The Science of Surge

Three years ago, a Web search that included PubMed yielded few research studies related to surge or surge capacity, whether specific to hospital emergency departments (EDs) or to catastrophic events. The information on the Internet yielded mostly PowerPoint slides of meeting presentations by notable individuals. At that time, the few published reports on disaster-related surge were mostly opinion or non–evidence-based assertions. A review of texts related to medical disaster response published at the time also yielded an astounding paucity of information on surge. At best, they noted that plans for surge should be developed.

By contrast, the science of ED crowding, a consequence of daily surge (also referred to as regular surge and routine surge), was already well developed. Many of the methods used borrowed heavily from operational and management science and a division thereof called service management.[1] These methods included concepts such as queuing theory[2–4] and discrete event simulation modeling,[5,6] and use of these techniques to analyze daily surge experienced by EDs has continued to mature. Interestingly, the actual operational definition of "crowding" has not yet attained uniform agreement, although tools to measure the phenomenon have been developed and tested.[7]

Recognizing the importance of developing the scientific underpinnings of disaster planning and response, the Agency for Healthcare Research and Quality, among a few other organizations, decided to support formal research inquiry into extraordinary surge[8,9] (also referred to as catastrophic surge, critical event surge, and disaster surge), the endeavors of which are just now reaching fruition and are being presented and published.[10–15] Many other reports remain conceptual, but such reports are increasingly based on best evidence when available.[16]

CONCEPT OF SURGE, SURGE CAPACITY, AND SURGE RESPONSE CAPABILITY

Before the *Academic Emergency Medicine* consensus conference entitled "The Science of Surge," held in San Francisco in May 2006, the concepts of surge and surge capacity were not applied to daily health care practice, but rather were the vernacular of disaster or emergency preparedness. In this realm, formal definitions of surge capacity have been offered,[17,18] but "surge" itself remains undefined. The term "**surge response capability**" as a function of these two concepts has not, to our knowledge, previously been introduced (Figure 1) but will be discussed later in this report. The lack of accepted definitions hinders research, because metrics of measurement cannot be developed in absence of conceptual clarity.

During a recent Agency for Healthcare Research and Quality–sponsored conference, surge was undefined but was acknowledged to have components of volume and time.[18] Event type and scale broadly determine surge. We offer the following conceptual definition of surge. Surge is defined as a sizable increase in demand for resources compared with a baseline demand. Related to health care, surge implies a sizable increase in demand of medical or public health resources. In addition to influx (volume rate), surge is further composed of the following components: event (type, scale, and duration) and resource demand (consumption and degradation) (Figure 1). Contrary to current thinking, surge itself is largely independent of resource availability (surge capacity). However, as explained later, it is related to capacity insofar as both are functional elements defining surge response capability (Figure 1).

Surge capacity is the maximum potential delivery of required resources, either through augmentation or modification of resource management and allocation. Surge capacity contains the elements of system, space, staff, and supplies, as outlined by Barbisch and Koenig.[19] Surge capacity is not necessarily or entirely independent of surge, because the demand characteristics of the surge itself may consume and degrade resources. Again, the two parameters are linked in that they define surge response capability.

Finally, surge response capability is a concept we are forwarding here. We believe this concept has been confused with surge capacity. Rather, it is the ability of surge capacity (i.e., the resources that can be made available) to accommodate the surge (demand for resources). In essence, it is the measurable function of surge capacity related to surge (Figure 1). When surge capacity exceeds the demands of surge, the response capability is >1. Under these circumstances, the surge may not even be perceived. On the other hand, when surge capacity is insufficient to meet surge demand, surge response capability is inadequate. This may appear intuitive, and critics may argue that surge capacity alone subsumes this definition. However, resource availability and maximized management (capacity) are independent of the event that creates incremental demand (i.e., surge). The extent to which surge capacity can accommodate the surge is surge response capability. The science of surge can only be advanced if these concepts are appropriately defined such that metrics can be applied.

