

A CONSTRAINED-FLOW LENS FOR EMERGENCY DEPARTMENT CROWDING AND AMBULANCE RAMPING: ANALOGY, QUEUES AND EVIDENCE

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ABSTRACT

OBJECTIVE:

To present a conceptual research note that integrates a constrained-flow analogy, queueing relationships and emergency-care evidence to support investigation of emergency department (ED) crowding and ambulance ramping.

DESIGN:

Evidence-informed conceptual research note.

SETTING:

Australian public hospitals, with Queensland examples where definitions are jurisdiction specific.

MAIN OUTCOME MEASURES:

Candidate measures of demand, census, time, utilisation, variability, boarding, patient off-stretcher time and safety.

RESULTS:

Bernoulli's principle is retained only as an intuitive analogy for restrictions and upstream accumulation. Little's law provides the principal descriptive relationship between average number, effective flow and time; Kingman's approximation explains how high utilisation magnifies variability. Established input-throughput-output models and Australian evidence locate ambulance ramping within whole-of-hospital access block. Intervention evidence is mixed and does not support universal prescriptions.

CONCLUSIONS:

The framework may translate visible congestion into measurable hypotheses, but it is not a predictive hydraulic model. Construct validation, retrospective analysis, queueing analysis, simulation and prospective testing are required before operational use.

KEYWORDS

emergency department; ambulance ramping; access block; patient flow; queueing theory; Little's law; health service management

INTRODUCTION

Emergency department (ED) crowding and ambulance ramping are persistent safety and access problems. Reviews describe interacting input, internal-process and output causes, with output failure – especially boarding and access block – often propagating congestion through the hospital [1-4]. Queensland evidence similarly associates ramping with access block and hospital occupancy rather than ambulance arrivals alone [5,6].

This research note offers a managerial translation framework, not a new law of patient flow. Its contribution is the integration of three layers: an intuitive constrained-flow analogy; established queueing relationships; and empirical measurement followed by local validation. It complements the input-throughput-output model [2], adding questions that connect pathway mapping to measurable operational hypotheses.

METHODS

The framework was tested against foundational queueing scholarship, systematic reviews of ED crowding and interventions, Australian access-block and ramping studies, simulation literature and Queensland operational definitions. Claims were classified as established, evidence-supported interpretation, mathematical relationship, analogy, proposed application or hypothesis. No patient data were analysed and no independent personal technical endorsement is claimed.

FINDINGS

Layer 1 – conceptual analogy. In fluid mechanics, Bernoulli's equation expresses conservation of mechanical energy along a streamline under restrictive conditions, including steady, incompressible and effectively inviscid flow without unaccounted energy losses. Patients are not fluid particles and an ED is not a closed hydraulic system. ED care includes autonomous behaviour, clinical priority, heterogeneous service needs, multiple servers, dynamic staffing, interruptions, blocking and feedback. No claim is made that Bernoulli's equation predicts ED waiting time, patient speed or queue size. Only a limited intuition is borrowed: restrictions can cause upstream accumulation, and usable capacity depends on safely staffed capability rather than physical space alone. 'Pressure' has no direct ED equivalent and is replaced here by congestion, accumulated demand or queue burden. Figure 1 places that intuition within the established input-throughput-output model.

Layer 2 – quantitative discipline. Little's law is $L = \lambda W$. For a defined process and sufficiently stable observation period, L is the long-run average number of patients present, λ is the effective arrival or completion rate per unit time, and W is average time in the process [10]. Units must match, boundaries must be explicit, and flow must be stable enough that average entry and exit rates are comparable. It is a long-run relationship, not an individual forecast or causal model. For illustration, $L = 60$ patients and $\lambda = 10$ patients/hour gives $W = L/\lambda = 6$ hours. Reducing one component of average time by one hour would be one-sixth of this baseline only if the boundary, demand, completion rate and other delays remained unchanged. It is therefore arithmetic, not a prediction of a 17% ED-length-of-stay improvement.

