 of the 29 surveyed facilities reported having access to an on-site PSA oxygen plant, which indicates significant reliance on PSA plants to meet oxygen needs. Table 10 highlights these 19 facilities and some key details about their PSA plants. Unfortunately, not all specifics were available for each facility.

Table 10. Facilities with pressure swing adsorption plants.

Region	Facility	Model	Maximum production capacity of the plant in cubic meters per hour	Average consumption per month in cubic meters	Piping
Dakar	Bouffler	–	39 Nm^3/H	600 m^3	Yes – oxygen
	CTEpi Fann	Mil's	5 Nm^3/H	–	Yes – oxygen
	Hôpital d'Enfant Diamniadio	Yuwell 7G-10A	10 Nm^3/H	577 m^3	Yes – oxygen
	Réanimation Cuomo	Mil's	5 Nm^3/H	–	Yes – oxygen, air, vacuum
	Hôpital Général Idrissa Pouye	–	21 Nm^3/H	–	Yes – oxygen, air
	Centre Hospitalier de l'Ordre de Malte	–	7 Nm^3/H	150 m^3	No
	Hôpital Aristide le Dantec	Mil's	7 Nm^3/H	–	Yes – oxygen
	Hôpital Dalal Jamm	Novair Premium 300 HF	63 Nm^3/H	–	Yes – oxygen, air, vacuum
Diourbel	Mathlaboul Fawzeini	Mil's	15 Nm^3/H	1,200 m^3	Yes – oxygen
Fatick	Centre Hospitalier Régional de Fatick	Carrefour Medical	14 Nm^3/H	–	Yes – oxygen, air, vacuum
Kaffrine	Etablissement Publique de Santé Niveau 1	–	5 Nm^3/H	–	Yes – oxygen
Kaolack	Hôpital Régional Elhadj Ibrahima Niass	Mil's	7 Nm^3/H	–	Yes – oxygen
Kolda	Centre Hospitalier Régional de Kolda	Mil's Rifair	10 Nm^3/H	–	No
Louga	Centre Hospitalier Régional Amadou Sakhir Mbaye de Louga	Mil's	21 Nm^3/H	–	Yes – oxygen
Matam	Hôpital Regional de Matam	Mil's	10 Nm^3/H	–	Yes – oxygen, air, vacuum

Region	Facility	Model	Maximum production capacity of the plant in cubic meters per hour	Average consumption per month in cubic meters	Piping
Saint-Louis	Centre Hospitalier Régional de Saint-Louis	Mil's	14 Nm^3/H	–	Yes – oxygen
Tambacounda	Centre Hospitalier Régional de Tambacounda	–	21 Nm^3/H	–	No
Thiès	Hôpital El Hadji Amadou Sakhir Ndjiéguène	Mil's PRO2XY, OX7, PM2	7 Nm^3/H	–	Yes – oxygen, vacuum
Ziguinchor	Centre Hospitalier Régional de Ziguinchor	–	21 Nm^3/H	–	No

Nearly all regions surveyed (12/13) reported having a facility with a PSA plant. Notably, Hôpital Dalal Jamm had significantly higher capacity than other facilities, as it was the largest surveyed facility in Dakar. Most facilities with on-site plants (15/19) reported being piped for bedside oxygen delivery. A key immediate priority would be to pipe the remaining 4 facilities to improve oxygen accessibility within a facility and reduce the need for refilling of cylinders. A majority of the surveyed PSA plants were manufactured by the French company Mil's, which is certified by the International Organization for Standardization.

Oxygen consumables

Oxygen consumables are devices or oxygen delivery interfaces that facilitate administration of oxygen therapy to the patient. Because consumables are not durable, reusable devices, their availability can greatly fluctuate over time. For this report, the consumable quantities observed present a snapshot in time and could be lower or higher than average availability for an individual facility, depending on whether that facility had recently ordered new inventory. Examining consumable quantities across districts and nationally helps to stabilize this variation. The study did not obtain trends of consumable stockouts for facilities, and therefore cannot make observations about other important variables, such as average availability for specific consumables. Table 11 highlights some key oxygen consumables across the regions of Senegal.

