Surge Capacity: Analysis of Census Fluctuations to Estimate the Number of Intensive Care Unit Beds Needed

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Objective. To compare methods of characterizing intensive care unit (ICU) bed use and estimate the number of beds needed.

Study Setting. Three geographic regions in the Canadian province of Manitoba.

Study Design. Retrospective analysis of population-based data from April 1, 2000, to March 31, 2007.

Methods. We compared three methods to estimate ICU bed requirements. Method 1 analyzed yearly patient-days. Methods 2 and 3 analyzed day-to-day fluctuations in patient census; these differed by whether each hospital needed to independently fulfill its own demand or this resource was shared across hospitals.

Principal Findings. Three main findings were as follows: (1) estimates based on yearly average usage generally underestimated the number of beds needed compared to analysis of fluctuations in census, especially in the smaller regions where underestimation ranged 25–58 percent; (2) 4–29 percent fewer beds were needed if it was acceptable for demand to exceed supply 18 days/year, versus 4 days/year; and (3) 13–36 percent fewer beds were needed if hospitals within a region could effectively share ICU beds.

Conclusions. Compared to using yearly averages, analyzing day-to-day fluctuations in patient census gives a more accurate picture of ICU bed use. Failing to provide adequate “surge capacity” can lead to demand that frequently and severely exceeds supply.

Key Words. Critical care, bed occupancy, resource allocation

Intensive care units (ICUs) are an integral part of all modern health care systems. Because they care for the sickest patients, and because of the high cost of ICU care (Luce and Rubenfeld 2002), it is important to carefully consider the number and operating efficiency of ICU beds. Excess beds waste resources, while too few can render us unable to provide necessary care to some critically ill patients. Consequences of insufficient ICU capacity to handle surges in

demand are magnified in times of epidemics, such as the recent H1N1 influenza epidemic (Helferty et al. 2010).

Challenges to ICU resource planning include limited information about the population incidence of critical illness (Lyons et al. 2000) and the unpredictable timing of critical illness. The latter results in substantial fluctuations in the number of patients in a hospital who need ICU care at any given time (Jenkins, O'Connor, and Cone 2006).

It seems unlikely that the 7-fold variation in ICU beds per capita between industrialized countries reflects commensurate differences in underlying rates of critical illness (Wunsch et al. 2008; Carr, Addyson, and Kahn 2010). In the absence of an effective method for determining the ideal number of ICU beds needed for a given population, such dramatic variation more likely reflects differences in health system organization, including ICU admission, transfer, and discharge practices, and availability of ward and stepdown units to care for patients after the ICU.

From an econometric standpoint, identifying the ideal number of ICU beds involves agreeing upon some metric to optimize. When corporations seek to optimize their functioning, the metric is usually profits, but health care is a different sort of industry (Arrow 1963). Candidate metrics, including health, costs, and cost-effectiveness, are problematic to define and measure. Not only is there no consensus, but a single appropriate metric may not exist.

Nonetheless, in the real world, health care system administrators must decide how many hospital beds to operate, and what they commonly use to make such decisions is information that is regularly collected and reported to them, specifically occupancy rates averaged over long timescales, such as a year (Florida Agency for Health Care Administration 2012; Carney 2011; New Jersey Commission on Rationalizing Health Care Resources 2008;

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Lylwodraeth Cymru Welsh Government 2013). However, because such long-term averages fail to account for fluctuations that occur on shorter time scales of hours to days, they do not accurately represent the dynamic nature of the demand for this resource (Costa et al. 2003; DeLia 2006). In this analysis, we compare the long-term average approach with other methods for describing ICU bed use in populations, using data available to the administrators and policy makers of many health systems. Comparison of these methodologies will facilitate identification of issues relevant to ICU bed planning.

METHODS

We studied ICU occupancy in the Canadian province of Manitoba, which in 2007 had a 1.2 million population, and 118 adult ICU beds in 21 ICUs in 16 hospitals. This work was performed on the deidentified, population-based data repository housed at the Manitoba Centre for Health Policy as part of a larger study on critical illness in Manitoba (Garland et al. 2011). The repository includes clinical data from the Manitoba Integrated Critical Care Database (MICCDB), which accurately identifies admission and discharge timing for ICU patients (Garland et al. 2012).

