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INTEGRATING EPIDEMIC SIMULATION INTO CRISIS MANAGEMENT PROGRAMS: LESSONS FROM UKRAINE

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Crisis-management programs (PHEOC/ICS) need decision-ready analytics under uncertainty. Russian war in Ukraine, marked by attacks on health care, sustained displacement, and environmental shocks, exposes the limits of ad-hoc modelling and the value of routine, integrated simulation support. To synthesize recent evidence on how epidemic simulation can be embedded in crisis-management workflows and to distill practical lessons from the Ukraine context. Methods: Rapid narrative review of 2023–2025 peer-reviewed studies and authoritative guidance. Findings were thematically mapped to PHEOC/ICS functions. The literature converges on four effective integration points: planning, operations, logistics, and risk communication. Multi-model ensembles are most reliable for short horizons; scenario exercises support medium-term strategy when assumptions are explicit and versioned. Displacement-aware inputs can triangulate shifting catchments; modular focus areas include measles catch-up, polio immunity maintenance, TB care cascades, and WASH-sensitive risks after infrastructure damage. Enablers are a fixed cadence, standard one-page briefs, clear roles (modelling liaison), equity checkpoints, and decision logs. Common barriers are data plumbing, staffing, and product–process mismatches. We provide an operational template and a concise checklist that translate current evidence into routine command practices: weekly ensemble briefs, scheduled scenario cycles, displacement-aware data pipelines, and explicit mapping of outputs to ICS artefacts. These steps are immediately actionable in Ukraine and transferable to other high-constraint settings.

Introduction

Public health emergencies place decision makers under tight time and information constraints. Incident management frameworks, such as the Public Health Emergency Operations Centre (PHEOC) and the Incident Command System (ICS), were built to structure those decisions by coordinating information, operations, and logistics across agencies [1]. Epidemic simulation can add value in this setting by translating surveillance and capacity data into short-term forecasts and scenario comparisons aligned with incident action planning [2]. Evidence from the COVID-19 period shows the promise of modelling and the limits that arise when assumptions shift or uncertainty is not communicated well [3]. Recent reviews argue that models inform policy best when integrated into established response workflows, with clear products, cadence, and roles [4]. However, scoping work on PHEOCs finds that such integration remains uneven, with data management, staffing, and governance gaps [5]. These points motivate a focused synthesis on how to embed epidemic simulation into crisis management programs in feasible and useful ways.

Ukraine offers a critical case. Since the escalation of the Russian war in 2022, the health system has faced sustained attacks on facilities and personnel, persistent displacement, and strain on routine services. WHO has documented more than two thousand attacks on health care in Ukraine [6], and UNHCR reports millions of people displaced inside the country and across borders [7]. These conditions complicate surveillance, supply chains, and access to care, precisely the areas where crisis programs and decision support must perform.

The epidemiological risk landscape has also shifted. The WHO European Region reported the highest number of measles cases in over 25 years in 2024, underscoring the danger of immunity gaps in mobile and hard-to-reach populations [8]. At the same time, Ukraine's 2021 cVDPV2 polio outbreak was officially closed in September 2023, showing that targeted vaccination can succeed despite conflict [9]. Tuberculosis (including drug-resistant TB) remains a regional concern, with WHO's 2024 global report and country assessments noting elevated incidence and challenges linked to displacement and service disruption [10]. Conflict-related environmental shocks further raise risk: the 2023 destruction of the Kakhovka Dam degraded water and sanitation infrastructure and, according to recent studies, mobilized legacy heavy metals and other contaminants, hazards that can elevate water- and rodent-borne disease risks in affected communities [11]. Together, these signals illustrate the need and the opportunity to use simulation to anticipate burdens and compare interventions under constraints.

Operationalizing simulation in this setting requires reliable situational inputs. Recent work shows that displacement and population mixing, key drivers of infectious spread, can be monitored using complementary data sources [12]. Studies have nowcast internal displacement in Ukraine using social media activity, GPS-based human mobility, and satellite-based vehicle counts, offering different coverage and bias profiles [13]. Combined with routine surveillance and capacity data, these streams can help parameterize timely models to inform planning meetings and resource allocation.

This rapid review synthesizes practical lessons on integrating epidemic simulation into crisis management programs, drawing on Ukraine as the primary context. We map where models can support the ICS/PHEOC cycle, summarize enablers and barriers identified in recent guidance and reviews, and distil actionable steps suitable for short, repeatable decision cycles. The aim is to translate current evidence into simple, usable guidance for teams making high-stakes choices under uncertainty.

Methods

We conducted a rapid narrative review to synthesize how epidemic simulation is integrated into crisis management programs, with Ukraine as the focal context. Methods followed evidence-informed rapid-review guidance and recent handbooks for narrative synthesis. Specifically, we drew on the 2024 Cochrane Rapid Reviews Methods recommendations, the JBI Manual for Evidence Synthesis, and reporting resources for non-meta-analytic syntheses.