Table 11. Quantities of oxygen consumables, by region.

Region	Nasal cannula / prongs - adult	Nasal cannula / prongs - pediatric	Nasal cannula / prongs - neonate	Nasal catheter - adult	Nasal catheter - pediatric	Nasal catheter - neonate	Oxygen mask - adult	Oxygen mask - pediatric
Dakar	80	35	10	1	0	0	82	30
Diourbel	4	0	0	0	0	0	6	0
Fatick	0	0	0	0	0	0	3	0
Kaffrine	0	0	0	0	0	0	0	0
Kaolack	0	0	0	0	0	0	0	0
Kolda	0	0	0	0	0	0	0	0
Louga	0	0	0	0	0	0	2	0
Matam	0	0	0	0	0	0	0	0
Saint-Louis	0	0	0	0	0	0	0	0
Sédhiou	0	0	0	0	0	0	0	0
Tambacounda	0	0	0	0	0	0	0	0
Thiès	0	0	0	2	2	0	0	0
Ziguinchor	0	0	0	0	0	0	10	6
Grand total	**84**	**35**	**10**	**3**	**2**	**0**	**103**	**36**

Facilities in Dakar held the overwhelming majority of oxygen delivery consumables. Overall, cannula and oxygen masks were significantly more prevalent than nasal catheters at the time of the assessment. Comparing the relationship of oxygen consumables to oxygen delivery equipment is important in evaluating how effectively medical equipment is being used in facilities. For instance, if a facility has a very large number of oxygen concentrators, but very few masks for oxygen delivery, then treatment capacity is constrained. The lack of consumables reported in regions other than Dakar is highly concerning. Facilities with shortages may be forced to ration or reuse consumables, and reusing them has significant cross-contamination/cross-infection risks. Additionally, even though a facility has adequate oxygen gas supply, without adequate consumables, patients may be unable to actually receive oxygen therapy.

Estimates of national respiratory care needs

A key purpose of the biomedical facility assessment was to provide data to estimate countrywide COVID-19 oxygen and respiratory care needs. The PATH team used the data to model scenarios and evaluate gaps in respiratory care availability in the sampled facilities in order to enable policymakers to make data-driven decisions regarding respiratory care equipment and medical oxygen distribution systems in response to COVID-19. The model estimates the gap between existing respiratory care delivery capacity in Senegal and the oxygen delivery capacity required to respond to a six-month COVID-19 outbreak at varying levels of severity.

Respiratory care for COVID-19 is more complex than traditional oxygen provision. Severe and critical COVID-19 patients often require high flow rates of oxygen over prolonged periods of time, as well as mechanical ventilation. In addition, patients need to be placed under consistent surveillance by health care workers to ensure that treatment can be adjusted in the event of further decompensation. As such, a significant amount of oxygen and durable and consumable respiratory care equipment is required.