We evaluated all admissions of Manitobans ≥ 17 years old to adult ICUs, with hospital discharge during seven fiscal years 2000–2006 (April 1, 2000–March 31, 2007) in three of the province's aggregate geographic regions: Winnipeg, North rural, and South rural. The Winnipeg region is an urban center with a population of 646,500 in an area of 600 km², containing 82 ICU beds in 11 ICUs within six hospitals (12.7 beds/100,000 population). The North rural region has a population of 68,300 living in a large, remote area of 378,500 km², and eight ICU beds in three hospitals (11.7 beds/100,000 population). The South rural region has a population of 226,100 living over an area of 61,800 km², and 13 ICU beds in four hospitals (5.7 beds/100,000 population). Each rural hospital has a single ICU of 2–4 beds.

We assessed ICU occupancy using dates and times of ICU admission and discharge in the MICCDB. However, since MICCDB timing for the rural ICUs before 2004 included only dates, we assigned time of ICU admission as noon and ICU discharge as 11:59 if admission and discharge dates were different. For admission and discharge on the same date, we assigned time of ICU admission as noon and ICU discharge as 18:00; this 6-hour interval was chosen because post-2004 it was the mean ICU length-of-stay (LOS) for patients

admitted and discharged on the same date. We calculated ICU LOS as the interval, in fractional days, between ICU admission and discharge. Cumulative patient-days each year was calculated as the sum of all ICU LOS in that year.

ICU admission/discharge timing were used to identify the maximum number of ICU beds simultaneously occupied at any point during a calendar day. This parameter, designated as Daily Peak Bed Occupancy (DPBO), was calculated separately for each day in each hospital, and cumulatively for all hospitals in an aggregate region. Upon request, the authors will supply SAS programming code for performing DPBO calculations from ICU admission and discharge time data.

A key feature in describing ICU bed use is the *level of conglomeration* of individual ICUs. Conglomeration of multiple ICUs indicates that they were considered to function as if they were a single ICU. Therefore, any patient needing admission to an ICU with no empty beds could be admitted to a vacant bed in one of the other related ICUs, even if it was in a different hospital. We always assumed conglomeration of ICUs within a given hospital. For some analyses, we considered conglomeration of ICU beds across hospitals within each aggregate region.

Methods for Describing Regional ICU Bed Use and Estimating Bed Requirements

Method 1: Yearly Patient-Days Method. In each region for each year, we divided cumulative ICU patient-days by 365.25 to obtain annual averages of occupied ICU beds. We then estimated regional ICU bed requirements as average bed occupancy divided by an optimal occupancy rate (Department of Health 2010); using an optimal value of 80 percent, derived from data indicating that higher values are associated with an unacceptable frequency of having to turn patients away due to being full, and worse patient outcomes (Iapichino et al. 2004; McManus et al. 2004).

Method 2: Region-Level DPBO Method. This method considered all ICU beds in a geographic region as shared or conglomerated. For each day, we identified the maximum number of ICU beds simultaneously occupied across a region, the region-level DPBO. The distribution of this parameter reflects the fluctuations in regionally conglomerated ICU bed usage. For example, the 95th percentile of this distribution is the number of simultaneously occupied ICU beds that was exceeded on 5 percent of days during the year (i.e., 18 days). We

calculated the minimum, maximum, median, and various percentiles of the regionally conglomerated DPBO for each year.

Method 3: Hospital-Level DPBO Method. In contrast to Method 2, here each hospital is considered to be a self-contained entity that must fulfill its own ICU demand. For each day, we identified the maximum number of ICU beds simultaneously occupied in a hospital, the hospital-level DPBO. The distribution of this parameter reflects the fluctuations in hospital-conglomerated ICU bed usage. We calculated the minimum, maximum, median, and various percentiles of the hospital-conglomerated DPBO for each year. Though these parameters were hospital specific, we report them by region; that is, the median DPBO for a region was the sum of the median DPBO values for each hospital in that region.

Table 1 shows a simplified example of how Method 2 and 3 differ for 1 week in a hypothetical region with two hospitals, each having four ICU beds. The maximum number simultaneously occupied in the region was six (Method 2). However, as the maximum DPBO for each hospital was four, the region needed eight beds if both hospitals had to independently satisfy their needs (Method 3).

