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Adapting Visually Enhanced Mental Simulation for Hospital Disaster Preparedness

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advancing-simulation-practice

Keywords: Translational simulation, Visually Enhanced Mental Simulation, disaster preparedness, mass casualty incident

Posted Date: November 18th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11255917/v1

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Additional Declarations: Competing interest reported. VB is Senior Editor at Advances in Simulation. VB is employed by Bond University, which delivers courses and consultancy in translational simulation. VB is also a Director of Simulation Simplified, a company that manufactures equipment for VEMS training. NS and LO declare no competing interests.

Adapting Visually Enhanced Mental Simulation for Hospital Disaster Preparedness

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Abstract

Hospital disaster preparedness requires testing how planned responses function under the complexity, interdependencies and competing demands of surge conditions. Yet hospitals often have limited spare capacity for such testing: the staff, space and resources required for large-scale exercises are the same resources needed to maintain ongoing patient care. This creates a design challenge: how can hospital systems be meaningfully stress-tested within the constraints of routine operations?

We adapted Visually Enhanced Mental Simulation (VEMS) for hospital-wide disaster systems testing within an operating tertiary hospital. We conducted a six-patient multi-casualty exercise across 14 clinical and operational departments while routine hospital operations continued. Patients and selected resources were represented using paper-based materials, while participants worked through usual professional roles, communication systems, transport pathways and operational processes wherever feasible.

Clinical procedures were selectively abstracted where physical performance was not required for the system question, while elapsed time, evolving patient conditions, resource constraints and downstream consequences were preserved. Dynamically facilitated patient trajectories allowed clinical and organisational decisions, resource use and operational delays to generate consequences across the distributed exercise. The exercise exposed interactions between otherwise distributed parts of the hospital response, including gaps in notification pathways, competing blood-product demand, constraints arising from theatre space and staffing, and delays associated with patient transport. Exercise observations and interdisciplinary debriefing generated 12 recommendations that progressed through hospital governance and informed subsequent organisational changes. Hybrid VEMS offers a practical method for systems-focused simulation within an operating hospital by simplifying physical representation while preserving the consequential interdependencies through which hospital response is coordinated and enacted. We propose four principles for its application: design from the system question; abstract representation while preserving consequences; preserve operational function without compromising clinical care; and invest in dynamic facilitation.

Keywords: Translational simulation; Visually Enhanced Mental Simulation; disaster preparedness; mass casualty incident;

1. Introduction

Written disaster plans are necessary for hospital preparedness, but may not reflect how people, processes and resources will interact under pressure. Effective disaster response depends not only on clinical capability or protocol adherence, but also on coordination, resource management and adaptation as situations evolve (1). Yet testing these elements of disaster response is resource-intensive and disruptive, particularly in hospitals already operating near capacity. This creates a preparedness paradox: the systems most in need of testing may have the least capacity to accommodate that testing. We suggest addressing this paradox through thoughtful application of novel simulation approaches and modalities – to achieve effective disaster response testing within contemporary health service constraints.

Existing simulation approaches demonstrate that meaningful disaster preparedness testing does not require physical replication of a mass-casualty event. Established methodologies, including the Emergo Train System (ETS) and the MACSIM simulation system, use simplified physical representations to examine casualty management, command, coordination, and resource utilisation across major incident response (1-3). Tallach and colleagues similarly used iterative low-fidelity exercises to identify latent system problems and refine disaster plans while normal emergency care continued (4). Together, this work demonstrates that meaningful disaster systems testing does not depend on close physical resemblance to a mass-casualty incident.

Despite these advances, a practical design challenge remains: how to move beyond simply simulating disaster response to operational stress-testing the clinical and organisational interfaces through which that response is accomplished, without substantially disrupting ongoing care. This requires those designing exercises to determine which people, decisions, resources, and operational interfaces must remain functionally connected for the disaster response elements being examined.