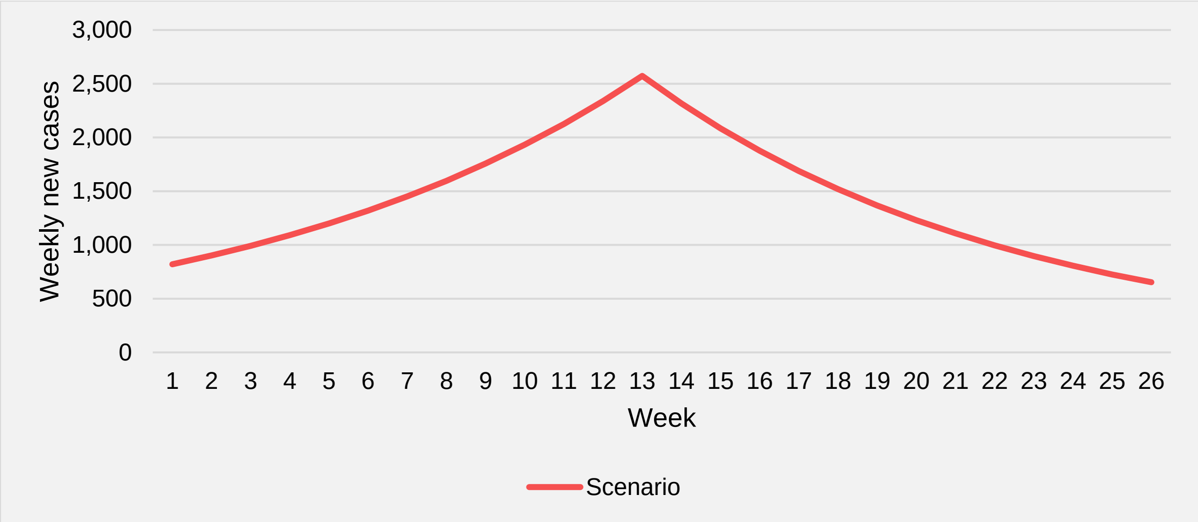
Modeled results

In agreement with the Senegal COVID-19 Emergency Operations Center, a six-month hypothetical COVID-19 outbreak scenario peaking at 2,573 new cases per week was selected to be modeled. Under this scenario, a significant gap in available equipment to treat COVID-19 patients was estimated. Moreover, under current designated ICU capacity for critical COVID-19 patients (36 beds), the model concluded that a significant number of patients requiring ICU care would be unable to access it due to capacity having been reached. National oxygen production capacity was estimated to exceed predicted need, although individual facilities may still face gaps depending on facility oxygen availability. If ICU capacity were expanded, then additional provision of oxygen would be required to account for additional patients receiving ICU care.

Peak weekly oxygen need during the hypothetical outbreak was estimated at 34,372,800 liters (see Appendix B for methodology). At this level, all 36 surveyed COVID-19-designated ICU beds would be filled with critical patients, and 233 COVID-19-designated general beds would be filled with severe COVID-19 patients. Maximum weekly supply was estimated to be 51,984,680 liters, assuming all PSA plants were 100% operational, available cylinders were filled, and concentrators were functional.

Figure 6 shows the hypothetical six-month outbreak that was modeled for this gap assessment.

Figure 6. New cases per week over a six-month (26-week) hypothetical COVID-19 outbreak scenario.