Kingman's approximation for a stable GI/G/1 queue is $Wq \approx [\rho/(1-\rho)] \times [(ca^2+cs^2)/2] \times E[S]$ [11]. Wq is mean queueing delay; ρ is utilisation; ca and cs are coefficients of variation of interarrival and service times; and $E[S]$ is mean service time. In plain language, bunching of arrivals and variation in clinical work matter increasingly as utilisation approaches full capacity. ED studies have used more suitable time-varying queueing models for staffing [12]. A whole ED is not GI/G/1: it contains parallel servers, acuity priorities, possible pre-emption, abandonment, blocking, time-varying demand and linked downstream queues. Kingman is an explanatory approximation at a carefully defined stage, not a whole-ED calculator.

Layer 3 – clinical evidence and measurement. Clinical priority supersedes first-in-first-out flow. Resuscitation, Australasian Triage Scale urgency, isolation, mental-health and paediatric needs, diagnostic uncertainty, staff skill mix, specialty and intensive-care capacity, interhospital transfer and social discharge complexity alter pathways. Ambulance ramping

should be analysed as a hospital-system signal: Australian studies link access block with crowding, diversion and adverse outcomes [5-9].

Queensland's 30-minute measure is patient off-stretcher time (POST): the interval from presentation at ED triage to transfer from the ambulance stretcher to an ED bed, with the protocol aiming for reception, treatment-area placement and completed clinical handover within 30 minutes [19]. It is a jurisdiction-specific process measure, normally reported as the percentage meeting the threshold – not a universal clinical outcome, median or 90th percentile. Safety, deterioration and handover quality must accompany it.

FIGURE 1. THREE-LAYER CONCEPTUAL PATIENT-FLOW FRAMEWORK.

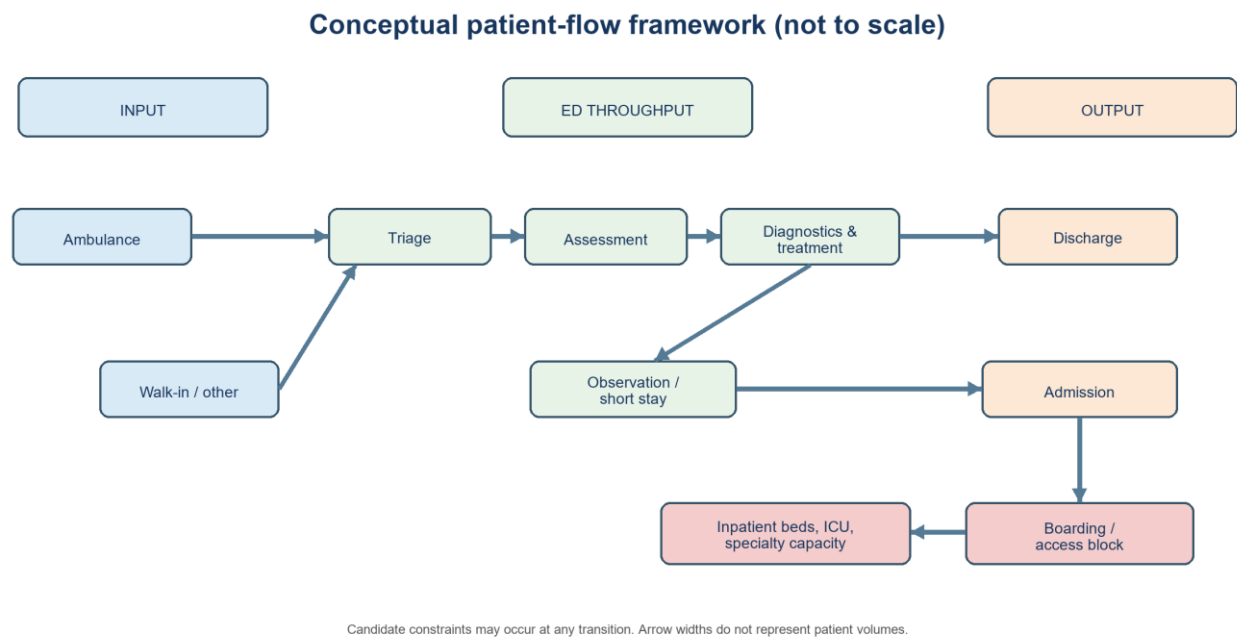


Figure 1. Three-layer conceptual patient-flow framework. The structure complements the input-throughput-output model; arrows and box sizes are illustrative, not measured volumes.