Translational simulation provides a useful orientation for this purpose, extending simulation beyond rehearsal towards exploration of system performance and healthcare improvement (5, 6). This purpose-first orientation shifts attention from maximising physical resemblance towards selecting simulation features according to the functions they need to serve (7, 8). For disaster systems testing within a capacity-constrained hospital, this means engaging the relevant people and preserving the processes, information flows, resource

constraints and interdependencies necessary to examine the system problem, without reproducing the physical scale of a mass-casualty event.

Visually Enhanced Mental Simulation (VEMS) uses paper representations of patients, clinical equipment and resources to support clinical decision-making and teamwork learning objectives, without requiring physical patients or manikins (9). We adapted VEMS for distributed, multi-department disaster systems testing within a tertiary hospital. The resulting hybrid methodology combined dynamically facilitated patient trajectories with distributed participation and authentic or functionally equivalent operational infrastructure. Decisions about one patient could therefore affect subsequent patients through changes in clinical priority, resource availability and operational capacity.

In this paper, we describe the conceptual foundations, design principles and practical delivery of this approach, illustrated through a six-patient, 14-department multi-casualty exercise conducted alongside ongoing clinical care.

2. Context

2.1 Organisational setting

The Royal Brisbane and Women's Hospital (RBWH) is a large tertiary referral and major trauma centre in Queensland, Australia, with approximately 1,000 inpatient beds and a central role in the state's disaster response network. Sustained clinical demand limits the capacity to release staff, clinical space and operational resources for large-scale disaster preparedness exercises.

In Queensland, a Code Brown activates hospital emergency management arrangements in response to an external emergency or mass-casualty event, initiating coordinated clinical and operational responses across the organisation. We use the term Code Brown in this article to describe this hospital-level major incident response.

2.2 Teamwork and Collaborative Training

The exercise was commissioned by the RBWH Trauma Service to examine frontline hospital mass casualty preparedness. Design and delivery were undertaken by two authors (NS and LO) in their roles as leads for Teamwork and Collaborative Training (TACT), the hospital's embedded translational simulation service. TACT operates through a consultancy model, partnering with clinical and operational services to design simulation around identified healthcare system priorities rather than delivering predetermined educational programmes (10). NS is an emergency physician, and LO is an emergency nurse. TACT had conducted longitudinal interdisciplinary trauma simulation across the hospital for two years before this exercise. These established relationships and local system knowledge supported cross-departmental participation and are relevant to transferability.

3. Conceptual Foundations and Design Logic

3.1 Purpose before modality: Translational Simulation

Exercise design began by defining the system questions rather than a predetermined scenario, casualty number or simulation modality. Consistent with translational simulation's purpose-first orientation, these questions determined which participants, decisions, resources and interfaces needed to be represented. Simulation scale therefore followed the system question rather than serving as a proxy for realism or complexity**.** The input-process-output framework for translational simulation provides the organising structure for describing exercise design, delivery and translation into organisational action (6).

3.2 Preserving functional interdependencies

Although paper-based approaches are commonly characterised as "low fidelity", this terminology can obscure important distinctions between physical representation and functional task alignment (7). Cognisant of this distinction, our design choices prioritised interactions relevant to hospital disaster preparedness over

physical resemblance. Patients and selected resources were represented on paper, while participants worked in their usual professional roles through existing communication systems, transport and operational pathways wherever feasible. These simulated and operational elements remained dynamically connected**:** patient deterioration altered clinical priorities, resource use affected subsequent availability, and decisions about treatment, theatre access and patient movement generated competing demands across services. Isolated or functionally equivalent systems were used where live infrastructure could not be used safely. The design therefore deliberately abstracted some elements of care while preserving the interdependencies relevant to the system question.