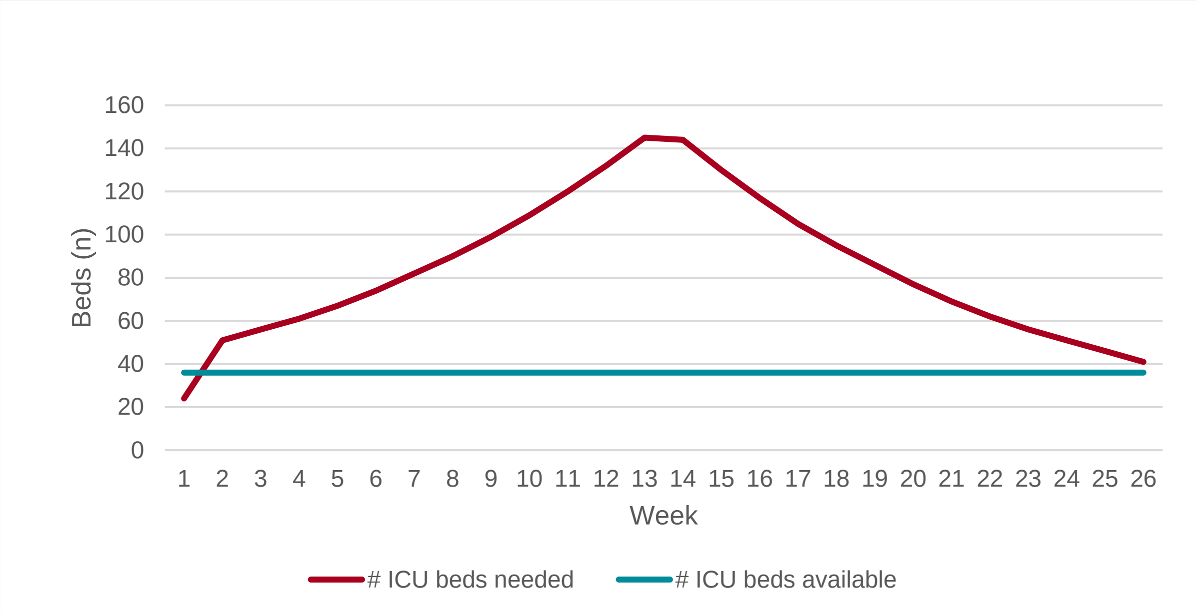


PATH predicted the number of COVID-19 cases in Senegal over the next six months by utilizing available data on cases in the country up to January 4, 2021. Cases per week were forecasted to grow at 10% until the midpoint of the forecasted outbreak, at which time, they would decline by a predicted 10% per week. The total number of new COVID-19 cases for the base scenario was 37,365, with a maximum of 2,573 new cases in week 13. Data on COVID-19 case progression was provided by the Senegal Ministry of Health Emergency Operations Center. The forecasted outbreak is meant to serve as a guide for determining gaps in bed, oxygen, and equipment availability, and is not an epidemiological projection of future COVID-19 cases.

National equipment, bed, and oxygen needs in this scenario were estimated using a model that presumed that 19% of active COVID-19 cases at any given point would require hospitalization,[6] and 41% of hospitalized patients would require some degree of oxygen therapy.[7] Of the cases that would require oxygen, 62% were presumed to be in the “severe” category, requiring 10 LPM of oxygen for six days. The remaining 38% were presumed to be in the “critical” category, requiring mechanical intubation with 30 LPM of oxygen for 14 days.[8] This case flow framework was developed using available literature by PATH and input from PATH stakeholders. Further specifications of this framework are available in Appendix B. Additionally, per Emergency Operations Center guidance, only 30% of surveyed general beds and 50% of surveyed ICU beds were dedicated to COVID-19 patient care. This equates to 522 general beds and 36 ICU beds.

Figure 8 contrasts ICU availability with need over the course of the outbreak, highlighting the lack of available ICU beds. Beyond the first week of the hypothetical outbreak, there would be a shortfall in ICU bed availability. This is of significant concern, as it indicates that ICU capacity is not adequate to meet patient demand.

Figure 7. Intensive care unit bed capacity versus needs over the course of a hypothetical six-month (26-week) outbreak.



Abbreviation: ICU, intensive care unit.

The tables below outline respiratory care equipment availability nationwide at the time of the survey and estimate the shortfall in equipment to adequately service beds at surveyed facilities.

Table 12 shows durable equipment (reusable for care of multiple patients), and Table 13 shows consumable equipment (usable for treatment of only a single patient).

As indicated in prior sections, health facilities of various levels across 13 of 14 regions of Senegal were surveyed by PATH to quantify ICU bed capacity, current oxygen production capacity, and availability of essential respiratory care equipment for treating COVID-19 patients.[f] Information was not collected on every piece of equipment in the essential equipment list during the biomedical equipment survey, so where data were unavailable, the model assumed there were zero pieces of that equipment type. There were significant shortages of both durable and consumable pieces of equipment, implying that despite there being adequate medical oxygen availability to manage a COVID-19 outbreak, there is limited capacity to deliver the oxygen to patients.

f. Essential equipment for COVID-19 treatment was defined by the World Health Organization COVID-19 Essential Supplies Forecasting Tool: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/covid-19-critical-items.

Table 12. Durable equipment supply gaps.