TABLE 1. BOUNDARIES OF THE CONSTRAINED-FLOW ANALOGY

Physical concept	Managerial analogy	Observable ED measure	Important limitation
Flow rate	Patients completing a defined stage per unit time	Stage completions/hour	Patients differ in acuity and service need.
Restriction	Constraint in safely staffed capability	Queue, delay, occupancy, staffing or bed availability	The cause must be established; a visible queue may be downstream driven.
Cross-sectional area	Parallel safe service capacity	Open staffed spaces/servers and skill mix	Physical space without staff is not usable capacity.
Pressure	Upstream accumulation only	No direct physical equivalent; use census, queue size or delay	Not a literal measurable pressure.
Friction/energy loss	Avoidable process delay or variability	Turnaround distributions and interruptions	No one-to-one physical equivalent.

OPERATIONAL INTERPRETATION

Candidate responses must follow diagnosis of the constraint. Fast-track or split-flow may reduce waiting for selected lower-complexity groups, but overall evidence for flow interventions is weak and queues can move elsewhere [14]. Short-stay units require clear eligibility and governance; evidence is insufficient for broad claims [15]. Discharge lounges have heterogeneous, largely descriptive evidence and cannot compensate for inadequate inpatient capacity [16]. Expanding ED beds alone did not improve time-based outcomes in an Australian multisite study, reinforcing the need for whole-system analysis. Timed targets may improve flow, but Australian mortality findings are mixed and targets can distort priorities if safety is not protected [17].

Managers should therefore link theory, evidence and measurement: define the boundary; locate input, internal-process or output constraints; quantify average numbers and times; examine time-of-day demand, staffing and variation; and test whether an intervention relieves rather than relocates delay. Outcome measures may include ED length of stay, boarding, left-without-being-seen, reattendance and patient experience. Process measures may include POST, diagnostic turnaround and admission-to-bed time. Balancing measures include mortality where relevant, deterioration, adverse events, workload, equity, handover quality and downstream congestion.

VALIDATION AGENDA

Stage 1 tests construct validity: do clinicians, ambulance personnel, managers and analysts agree that the framework identifies recognised constraints? Stage 2 uses retrospective data on arrivals, census, POST, ED length of stay, boarding, occupancy, staffing, admissions, diagnostics and ambulance unit-hours. Stage 3 applies Little's law at defined stages and analyses utilisation, variability and temporal patterns. Stage 4 uses discrete-event simulation for interacting queues and high-risk redesign; reviews show promise but weak reporting and limited implementation evidence [13,20]. Stage 5 prospectively pilots one intervention with predetermined inclusion, escalation and stop criteria. Stage 6 compares baseline, intervention and sustainability, including balancing outcomes. Clinical prioritisation and safety remain constraints, not tradeable outputs.

DISCUSSION AND CONCLUSIONS

The framework is accessible and integrates intuition, mathematical discipline and clinical evidence. It is not a literal hydraulic representation, a substitute for clinical judgement, an alternative to established crowding models, or a replacement for detailed queueing, simulation and local analysis. Its main limitations are the imperfect physical analogy, absence of empirical testing of the combined framework, non-stationary and heterogeneous ED operations, data-definition variation and the risk of optimising a visible queue while worsening another.

Bernoulli provides bounded intuition; Little's law provides the principal descriptive anchor; Kingman explains why utilisation and variability interact; ED evidence determines whether candidate actions are clinically plausible; and local analysis determines whether they work. Future research should test construct validity, compare the framework with existing patient-flow methods, assess managerial comprehension, evaluate safety and equity, and establish whether the integration improves operational decisions beyond existing models.

DECLARATION OF CONFLICTING INTERESTS:

The author declares that there is no conflict of interest.

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