4. Design and Methodology

4.1 Input phase: Problem definition and design

TACT led exercise design, drawing on embedded clinical knowledge, review of hospital disaster plans and targeted consultation with people responsible for relevant parts of the response. Consultation explored how activation, patient prioritisation, blood supply, theatre access, patient movement and surge capacity were expected to function, and identified interfaces where planned processes and actual work might diverge. Trauma and emergency clinicians also advised on the clinical plausibility of patient trajectories.

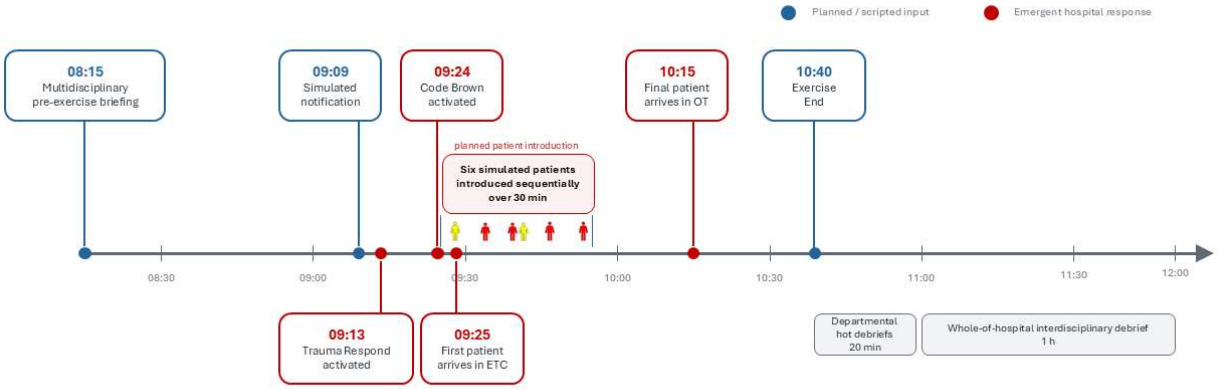
Four system functions were selected for focused inquiry: Code Brown activation and notification; interdepartmental coordination under concurrent demand; blood-product management and prioritisation; patient flow and decanting during surge. These questions determined which services, workflows and resource dependencies needed to be represented in the exercise.

4.2 Process phase: Scenario design

The exercise was conducted on 20 November 2024 alongside routine hospital operations. Participants knew the date, approximate timing, exercise objectives, relevant interfaces and that they would work in their usual roles but were not told the incident mechanism or number of simulated patients. Following a multidisciplinary pre-exercise briefing at 08:15, participants returned to usual clinical and operational duties.

The scenario involved a multi-casualty incident following a stabbing event at a shopping centre. Six simulated patients – four critically injured and two seriously injured – were designed to be introduced sequentially over 30 minutes following a simulated pre-hospital notification. Five required urgent operative intervention, including two requiring immediate damage-control surgery. The timing of subsequent hospital response processes, including Trauma Respond and Code Brown activation, was not scripted; these arose through participants working within usual response pathways (Fig. 1).

Figure 1. Planned scenario inputs and observed hospital response during the multi-casualty exercise



ETC = Emergency and Trauma Centre; OT = operating theatre.

Six casualties were pragmatically selected to create concurrent demand across multiple interfaces while preserving individual patient-level granularity and operational feasibility. The number was not intended to represent a predetermined threshold for system stress, and whether this level of demand would expose meaningful operational constraints was unknown.

The active exercise ran for approximately 90 minutes, followed by 20-minute departmental hot debriefs, and a one-hour cross-departmental debrief. This schedule was designed to permit exercise delivery and debriefing within a half-day period.