Equipment *(Devices marked with an "*" were not recorded during data collection; availability assumed to be 0)*	**Nationwide**		
	Current equipment availability	**Equipment needed to fully supply beds**	**Estimated equipment shortfall**
Infrared thermometer*	0	9	9
Pulse oximeter (adult + pediatric probes)	77	179	102
Patient monitor, multiparametric with ECG, with accessories	6	50	44
Patient monitor, multiparametric without ECG, with accessories	475	33	0
Oxygen source (concentrator, cylinder, or pipe supply)	55	179	124
Laryngoscope (direct or video type)	77	34	0
Patient ventilator, intensive care, with breathing circuits and patient interface	19	34	15
CPAP, with tubing and patient interfaces, with accessories	83	9	0
High-flow nasal cannula, with tubing and patient interfaces	77	9	0
Electronic drop counter, intravenous fluids*	0	129	129
Infusion pump*	0	33	33
Blood gas analyzer, portable, with cartridges and control solutions*	0	5	5
Ultrasound, portable, with transducers and trolley*	0	5	5
Drill for vascular access, with accessories and transport bag*	0	5	5
Electrocardiograph, portable, with accessories*	0	5	5
Suction pump	92	83	0
Bubble humidifier, non-heated*	0	142	142
Tubing, medical gases, internal diameter 5 mm*	0	5	5
Flow splitter, 5 flowmeters 0–2 LPM, for pediatric use	0	5	5
Flowmeter, Thorpe tube, for piped oxygen 0–15 LPM	180	17	0
Conductive gel, container*	0	64	64
Catheter, nasal, 40 cm, with lateral eyes, sterile, single use; sizes: 10 Fr, 12 Fr, 14 Fr, 16 Fr, 18 Fr	5	158	153
Compressible, self-refilling ventilation bag, capacity >1,500 mL, with masks (small, medium, large)	57	17	0

Abbreviations: CPAP, continuous positive airway pressure; ECG, electrocardiogram; LPM, liters per minute.

Table 13. Consumable equipment supply gaps.

Equipment *(Devices marked with an "*" were not recorded during data collection; availability assumed to be 0)*	**Nationwide**		
	Current equipment availability	**Equipment needed to fully supply beds**	**Estimated equipment shortfall**
Nasal oxygen cannula, with prongs, adult and pediatric	119	1,252	1,133
Mask, oxygen, with connection tube, reservoir bag, and valve; high-concentration single use (adult)	103	1,252	1,149
Venturi mask, with percent oxygen lock and tubing (adult)	0	1,252	1,252
Airway, nasopharyngeal, sterile, single use, set, sizes of 20 Fr, 22 Fr, 24 Fr, 26 Fr, 28 Fr, 30 Fr, 32 Fr, 34 Fr, 36 Fr	0	1,700	1,700
Airway, oropharyngeal, Guedel, set, sizes of No. 2 (70 mm), No. 3 (80 mm), No. 4 (90 mm), No. 5 (100 mm)	97	1,700	1,603
Colorimetric end-tidal carbon dioxide detector, single use, adult	12	1,700	1,688
Cricothyrotomy, set, emergency, 6 mm, sterile, single use*	0	850	850
Endotracheal tube introducer	211	1,700	1,489
Tube, endotracheal	211	1,700	1,489
Laryngeal mask airway	5	1,700	1,695
Lubricating jelly for critical patient gastroenteral feeding and airway management and intubation*	0	64	64
Filter, heat, and moisture exchanger, high efficiency, with connectors, adult*	0	2,525	2,525

Conclusion and policy recommendations

The data collected through this biomedical equipment assessment yield new insight into the respiratory care treatment capacity of health facilities across Senegal. This report provides a view into availability of oxygen delivery equipment, oxygen production equipment, and consumables that are critical to providing respiratory care treatment for COVID-19 and beyond. Understanding the availability of respiratory care equipment is the first step in accurately estimating the gap in equipment supply and understanding health facility capabilities and limitations for treating COVID-19 patients. An overall scarcity of critical equipment and unequal distribution across surveyed facilities was observed in Senegal. Equitable allocation of new equipment will be a more complex task than simply purchasing equipment to fill the gap and then dividing it between facilities.