Estimating bed requirements using Methods 2 and 3 requires selecting the acceptable frequency of bed demand exceeding supply, necessitating other arrangements to care for the excess patients, or difficult triage decisions. If having insufficient ICU beds is acceptable 5 percent of the time (18 days a

Table 1: Hypothetical Example over One Week Comparing Daily Peak Bed Occupancy (DPBO) at Two Different Levels of ICU Bed Conglomeration (Methods 2 and 3) in a Region with ICUs in Two Hospitals

	<i>Day 1</i>	<i>Day 2</i>	<i>Day 3</i>	<i>Day 4</i>	<i>Day 5</i>	<i>Day 6</i>	<i>Day 7</i>	<i>Maximum DPBO in Each Hospital over the Week (Method 3)</i>
Hospital A DPBO	2	1	3	4	2	3	2	4
Hospital B DPBO	2	3	3	1	2	1	4	4
Region-level DPBO (Method 2)	4	4	6	5	4	4	6	

year), then the 95th percentile estimates bed requirements. If it is acceptable only 4 days/year, then the 99th percentile of DPBO estimates bed requirements. The maximum observed value of DPBO estimates ICU bed requirements when it is never acceptable for demand to exceed supply.

Because fractions of a bed are meaningless, we rounded estimates of the needed number of ICU beds upwards to the next integer.

This study was approved by The Health Research Ethics Board of the University of Manitoba, and the Manitoba Health Information Privacy Committee. Analyses were performed with *SAS* version 9.1 (SAS Institute, Cary, NC, USA).

RESULTS

Cumulative yearly patient-days averaged over all 7 years in the North rural, South rural, and Winnipeg regions were, respectively, 443 ± 155 , $1,154 \pm 183$, and $20,689 \pm 956$ (mean $\pm$ SD). By the yearly patient-days method, the North rural, South rural, and Winnipeg regions needed, respectively 2, 4, and 71 ICU beds (Table 2).

Average annual occupancy ignores day-to-day fluctuations in demand. As assessed by DPBO, all regions experienced substantial fluctuations with both region-level (Method 2, Table 3) and hospital-level (Method 3, Table 4)

Table 2: ICU Bed Use and Estimated Bed Requirements by Region, Using the Yearly Patient-Days (Method 1), Assuming an Optimal Average Occupancy Rate of 80%

Year	North Rural Region		South Rural Region		Winnipeg Region	
	Average Occupied Beds	Number of Beds Required*	Average Occupied Beds	Number of Beds Required*	Average Occupied Beds	Number of Beds Required*
2000	1.7	3	3.7	5	55.8	70
2001	0.9	2	3.6	5	55.4	70
2002	0.6	1	3.8	5	53.7	68
2003	1.6	2	3.1	4	54.8	69
2004	1.3	2	2.7	4	57.7	73
2005	1.5	2	2.8	4	57.6	73
2006	0.9	2	2.6	4	61.6	78
Mean	1.2	2	3.2	4	56.6	71

*Cumulative ICU bed-days/365.25/0.80), rounded up to the next integer.

Table 3: Daily Peak Bed Occupancy Using the Region-Level Method (Method 2), by Region and Year

	2000	2001	2002	2003	2004	2005	2006	Mean $\pm$ SD
North rural region								
25th percentile	1	0	0	1	1	1	0	1 $\pm$ 1
Median	2	1	1	2	2	2	1	2 $\pm$ 1
75th percentile	3	2	1	3	3	3	2	3 $\pm$ 1
95th percentile	5	3	3	4	4	3	3	4 $\pm$ 1
99th percentile	6	5	4	5	4	4	4	5 $\pm$ 1
Maximum	8	6	5	5	4	5	4	6 $\pm$ 2
Maximum–Median	6	5	4	3	2	3	3	
(Maximum–Median)/ Median, %	300	500	400	150	100	150	300	
South rural region								
25th percentile	3	3	3	3	3	3	3	3 $\pm$ 0
Median	5	4	4	4	4	4	4	5 $\pm$ 1
75th percentile	6	5	6	5	5	5	4	6 $\pm$ 1
95th percentile	8	8	7	6	6	6	6	7 $\pm$ 1
99th percentile	9	10	8	7	7	7	7	8 $\pm$ 2
Maximum	9	11	11	8	8	9	7	9 $\pm$ 2
Maximum–Median	4	7	7	4	4	5	3	
(Maximum–Median)/ Median, %	80	175	175	100	100	125	75	
Winnipeg region								
25th percentile	55	56	54	55	56	59	60	57 $\pm$ 3
Median	59	60	57	59	60	62	64	61 $\pm$ 3
75th percentile	62	63	60	63	64	65	67	64 $\pm$ 3
95th percentile	66	67	63	67	68	69	72	68 $\pm$ 3
99th percentile	69	72	66	70	71	74	74	71 $\pm$ 3
Maximum	70	76	70	72	73	77	77	74 $\pm$ 4
Maximum–Median	11	16	13	13	13	15	13	
(Maximum–Median)/ Median, %	19	27	23	22	22	24	20	