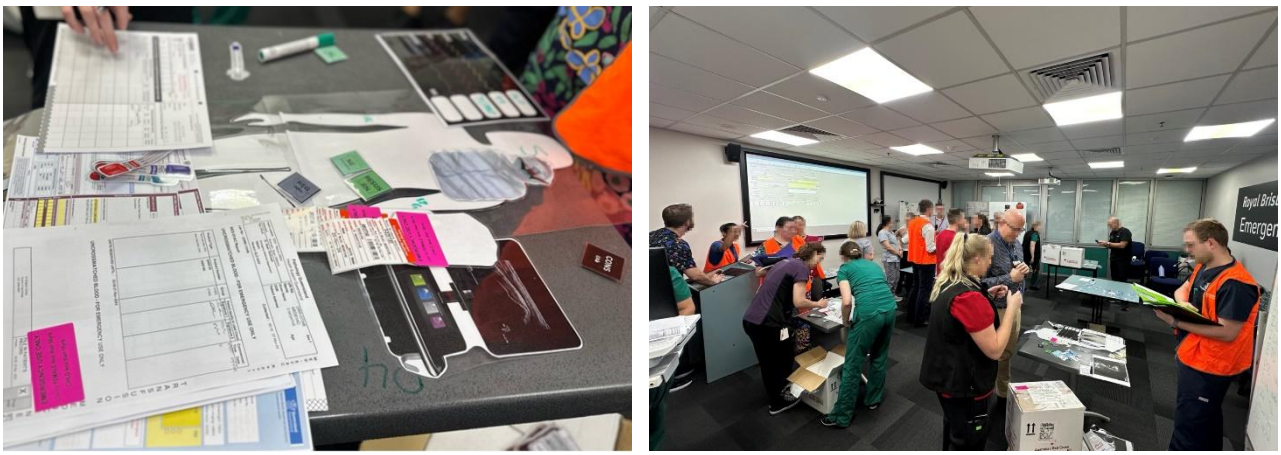
4.3 Process phase: Hybrid VEMS modality

Each patient was represented visually as a laminated paper silhouette. An emergency clinician facilitator stood next to each patient and provided handover information, observations, clinical findings and investigation results in real time. Patient materials included relevant investigation results and the hospital forms, charts and patient-identification labels normally used for trauma care and resource requests (Fig. 3).

The clinical progression of each patient case was based on plausible penetrating-trauma presentations,

informed by prior clinical experience and refined with trauma-clinician input. Facilitators contributed to case development and were briefed on expected clinical progression, key decision points and agreed parameters for deterioration or improvement.

Figure 3. Example patient representation and hybrid VEMS exercise in progress



The exercise focused on roles, processes and interdependencies rather than procedural skill. Procedures that did not need to be physically performed were therefore abstracted: participants stated the intended intervention, while a facilitator described the patient's physiology and clinical progression before advancing the clinical state after an agreed interval. Participants then enacted the decisions, communication and coordination required to progress care. Expected timings for investigations and service responses were obtained pragmatically from relevant departmental leads rather than from formal audit measurement. Patient case progression was matched to operational conditions, with staff, equipment and blood products treated as finite resources. Blood Bank used its usual ordering workflow and recreated available inventory as individually labelled paper products. Products were ordered and transported through usual pathways and removed from simulated stock as allocated, allowing resource use for one patient to alter availability for subsequent patients. Operative prioritisation and transfer decisions similarly generated downstream demands.

Centralised control of the exercise was deliberately light. One lead coordinated patient arrivals into ED triage, while a second remained mobile and available by DECT to troubleshoot ambiguity or safety concerns. Otherwise, the response unfolded through usual workflows. For example, surgical review in ED led to direct communication with the theatre coordinator, who worked with the anaesthetist in charge to identify theatre

and staff capacity before decisions were communicated back to ED and patients were physically transferred between represented clinical areas. Coordination was not scripted. Unanticipated decisions, delays and workarounds were generally allowed to unfold, with their downstream consequences incorporated into the evolving exercise rather than redirected towards a predetermined pathway.

Table 1 illustrates how the hybrid design deliberately varied physical representation while preserving the functional relationships relevant to each system question.