Key recommendations for next steps:

- Contrast distribution of equipment observed in this report against needs in different regions and develop plans to reallocate or procure additional equipment to address needs.
- Utilize the gap analysis and oxygen need estimation to develop costed operational plans to increase the availability of respiratory care equipment.
- Develop specific requests and advocacy directed to donors and partners to backstop potential budget shortfalls.
- Use the WHO Assessment of Human Resources for Health[9] tool to calculate human resources constraints on the effective delivery of health care. The survey could also assess the skills capacity of each facility, allowing for insight into the quality of equipment management, installation, and maintenance.
- Review existing PSA infrastructure and ensure that plants are able to run at maximum capacity and have maintenance contracts in place.
- Further collect data on respiratory care service capacity through an expanded facility assessment.
- Estimate long-term national oxygen need inclusive of COVID-19 and non-COVID-19 respiratory care, to contribute to the development of a national oxygen infrastructure development policy (oxygen road map).
- Determine absorptive capacity for liquid oxygen as a part of a future oxygen supply system.

[9] WHO Assessment of Human Resources for Health: https://www.who.int/hrh/tools/hrh_assessment_guide.pdf?ua=1

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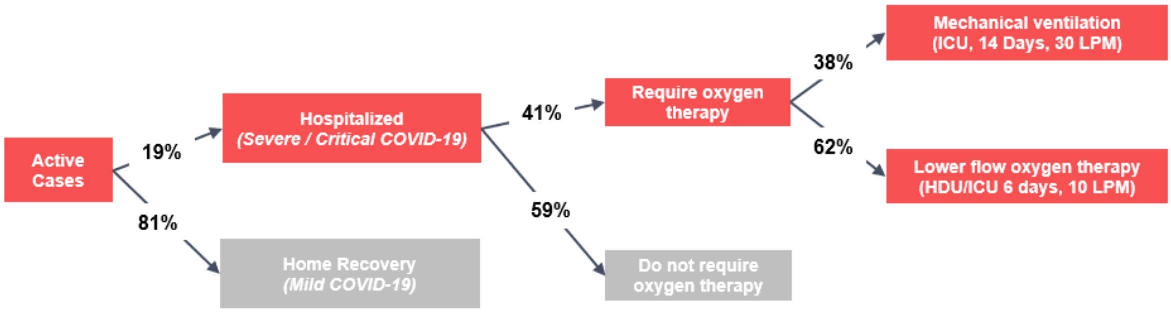
Appendix A. List of surveyed health facilities by region

Region	Health facilities
Dakar	Hangar
	Bouffler
	CTEpi Fann
	Hôpital d'Enfant Diamniadio
	Réanimation Cuomo
	Hôpital Général Idrissa Pouye
	Centre Hospitalier de l'Ordre de Malte
	Hôpital Aristide Le Dantec
	Hotel Novotel
	Centre de Prise en Charge Extra Hospitalière
	Centre de Santé de Yeumbeul
	Hôpital Dalal Jamm
	Centre Hospitalier National Psychiatrique
Diourbel	Mathlaboul Fawzeini
	Centre de Santé de Bambey
Fatick	Centre Hospitalier Régional de Fatick
Kaffrine	Etablissement Publique de Santé Niveau 1
Kaolack	Hôpital Régional Elhadj Ibrahima Niass
Kolda	Centre Hospitalier Régional de Kolda
Louga	Centre Hospitalier Régional Amadou Sakhir Mbaye de Louga
Matam	Hôpital Régional de Matam
Saint-Louis	Centre Hospitalier Régional de Saint-Louis
Sédhiou	Etablissement Publique de Santé Niveau 1
Tambacounda	Centre Hospitalier Régional de Tambacounda
Thiès	Base Militaire
	Centre Extra Hospitalière de Guéreo
	Hôpital El Hadji Amadou Sakhir Ndjiéguène
Ziguinchor	Kayocoulo
	Centre Hospitalier Régional de Ziguinchor

Appendix B. COVID-19 patient distribution flow



Abbreviations: HDU, high dependency unit; ICU, intensive care unit; LPM, liters per minute.