The definitions offered here are somewhat new and may prove controversial. It is likely that these concepts will be refined further over time by other investigators and experts. Although our concern in this report is with health care, the concepts should be equally

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$$\textbf{Surge Response Capability} = \textbf{Planning} * \frac{\textbf{Maximized Available Resources}}{\textbf{Resource Demand}}$$

$$= \textbf{Planning} * \frac{\textbf{Surge Capacity}}{\textbf{Surge}}$$

$$= \textbf{Planning} * \frac{\textbf{System}_{(\text{integrity})} * \textbf{Space}_{(\text{size} * \text{quality})} * \textbf{Staff}_{(\text{numbers} * \text{skill})} * \textbf{Supplies}_{(\text{volume} * \text{quality})}}{\textbf{Event}_{(\text{type} * \text{scale} * \text{duration})} * \textbf{Influx} * \textbf{Resource Demand}_{(\text{consumption} + \text{degradation})}}$$

Figure 1. **Functional relationship of surge response capability to surge capacity and surge. Note that planning, which is actually a system component, is shown as a major stand-alone variable to emphasize its importance.**

applicable to electricity grids, public transportation, theater offerings, and so on.

HEALTH SYSTEM DAILY SURGE AND EXTRAORDINARY SURGE

How do the concepts of daily surge and extraordinary surge relate? The two concepts are similar in that both contend with a sizable increase in medical or public health resource demand and challenge system capacity. However, extraordinary surge, a term reserved for catastrophic events, is larger scale, is more complex, and has incremental nonlinear multicomponent interactions with capacity compared with its simpler cousin, daily surge. In addition, there are considerable differences that may affect research approaches to studying the problem and finding solutions.

While it is hard to deny that ED crowding exists, not all believe that daily surge as a concept exists. The fact that the term "daily surge" was coined coincident with the *Academic Emergency Medicine* consensus conference, and is not previously found in the literature, supports this view. It is also argued that because crowding is not concerned with sizable abrupt, unanticipated, or sudden demand, there is no concept of surge. It is also argued that daily surge is predictable, and because it is routine and expected, it cannot be a surge. In contrast, others argue that the fact that an incremental demand in health care resources is predictable and occurs routinely does not render the phenomenon any less real. Data presented by McCarthy et al. elsewhere in this issue reveal sizable and abrupt (but not completely unanticipated) increments in hospital-based health care resource demand on a routine basis.[20] Further, crowding, the result of mismatch between demand (surge) and resource availability (capacity), can be considered a measure (not a favorable one) of surge response capability. Perhaps the best conceptual view is that of a broad continuum with daily surge and extraordinary surge at the two extremes. Asplin et al., in this issue, offer a reasonable differentiating approach.[21] Daily surge response capability invokes only routinely available capacity (resources). At the other end of the continuum, a disaster plan is activated, triggering augmentation or alternate management of resources on a much larger scale as a means to accommodate the surge. It is easily imagined that there are scenarios of degree between. Regardless, the basic tenets of the interrelationships between surge response capability, surge capacity, and surge appear to hold for both daily and extraordinary situations.

Although conceptually related, daily surge issues are distinct in many ways from extraordinary surge. Daily surge and the consequences of crowding refer almost exclusively to ED experiences. It is fundamentally based on economic hospital-based decisions, complicated by misunderstood data indicating that many patients seeking ED treatment do not really have a true emergency, and thus crowding is viewed as a problem of unnecessary visits.[22] A large component of the capacity-to-demand mismatch is related to inpatient census.[23–25] In contradistinction to catastrophic events, the components of daily surge and surge capacity, as well as their relative contribution to crowding, have been well defined for the better part of two decades. Thus, solutions to effectively increase daily response capability and components exerting the greatest effects are evident.[26]

Given that the problem is primarily economic, incentives to address ED crowding are mixed at best. On the one hand, there are ample data indicating that admissions to hospitals from sources other than the ED are more revenue generating.[27–30] Elective admissions and transfers are even more financially advantageous. Thus, at the level of the individual admitting attending physician or admitting service level, admissions from the ED are among the lowest of priorities in many hospitals.

Further, timeliness of consultations to the ED also appears to be highly associated with economic prospects.[31] Obtaining consultations from on-call specialists in nonacademic centers has recently reached crisis proportions, as specialists are opting out of emergency coverage.[32] The only incentives countering these trends are hospital image and avoidance of costly malpractice suits, as well as Emergency Medical Treatment and Active Labor Act investigations and citations. Given the extraordinarily thin financial margins under which many hospitals operate, hospital administrators and physician leaders may have very little maneuverability to truly address the issue of ED crowding.

Finally, emergency medicine itself is also responsible for buying into the economic model of impeded capacity. Because emergency medicine group practice is often for-profit or predicated on concerns of financial margin, management keeps attending staffing at a level in which physicians should never be idle. In this model, staffing for maximum known demand is not economically sound, because the physician or provider would be idle for considerable periods during lower demand times.