Table 1. Functional design of the hybrid VEMS exercise

System function	Simulated element	Operational function retained	Consequence preserved
Patient flow and decanting	A closed electronic ED clinical information system populated with patient-level data representing the preceding week's ED occupancy	The ED's familiar electronic interface and shared information environment available to ED and Patient Flow	Participants had to identify patients suitable for discharge, transfer or escalation; these decisions altered simulated available capacity
Communication and notification	Proxy DECT extensions and an exercise-specific Switchboard directory, with no overlap with live clinical numbers	Existing DECT devices and Switchboard processes	Participants navigated familiar communication tools and processes while exercise traffic remained isolated from clinical operations
Clinical prioritisation	Paper patient representations with dynamically facilitated clinical trajectories	Clinicians working in their usual professional roles	Treatment, delay and competing priorities altered patient state and subsequent clinical demand
Investigation and intervention timing	Procedures and investigations represented rather than physically performed	Expected completion times informed by relevant departmental leads	Results and intervention effects occurred after specified intervals, preserving elapsed time and downstream consequences.
Blood-product coordination	Simulated blood-product demand with paper stock tracked across patients	UR-labelled requests using the existing Blood Bank ordering process	Allocation of O-negative blood reduced the stock available for subsequent patients, creating competing demands across concurrent MHPs
Interdepartmental coordination	Distributed simulated patients generating concurrent clinical and operational demands	Participating services working through their usual roles and coordination structures	Decisions and resource allocation in one service altered priorities and demands encountered elsewhere

System function	Simulated element	Operational function retained	Consequence preserved
Patient transport	Paper patients requiring transfer between represented clinical areas	Patient support officers using actual hospital lifts and routes between exercise locations	Lift availability, transfer time and PSO workload influenced simulated patient movement
Physical geography	Clinical areas represented in adjacent non-clinical spaces: for example, 'ED' adjacent to the live ED on Ground Floor and 'Theatre Hub' adjacent to the live Theatres on Level 4	Actual hospital floors, routes and inter-floor relationships	Relevant distances and inter-floor dependencies remained part of communication, coordination and transfer work without occupying live clinical spaces

4.4 Process phase: Participants and faculty

More than 40 staff participated, representing 14 clinical and operational departments: emergency department, executive services, medical imaging, surgery, trauma service, blood bank, patient flow, patient support services and switchboard. Participation arrangements varied by service: some staff attended during non-clinical time, some departments added staffing to absorb exercise-related workload, and others, including patient support services, participated through their usual operational roles.

The simulation faculty comprised 13 facilitators assigned to individual patients and departmental observation roles. Because the patient cohort was small, facilitators could be matched with patient cases where they had contributed to scenario development. Communication between facilitators and exercise leads enabled changes in patient, resource or system state to be propagated across the distributed exercise.

4.5 Process phase: Simulation safety and system integrity

Authentic systems were used wherever this could be done safely. Where the exercise risked interfering with clinical care, the relevant function was isolated rather than omitted. Participants used existing DECT handsets and Switchboard processes with proxy telephone numbers, and ED and Patient Flow used a closed electronic environment for simulated decanting. Exercise communications were explicitly identified as simulated, with a "NO DUFF" convention reserved for real clinical or operational emergencies.

4.6 Output phase: Debriefing and reporting

Debriefing occurred at departmental and hospital levels. Immediately after the exercise, departments used locally adopted iSTART hot debriefs (Introduction and intent; Summary; Things that went well; Areas for improvement; Recommendations requiring follow-up; Thanks and take care) to document local observations and actions. The subsequent interdisciplinary debrief, structured around the exercise objectives, was audio-recorded to support reporting and enabled observations from different parts of the response to be compared and connected. Facilitators and exercise leads also recorded observations during the exercise.

The exercise leads subsequently met with relevant services to clarify findings and refine recommendations with those responsible for the work. Recommendations were assigned to relevant services and progressed through established governance, including the Trauma Review Committee and Emergency Management and Business Continuity Committee.