bed conglomeration. A parameter summarizing these fluctuations is the difference between maximum and median DPBO, representing the difference in census between the busiest day and a typical day. In the rural regions with their low ICU bed supply, this difference shows that the fluctuations greatly exceeded the typical census. Even with the much higher ICU bed supply in the Winnipeg region, these fluctuations were 19–42 percent of the typical census, equivalent to 11–46 beds.

Comparing the three methods for estimating the number of ICU beds needed shows several patterns (Table 5). First, comparing Methods 2 and 3 demonstrates that fewer beds are needed with ICU bed sharing across

Table 4: Daily Peak Bed Occupancy Using the Hospital-Level Method (Method 3), by Region and Year

	2000	2001	2002	2003	2004	2005	2006	Mean $\pm$ SD
North rural region								
25th percentile	1	0	0	1	1	1	0	1 $\pm$ 1
Median	2	1	0	2	1	2	1	2 $\pm$ 1
75th percentile	3	2	2	3	3	3	3	3 $\pm$ 1
95th percentile	7	4	3	5	4	5	3	5 $\pm$ 2
99th percentile	9	7	6	7	6	6	4	7 $\pm$ 2
Maximum	11	8	6	9	8	7	6	8 $\pm$ 2
Maximum–Median	9	7	6	7	7	5	5	
(Maximum–Median)/ Median, %	450	700	–	320	700	250	600	
South rural region								
25th percentile	2	2	2	2	2	2	2	2 $\pm$ 0
Median	5	5	5	4	4	4	4	5 $\pm$ 1
75th percentile	7	7	7	7	6	6	5	7 $\pm$ 1
95th percentile	10	14	10	10	9	9	8	10 $\pm$ 2
99th percentile	13	17	12	11	9	10	10	12 $\pm$ 3
Maximum	16	20	14	13	12	12	11	14 $\pm$ 4
Maximum–Median	11	15	9	9	8	8	7	
(Maximum–Median)/ Median, %	220	300	180	225	200	200	175	
Winnipeg region								
25th percentile	55	54	54	54	56	60	59	56 $\pm$ 3
Median	60	62	59	62	64	64	67	63 $\pm$ 3
75th percentile	67	69	65	67	70	70	74	69 $\pm$ 3
95th percentile	76	76	73	77	77	78	81	77 $\pm$ 3
99th percentile	82	81	78	82	80	82	86	82 $\pm$ 3
Maximum	82	88	80	88	85	87	95	87 $\pm$ 5
Maximum–Median	22	46	21	26	21	23	28	
(Maximum–Median)/ Median, %	37	42	36	42	33	36	42	

hospitals. For example, with effective regional bed sharing, the South rural region would have needed 3–5 fewer ICU beds. Second, fewer beds are needed if it is acceptable for demand to exceed supply more days per year. The South rural region needed 1–2 fewer ICU beds to avoid exceeding supply 18 instead of 4 days a year. Third, estimating needs based on yearly average usage is inadequate. Severe underestimation occurs when day-to-day fluctuations in demand are large in relation to the yearly average usage, as in the rural regions. If the South rural region possessed the 4 ICU beds indicated by Method 1, demand would have exceeded supply 67 days a year, even with regional bed sharing. In the larger Winnipeg region, Method 1

Table 5: Comparison of Methods for Estimating the Number of ICU Beds Required in Each Region, Averaged over All Seven Years

	<i>Number of Days/Year That Demand Exceeds Supply</i>						
	<i>18 Days/Year</i>			<i>4 Days/Year</i>		<i>Never</i>	
	<i>Method 1: Yearly Average Usage</i>	<i>Method 2: Regional Bed Sharing</i>	<i>Method 3: No Regional Bed Sharing</i>	<i>Method 2: Regional Bed Sharing</i>	<i>Method 3: No Regional Bed Sharing</i>	<i>Method 2: Regional Bed Sharing</i>	<i>Method 3: No Regional Bed Sharing</i>
North rural	2	4	5	5	7	6	8
South rural	4	7	10	8	12	9	14
Winnipeg	71	68	77	71	82	74	87

underestimated ICU bed needs unless there was effective regional bed sharing and it was acceptable for demand to exceed supply at least 4 days/year.