By contrast, response to extraordinary surge and attendant capacity is generally not economically based (beyond general concepts of continuity of operations, that is, business continuity). Rather, as with all aspects of disaster response, it is based on the higher humanity standard of equal access and the guiding principle of "greater good for the greatest number."

Finally, surge during catastrophic events is a broader concept than daily surge, and viewing the issue from the emergency medicine perspective alone is myopic. Daily surge is predominantly an economic hospital-based issue, with much of the problem related to inpatient capacity but with the consequences concentrated in the ED. By contrast, catastrophic surge has significantly more components. Revenue generation and meeting certain financial margins are limited drivers at best, and ED operations are just one facet. The broader public health system is frequently involved, as are community infrastructure, regional (even national) assets, and political institutions. In fact, in some scenarios, the ED may play only a modest role in a catastrophic event and in some may not play any role that is fundamentally different than for daily surge.

COMPONENTS OF SURGE CAPACITY

As noted, the components of daily surge and their interrelationships are well known and have been well studied for the better part of two decades. McCarthy et al. argue that daily surge is somewhat predictable on an institutional and regional emergency medical services (EMS) basis, for both seasonal, day of the week, and intraday effects.[20]

The Advisory Board Company conducted groundbreaking work during the late 1990s, delineating the various elements of ED crowding and the relative value of addressing the different components.[26] It was determined that there are 22 components related to ED bottlenecks and delays, each with its own subcomponents. They concluded that the greatest determinant of ED surge capacity was the "back-end" admission process. "Up-front" process improvements, while helpful, offered the least value in increasing capacity for a continuous or intermittent surge in patients.

During the 1990s, the concept of categorizing surge capacity into four broad components (system, space, staff, and supplies) did not exist. Table 1 categorizes the 22 impact components according to these four categories. These 22 components are a subset of the universe of components and represent the ones with the greatest effects. As noted earlier, it has been advanced that inpatient census, an issue of space and staff, is a major driver and perhaps has the greatest impact on ED crowding. Our own unpublished data contradict this notion. The Advisory Board Company itself did not characterize inpatient census as influential but noted that many of the processes involved in admissions (which falls under the rubric of "system") were the major impact components. It is also interesting to note that, generally speaking, apart from specific dedicated staff for specific tasks, staff components were not major influencers and supplies were virtually never a capacity component in question during daily ED surge (Table 1).

Unlike daily surge capacity, extraordinary surge capacity is not as well understood. The fundamental elements of extraordinary surge capacity have been broadly classified,[19] but the components within the classifications have not been detailed in a universal model. Table 2 is an initial attempt at delineating influencing components of extraordinary surge capacity, and Figure 1 depicts surge response capability as a function of the elements of surge capacity (resource availability) and surge (resource demand). The relative contributions of the broad categories depicted in Table 2 and Figure 1 remain unexplored. Moreover, the dynamics between extraordinary surge components and capacity components are infinitely

Table 1
Components of Daily Surge Capacity

System		
	Pre-ED bed	
		Triage method (short vs. long)*
		Registration method (pretreatment vs. bedside)*
	Physician tasks	
		Documentation methods
		Communications (physician vs. dedicated staff)
		Diagnostic results notification (passive vs. active)
	Ancillary ordering	
		Method (freeform vs. guidelines)
	Treatment	
		Ordering (guidelines vs. freeform)
	Space utilization	
		(routine use vs. swing rooms)
	Radiology reads	
		(EP first read vs. radiologist)*
		(EM preferential reads by radiologist vs. not)
	Admission process	
		Bed allocation (Preemptive request vs. post hoc allocation)*
		Nurse report technique
		Bed status alert
		Authority (EP vs. permission)
	Informatics	
		Patient tracking (present vs. not)*
		Inpatient bed status (instant vs. not)
		Physician profiling (yes vs. no)
	Other	
		Physician ancillary use profiling
Space		
	Laboratory (on site vs. distant)	
Staff		
	Phlebotomists (dedicated phlebotomy vs. multitasking personnel)*	
	Radiologists (dedicated to ED vs. not)*	
	Inpatient MDs (hospitalists vs. individual service)	
Supplies (no items)†		

EP = emergency physician; EM = emergency medicine.
* Judged as having the highest level of importance.
†The Advisory Board Company[26] did not report any issues related to ED crowding or capacity.