5. Findings and organisational responses

5.1 System interactions made visible

The six-patient exercise generated concurrent demands across the targeted clinical and operational interfaces. Several observations illustrate the types of system interaction made available for examination through the hybrid VEMS approach.

Activation and communication. Existing notification pathways did not include all required frontline services, requiring additional sequential notification. Conflicting uses of colour coding for unknown-patient identification and trauma priority also created ambiguity across departmental boundaries. These observations identified vulnerabilities in communication architecture and shared information rather than individual communication performance.

Blood-product coordination. Simulated O-negative blood availability was exhausted within 14 minutes of the first patient arrival, as individual teams requested products based on anticipated patient need without visibility into concurrent demand. This illustrated a coordination problem between otherwise appropriate local decisions and system-level resource availability.

Patient flow and transport. ED and Patient Flow teams used the closed electronic environment to identify opportunities for decanting, enabling simulated capacity to be redistributed during the exercise. Patient transfer between floors, however, generated delays related to lift access and transport demand. In response, the PSO coordinator introduced a dedicated lift-controller function during the exercise.

Perioperative capacity. Theatre space could be identified and cleared, but the ability to open additional theatres was constrained by available staffing. Information regarding patient priority and resource availability also differed between ED and perioperative teams at several points during the exercise.

5.2 Translation into organisational action

Exercise observations and debrief findings were consolidated into 12 recommendations and progressed through hospital governance, with examples of subsequent organisational responses shown in Table 2. These outputs are presented as illustrations of translation from simulation-generated system inquiry into organisational review and action, rather than evidence that the exercise improved disaster performance or patient outcomes.

Table 2. Examples of simulation-generated system observations and subsequent organisational responses

Exercise observation	**Subsequent organisational response**
Existing notification pathways did not include all required frontline services, requiring additional sequential notification *(see Section 5.1)*	Paging groups updated to include ICU, Patient Flow and PSO Coordinator
Confusion between trauma triage and unknown patient colour-coding systems, resulting in patient prioritisation confusion for theatre *(see Section 5.1)*	Unknown patient colour system revised in collaboration with Health Information Services and QEDSAP.
Concurrent blood-product requests rapidly depleted simulated O-negative stock	Working group established to examine a formal Blood Coordinator role
Transfer delays associated with inter-floor patient movement and lift access	Lift controller role formalised
Existing disaster plans did not specify management of intra-operative deaths during mass-casualty events	Disaster plans revised

6. Discussion

6.1 Hybrid VEMS supports selective abstraction

This exercise illustrates how VEMS can be extended from patient- and team-level simulation to distributed hospital systems. The methodological contribution is not reduced physical resemblance itself, which is well established in disaster simulation, but selective abstraction (11): simplified patient and procedural representations were coupled with authentic or protected operational systems so that clinical and organisational decisions retained downstream consequences.

We suggest this extends the principle of functional task alignment from individual tasks towards functional interdependence across a work system. Much of the friction in this exercise arose through participants interacting with existing workflows, finite resources and organisational interfaces, rather than from disruptions introduced by exercise control.

Hybrid VEMS therefore complements established disaster simulation approaches by examining distributed clinical and operational interdependencies with a relatively small physical footprint. For translational simulation practice, selective abstraction offers a way to connect exercise design directly with system inquiry and subsequent improvement action.

6.2 'Right-sizing' – designing scale for exercise purpose

The six-patient scenario was selected to preserve granularity and operational feasibility rather than to test a surge threshold. Nevertheless, coordination and resource pressures emerged, suggesting casualty number alone may be a poor proxy for system demand. Viewed through the established surge-capacity domains of staff, stuff, space and systems, constraints arose through interaction between domains: theatre space could be identified but not necessarily staffed, while available blood products were rapidly depleted by concurrent requests without system-level visibility.

This is consistent with MACSIM work showing that surge capacity gaps are identified through interactions among multiple functions, with different constraints becoming limiting over time (3). Exercise scale might therefore be calibrated to the interactions and operational pressures required by the preparedness question rather than casualty number alone. Larger exercises remain necessary where sustained surge, command structures or response at scale are the object of inquiry.