COVID-19 patient distribution references

Value	Description	Resource
19% of active cases hospitalized	Report of 72,314 COVID-19 cases in China, which indicated 81% of cases were "mild" and 19% were "severe" or "critical," with symptomology likely requiring medical attention.	Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72 314 cases from the Chinese Center for Disease Control and Prevention. *Journal of the American Medical Association*. 2020;323(13):1239–1242. http://doi.org/10.1001/jama.2020.2648.
41% of patients requiring oxygen therapy	Retrospective analysis of 1,099 hospitalized COVID-19 patients in China showing that 41% required oxygen therapy.	Guan W, Ni Z, Hu Y, et al. Clinical characteristics of coronavirus disease 2019 in China. *New England Journal of Medicine*. 2020;382:1708–1720. https://doi.org/10.1056/NEJMoa2002032.
38% of patients on mechanical ventilation	Study conducted at two hospitals in Cape Town, South Africa, following 293 patients treated with high-flow nasal oxygen, found that 38% of patients were eventually intubated and on mechanical ventilation.	Calligaro GL, Lalla U, Audley G, et al. The utility of high-flow nasal oxygen for severe COVID-19 pneumonia in a resource-constrained setting: a multi-centre prospective observational study. *EClinicalMedicine*. 2020:100570. http://doi.org/10.1016/j.eclinm.2020.100570.
6-day duration of nasal oxygen	Study of 244 admitted severe COVID-19 patients in Ethiopia showing a six-day median duration of supplemental oxygen.	Leulseged TW, Hassen IS, Edo MG, et al. Duration of supplemental oxygen requirement and predictors in severe COVID-19 patients in Ethiopia: a survival analysis. *medRxiv* preprint. https://doi.org/10.1101/2020.10.08.20209122.

Value	Description	Resource
	Study conducted at two hospitals in Cape Town, South Africa, following 293 patients treated with high-flow nasal oxygen, found the median duration of oxygenation for successfully treated patients was six days.	Calligaro GL, Lalla U, Audley G, et al. The utility of high-flow nasal oxygen for severe COVID-19 pneumonia in a resource-constrained setting: a multi-centre prospective observational study. *EClinicalMedicine*. 2020:100570. https://doi.org/10.1016/j.eclinm.2020.100570.
	Estimation based on observations at Queen Elizabeth Hospital, Blantyre, Malawi.	Raphael Kazidule Kayambankadzanja, research assistant, College of Medicine, Malawi; intensive care unit nurse, Queen Elizabeth Central Hospital, Blantyre
10 LPM flow rate for oxygenated patients	Estimation based on observations at Queen Elizabeth Hospital, Blantyre, Malawi.	Raphael Kazidule Kayambankadzanja, research assistant College of Medicine, Malawi; intensive care unit nurse, Queen Elizabeth Central Hospital, Blantyre
14-day duration of mechanical ventilation	Netherlands multicenter retrospective study of 553 patients on ventilation found the median duration of ventilation to be 13.5 days.	Botta M, Tsonas AM, Pillay J, et al. Ventilation management and clinical outcomes in invasively ventilated patients with COVID-19 (PRoVENT-COVID): a national, multicentre, observational cohort study. *Lancet Respiratory Medicine*. 2021;9(2):139–148. https://doi.org/10.1016/S2213-2600(20)30459-8.
30 LPM flow rate for ventilator patients	World Health Organization Essential Supplies Forecasting Tool base value.	World Health Organization website. Coronavirus disease (COVID-19) technical guidance: Essential resource planning page. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/covid-19-critical-items.

Abbreviation: LPM, liters per minute.