DISCUSSION

Illness, especially critical illness, is often unpredictable, resulting in significant fluctuation in patient numbers over hours and days. Administrators and policy makers must decide how many hospital and ICU beds to operate, and available data indicate that a common approach to this calculation uses average bed occupancy data, as in our Method 1. This method is used by governmental health agencies in North Carolina, South Carolina, Alabama, Connecticut (Carney 2011), New Jersey (New Jersey Commission on Rationalizing Health Care Resources 2008), Florida (Florida Agency for Health Care Administration 2012), and Wales (Lylwodraeth Cymru Welsh Government 2013). It has also been espoused for use in the medical literature (Nguyen et al. 2003; Mackay and Lee 2005; Corke et al. 2009). However, as these calculations assume unchanging patient flow, they cannot account for such fluctuations and are inadequate for understanding the dynamic nature of bed utilization, or estimating bed requirements. Our results show that bed supply decisions based on average census can easily result in inadequate “surge capacity” to cope with the actual fluctuations in demand, even including recommended leeway to avoid being near full capacity (Department of Health 2010).

A more complete understanding comes from examining the distribution of a new parameter, the Daily Peak Bed Occupancy. Its use identified large day-to-day variations in ICU bed use in all three geographic regions. Any data source containing the date and time of each patient's ICU admission and discharge allows calculation of the DPBO, and these fluctuations in occupied bed census. Given its ability to incorporate day-to-day fluctuations of ICU bed use, this new parameter is more useful for administrators and policy makers when planning ICU bed resources, compared to the widely used average occupancy data.

We found that conglomeration of ICU beds increases efficiency, accommodating the same number of patients with fewer beds. Examples include sharing of beds between different ICUs in a single hospital, or regionalization with sharing across hospitals. Compared to the situation where each hospital needed to fulfill its own demand for ICU beds, such regionalization resulted in 12–36 percent fewer ICU beds needed, with greater relative benefit in regions with a low number of ICU beds (Table 5). Bed sharing increases efficiency because fluctuation in demand for an entire conglomeration is less than the sum of the fluctuations of its individual parts. This finding is consistent with the results of complex statistical modeling based on queuing theory (de Bruin et al. 2007). However, even with regional conglomeration of beds, daily fluctuations in census were substantial; maximal census values in the low bed number rural regions were 80–500 percent above median values, and 19–27 percent above the median in the higher bed number urban region (Table 3).

Jurisdictions where all hospitals are under a single authority still have practical limitations to ICU bed sharing across hospitals. It is even more problematic for hospitals separated by long distances, such as in rural Manitoba. Therefore, these rural hospitals must be nearly independent in supplying their own ICU needs, and the number of ICU beds needed is better estimated by Method 3. Even in unified care systems in small geographic areas, there are delays and barriers to transferring patients between hospitals. Accordingly, the number of ICU beds needed in highly integrated hospital systems likely falls between the estimates of Methods 2 and 3. And there are other considerations besides efficient and cost-effective use of resources. Regionalized care may improve patient outcomes through the “practice makes perfect” mechanism (Kahn et al. 2006), but inter-ICU transfers may be associated with poorer patient outcomes (Escarce and Kelley 1990; Combes et al. 2005).

An unavoidable consequence of providing smaller hospitals or less populous regions with enough ICU beds to independently cope with their own

surges in demand is that their average bed occupancy will be low. It is incorrect to conclude that low mean or median occupancy necessarily indicates that fewer ICU beds would be sufficient. In our rural regions, for example, even with regionalization and bed supply set to allow demand to exceed supply up to 5 percent of days, average occupancy rates would have been under 45 percent (Table S1). Without regional bed sharing, even the more populous urban region would have experienced average occupancy rates below the optimal value of 80 percent suggested in the literature (Iapichino et al. 2004; McManus et al. 2004). Table S1 also demonstrates that decreasing the bed supply to increase average occupancy increases the frequency with which demand exceeds supply.