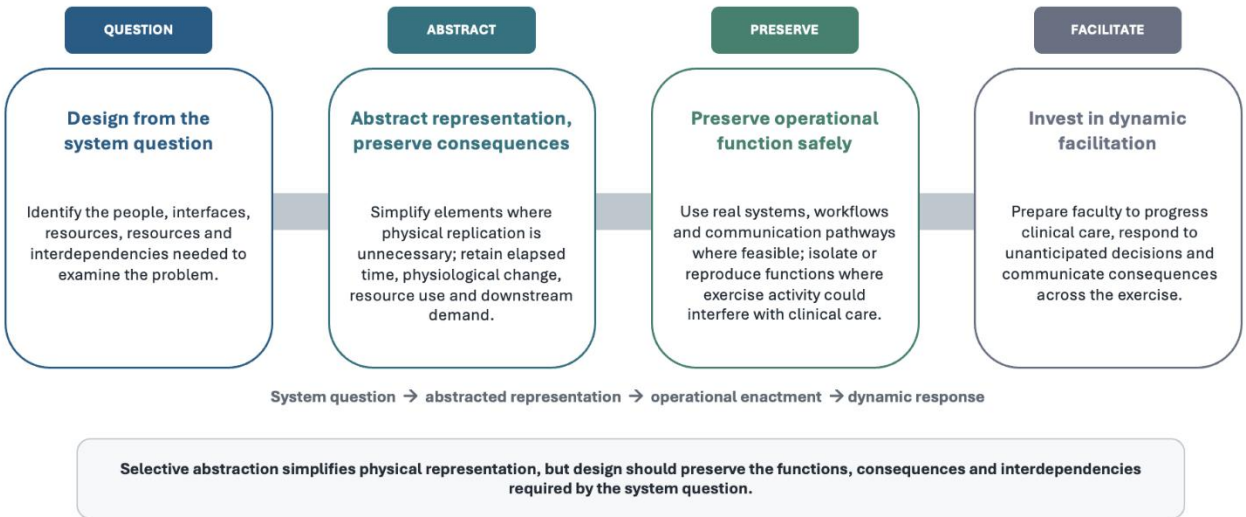
6.3 Simulation as joint problem discovery

The exercise was deliberately framed as system inquiry rather than participant assessment. Local and cross-departmental debriefs brought together distributed operational perspectives, and several potential solutions emerged from participants during the exercise and debriefing rather than being specified in advance. Systems-focused simulation may therefore do more than reveal whether planned processes succeed or fail. It can bring together staff who ordinarily see different parts of the response to identify problems and develop solutions together. This is consistent with translational simulation approaches that position healthcare professionals as partners in system improvement (5, 6). Progression through established governance provided a mechanism for these observations to enter organisational improvement processes.

6.4 Practical Implications for Translational Simulation Practice

Our experience suggests four design principles for applying hybrid VEMS to systems-focused translational simulation (Fig. 2): design from the system question; abstract physical representation while preserving relevant consequences; preserve operational function without compromising clinical care; and invest in dynamic facilitation. Although developed through disaster preparedness simulation, these principles may apply more broadly to simulation used to examine interactions across clinical and operational systems.

Figure 2. Design principles for hybrid VEMS in translational simulation



Dynamic facilitation warrants particular attention. Simplifying physical representation did not simplify exercise delivery. Faculty needed to track clinical trajectories, respond consistently to unanticipated decisions and communicate consequences across the distributed exercise. These capabilities may be applicable beyond hybrid VEMS and represent a relevant focus for translational simulation faculty development.

7. Limitations

This paper describes a single exercise conducted at a tertiary hospital with an embedded simulation service and established interdisciplinary relationships. These conditions likely supported exercise design, recruitment and delivery, but may limit generalisability to settings without comparable simulation infrastructure or institutional relationships.