Table 2
Components of Catastrophic Event Surge

System	Space	Staff	Supplies
Planning	Facilities	Numbers	Biologics
Community infrastructure	Medical care	Capability/skill set	Respirators
Government	Storage	Expertise	Personal protective equipment
Informal networks	Laboratory	Stamina	Standard supplies
Public health	Mortuary	Psych	Food and water
Incident command	Housing of staff		
All levels			
HEIC	Quality		
Regional cooperation	Size		
Multiagency	Capability		
Regional health system	Location		
Communications and information flow			
Supply chain distribution			
EMS/first responders			
Continuity of operations			
Cybersecurity			

HEIC = hospital epidemiology and infection control.

more complex and change according to event type and duration.

SCIENTIFIC UNDERPINNINGS OF SURGE

One goal of the "Science of Surge" consensus conference, the record of which is documented in this issue, was to determine whether the scientific methods applicable to daily surge could be shown to be applicable to extraordinary surge scenarios. However, no consensus was reached as to the relationship of one concept to the other, or whether they are related at all. The definitions offered in this report suggest that, in the least, daily surge and extraordinary surge may represent opposite ends of a continuum. Support for this concept is derived from the fact that methods of study are common to both phenomena.

Even before the work of the Advisory Board Company, the science of daily surge borrowed heavily from operations engineering and various modeling concepts such as queuing theory. Even chaos theory applications have been explored.[33,34] More recently, attention has been paid to patient safety issues related to daily surge and capacity constraints, but the methods of study for this line of inquiry are well developed. While there is much work that remains, such as the need for an accepted definition of crowding and universal metrics of measurement, overall, progress in the scientific underpinnings of the study of daily surge is quite mature compared with the study of extraordinary surge in catastrophic events.

Despite these fundamental differences, there are methods of inquiry applicable to both daily surge and catastrophic surge. Discrete event simulation modeling techniques have also been used to analyze surge issues in catastrophic events.[35–37] For example, Hirshberg et al. used data from 12 terrorist bombing incidents in Israel to determine that surgeons (not operating rooms), resuscitation rooms, and computed tomography scanner availability determined the admitting capacity of a hospital.[36]

Similarly, concepts developed to address scarce resource utilization in catastrophic events may be applicable to daily surge issues. Two recent lines of inquiry may assist with inpatient census issues. Hick and O'Laughlin recently published an ethical framework for the triage and allocation of intensive care unit beds and mechanical ventilation when these resources were insufficient due to a catastrophic event.[38] On a daily basis, intensive care unit resources are rationed routinely in many, and perhaps most, hospitals. In fact, the ethical framework for the current routine practice is not founded on public health principles. Those in great need and those likely to benefit may actually be denied the service, while the allocated resource continues to be used for those with low likelihood of beneficial outcome. Further, intensive care unit beds are often "reserved" for patients undergoing elective surgery, while patients who could benefit linger in the ED, clearly a less ideal environment for patients requiring intensive monitoring or care. "The most benefit, for the greatest number," the clarion call of disaster management, is not one that has yet been adopted in routine health care.

In a similar line of study, Kelen and the CEPAR Research Group have developed a framework for safe discharge of inpatients during disasters that may be applicable to daily surge as well.[14,15] Preliminary data indicate that, in fact, a sizable portion of inpatient beds can be freed using a technique of deciding early rapid discharge for patients with low risk of adverse events for a subsequent 72-hour period.[16]

SUMMARY

While it remains unclear to what extent daily surge and extraordinary surge are related, it is evident that their philosophical underpinnings are divergent. However, at least some tools appropriate for study are applicable to both, indicating conceptual similarities. The phenomena of daily surge and the components of daily surge capacity are well known and studied. The phenomenon of extraordinary surge, by comparison, is complex. The components of surge capacity for catastrophic events are only broadly defined, and many subcomponents remain undefined. Further, the relative impact of the various components under different event scenarios remains largely unknown.

The interactions of these components are not stable and are dependent on the event type and duration. Still, a new concept, surge response capability, can be expressed as a function of surge capacity and surge characteristics. The main challenge for developing the science of surge is to further delineate the components of surge capacity and surge and to develop measurable operational definitions that would be subject to testing and evaluation.

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Gabor D. Kelen, MD
(gkelen@jhmi.edu)

Melissa L. McCarthy, ScD
Department of Emergency Medicine
The Johns Hopkins University School of Medicine and The Johns Hopkins Office of Critical Event Preparedness and Response
Baltimore, MD

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