ICUs are highly stressed when the demand for beds exceeds the supply. Not surprisingly, we found that more ICU beds are needed to reduce the number of days per year when demand exceeds supply. Reducing these occurrences from 18 to 4 days/year would have required 4–40 percent more ICU beds in the three geographic regions we evaluated, with larger fractional increases in the regions with fewer ICU beds (Table 5). Eliminating such occurrences requires maintaining such a large number of beds that many are unused much of the time. For example, with region-level conglomeration in the Winnipeg region, the largest number of beds in simultaneous use over the study period was 77 (Table 3). But if that region had continuously maintained 77 ICU beds, it would have had an occupancy rate under 70 percent on more than one-quarter of all days. There are economic consequences of maintaining ICU beds that are empty much of the time. On the other hand, reaching full capacity is problematic because the system is unable to care for additional critically ill patients. Scarcity of ICU beds can influence clinician decision making (Singer et al. 1983; Strauss et al. 1986) and may negatively impact patient outcomes (Iapichino et al. 2004; Howie and Ridley 2008; Chrusch et al. 2009; Robert et al. 2012). Thus, determining the acceptable frequency of having inadequate ICU beds to meet demand is a complex, multifaceted issue.

While patient census information, as addressed in this analysis, is the starting point for estimating the number of ICU beds needed, there are other important considerations. There are three reasons that patient counts may underestimate the number of beds needed. First, when an ICU is at or near capacity, additional patients may be triaged away from ICU, and so be excluded from estimates based on observed ICU census (Strauss et al. 1986; McManus et al. 2004). Second, even without outright refusals for ICU admission, performance and outcomes are suboptimal if ICUs operate near capacity (Iapichino et al. 2004; McManus et al. 2004; de Bruin et al. 2007;

Chrusch et al. 2009), and delays in taking in new patients may result in adverse medical consequences (Chalfin et al. 2007; Robert et al. 2012). The magnitude of these difficulties is higher in ICUs or ICU systems with fewer beds and higher patient turnover rates (de Bruin et al. 2007). And third, when a new patient needs care in an ICU that is at capacity, usually the least sick existing patient is transferred out to a ward providing a lower level of care. Premature transfer under such “bed pressure” may result in adverse clinical outcomes (Goldfrad and Rowan 2000; Daly, Beale, and Chang 2001; Chrusch et al. 2009).

Patient census data can also overestimate the number of patients needing ICU care. This occurs when availability of lower care ward or stepdown beds are the limiting factor in transferring patients out of ICU. In such circumstances, patients remain in ICU longer than their medical situations require, which may also worsen patients’ outcomes (Garland and Connors 2013). In addition, in locales where patients are frequently admitted to the ICU following elective surgery, optimization of surgical scheduling can reduce fluctuations.

It is important to clarify that in this study, we did not address the complicated issues of what constitutes critical illness, or appropriate triage into or out of ICU. Indeed, it seems likely that some of the large variation in ICU bed supply between hospitals and countries is attributable to the different ways ICU beds are used. However, our methodology is still useful and valid for identifying the amount of ICU bed resources that are required to provide care for patients within an ICU or country, given constancy of admission/discharge practices and availability of post-ICU beds.

Regarding generalizability of our findings, there are two separate issues. First, for the reasons discussed, we believe that the relationships we observed regarding ICU conglomeration are fundamental to the nature of the stochastic processes of ICU admission and discharge, and thus generalizable. On the other hand, the specific ICU bed numbers derived from our Manitoba analysis are not generalizable to other systems or jurisdictions. Instead, use in a given jurisdiction of DPBO-based methods for analyzing the short-term fluctuations in census can be expected to clarify ICU bed number issues for that specific jurisdiction, given continuation of its current admission, transfer, and discharge practices.

In summary, we performed a population-based analysis using data from geographic regions with low or high numbers of ICU beds. Our census-based methods for analyzing ICU bed needs, based on the magnitude of short-term fluctuations in the Daily Peak Bed Occupancy, will

be of particular value to ICU administrators, policy makers, and other planners. For making projections within a given jurisdiction, it is these methods which are relevant, widely applicable, and generalizable. While analysis of the fluctuations of ICU census is the starting point for assessing the number of ICU beds needed by a hospital or region, planners must also determine or take account of (1) the acceptable frequency for having inadequate supply to cope with demand; (2) practicalities and consequences of ICU bed sharing across hospitals; (3) the fact that operating near capacity results in suboptimal performance and outcomes; and (4) the availability of regular ward and intermediate care beds to which ICU patients can be transferred once the need for ICU care has passed.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Appendix SA1: Author Matrix.

Table S1. Implications of Different Levels of Supply of Intensive Care Unit (ICU) Beds, by Region and Status of Regional Bed Sharing, 2000 to 2006.