Dynamic facilitation required substantial faculty input. The small patient cohort enabled close tracking of individual trajectories and their consequences across the exercise. Scaling this approach introduces trade-offs between patient-level granularity, facilitator workload and exercise complexity that are beyond the scope of this paper.

Operational constraints limited the extent to which usual workflows could be preserved. The exercise was not resource-neutral, requiring a mixture of non-clinical time, additional departmental staffing and participation through usual roles. Although proxy DECT numbers reduced interference with clinical traffic, some services retained usual contact pathways and minor confusion occurred between exercise and clinical communications. This illustrates an inherent trade-off in embedded systems simulation: increasing operational authenticity may also increase interference with the system being examined.

Exercise observations and organisational responses arose through an improvement process rather than a prospectively designed research study. Organisational impact is therefore described through recommendations and documented system changes; participant experience was not formally evaluated, and patient outcomes or validated measures of organisational learning were not assessed. Subsequent changes cannot be attributed solely to the simulation.

Finally, the conceptual framing is partly retrospective. Translational simulation informed the exercise purpose, while functional task alignment and related systems concepts were subsequently used to interpret and articulate design choices. They should therefore be understood as explanatory lenses rather than mechanisms tested by this exercise.

8. Conclusion

Hospital disaster preparedness requires methods that can examine system behaviour without suspending routine clinical operations. Hybrid VEMS offers one approach by combining simplified patient representations with dynamically facilitated trajectories and authentic or protected operational systems, allowing decisions and consequences to propagate across distributed clinical and operational work.

This exercise demonstrates the feasibility of multi-department systems inquiry alongside ongoing clinical care. Its central design principle was to simplify physical representation while preserving the relationships between clinical decisions, resources and operational systems. For disaster simulation, the methodological challenge may therefore be less about reproducing the physical scale of an event than preserving the interdependencies through which the hospital response is accomplished.

Declarations

Ethics approval and consent to participate

The exercise was undertaken as a hospital quality-improvement activity involving simulation of organisational processes, with no patient involvement or collection of patient data. In accordance with Metro North Health institutional guidance, formal research ethics committee approval was not required.

Consent for publication

Not applicable.

Availability of data and materials

Datasets are available on reasonable request

Competing interests

VB is Senior Editor at Advances in Simulation. VB is employed by Bond University, which delivers courses and consultancy in translational simulation. VB is also a Director of Simulation Simplified, a company that manufactures equipment for VEMS training.

NS and LO declare no competing interests.

Funding

No specific funding was provided for this work.

Authors' contributions

NS and LO designed and delivered the simulation exercise. NS interpreted the exercise findings, conceptualised the manuscript, refined and finalised the literature review, and wrote the original draft. LO conducted the primary literature review and reviewed the manuscript. VB contributed to the manuscript's conceptual framing and critically reviewed and edited successive drafts. All authors reviewed and approved the final manuscript.

AI-use disclosure statement

Generative artificial intelligence (ChatGPT, OpenAI) was used during manuscript preparation to support editing and refinement of author-generated text, including improvements to clarity, structure, consistency of terminology, and to assist with the design and formatting of figures. All substantive ideas, interpretations and conclusions were developed by the authors. The authors critically reviewed and edited all AI-assisted revisions and take full responsibility for the final content of the manuscript.

Abbreviations

DECT – Digital Enhanced Cordless Telecommunications

ED – Emergency Department

TACT – Teamwork and Collaborative Training

VEMS – Visually Enhanced Mental Simulation

QEDSAP – Queensland Emergency Department Strategic Advisory Panel

MACSIM – Mass Casualty Simulation System

PSO – Patient Support Officer

MHP – Major Haemorrhage Protocol

UR – Unit Record

RBWH – Royal Brisbane and Women's Hospital

ETS – Emergo Train System

ICU – Intensive Care Unit

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