We included sources that examine epidemic modelling/simulation used for or proposed to support incident management, emergency operations, or policy decision making, or describe crisis management frameworks relevant to modelling integration or analyze Ukraine's public health emergency management since 2022, where modelling or decision support is discussed. We considered peer-reviewed articles and authoritative organizational reports/guidance to ensure operational relevance. Framework references for PHEOC/ICS/HICS were used to anchor concepts.

We prioritized items published January 1, 2023 – August 25, 2025 to reflect current practice. Seminal earlier framework documents were retained when no newer equivalents existed.

We searched PubMed/MEDLINE, Scopus, and Web of Science for peer-reviewed literature, and we searched targeted grey literature portals and organizational sites.

Given the narrative, mixed-evidence scope, we assessed reporting quality and credibility rather than applying study-design-specific risk-of-bias tools across all sources. We used the SANRA quality elements for narrative and guidance documents to guide appraisal and structure notes on strengths/limitations. For textual/qualitative evidence, we used JBI 2024 textual-evidence guidance to judge clarity, coherence, and source authority.

Results

The literature converges on a practical view of where simulation fits inside emergency programs: models are most useful when their outputs are delivered at the same rhythm and decision points as an IMS or PHEOC. Guidance from WHO's EOC-NET and CDC's IMS materials describes those decision points, situation assessment, incident action planning, resource tasking, and public briefings, and emphasizes the information flows and roles that turn analyses into orders [14, 15]. In this frame, simulation is not an external «report» but a recurring input to the incident action plan and the briefing cycle.

Recent evaluations have found that multi-model approaches are the most dependable way to supply these recurring inputs [16]. Studies of the U.S. Forecast Hub and Scenario Modelling Hub show that ensembles stabilize performance and yield better-calibrated short-term forecasts than most single models [17]. At the same time, longer-range scenario exercises support planning when assumptions are explicit and versioned. These hubs also document what increases use in practice: fixed delivery schedules, common file formats, and concise uncertainty statements that explain what could change the recommendation.

Several reviews add why this «hub mindset» aligns with decision-making. First, decisions are often comparative rather than absolute, making ensembles and structured scenarios a natural fit [18]. Second, the design of scenarios matters: framing choices with decision analysis principles improves relevance and transparency [19]. Third, the interface needs care, knowledge-translation roles, standard slide templates, and decision logs to reduce friction between modellers and incident managers [20].

Applied to Ukraine's conditions since 2022, the same integration logic becomes more urgent. WHO/Europe has verified more than 2,254 attacks on health care as of February 2025, disrupting facilities, staff safety, supply routes, and routine data systems, precisely the elements an operations section depends on [6]. In parallel, UNHCR reports that millions of people remain displaced inside the country, and millions more are abroad, creating shifting catchments and uncertain denominators for service planning [7]. In such a setting, routine model products that plug into the incident briefing are more valuable than one-off analytics.

Recent studies also expand the data layer for displacement-aware planning. High-frequency social-media advertising data have been used to nowcast internal displacement at the subnational scale during the first months of the invasion [12]. Very high-resolution satellite car counts and other remote-sensing approaches provide complementary signals [21]. Newer work triangulates across digital traces to track flows across borders [22]. Each source has bias and coverage limitations, but together, they offer timely proxies when administrative data lags, useful for prioritizing outreach, staging supplies, and adjusting micro-plans.

The communicable disease picture in and around Ukraine sharpens the operational need for this pairing of models and command processes. WHO/Europe and UNICEF recorded 127,350 measles cases in the Region in 2024, the highest since 1997, while ECDC reports sustained transmission into early 2025 [8, 23]. Those signals argue for displacement-aware catch-up vaccination scenarios linked to incident triggers and logistics checklists. Conversely, the cVDPV2 polio outbreak

detected in 2021 was formally closed in September 2023, a reminder that targeted campaigns can deliver results even under wartime constraints when surveillance, micro-planning, and operations align [9].

Tuberculosis remains a persistent concern that crosses borders and care systems. The WHO Global Tuberculosis Report 2024 and the joint ECDC/WHO regional surveillance report describe ongoing burdens of TB and MDR/RR-TB and highlight pressures on case finding and continuity of care, precisely the weak points during conflict and displacement [10, 24]. For integration, the most relevant model outputs are those that stress-test the care cascade and quantify the effect of treatment interruptions on outcomes and resourcing.

Environmental shocks compound these risks. Peer-reviewed analyses of the Kakhovka Dam breach document pulses of sediment and nutrients into the north-western Black Sea and raise plausible concerns about contaminant mobilization and WASH-related disease hazards downstream [25]. UNEP's independent assessment and scientific reporting underscore how cascading environmental effects alter the operating environment for public health programs [26]. In such contexts, the literature supports using scenario-based simulations to test whether safe-water distribution, vector control, and surveillance boosts are adequate under different access and supply constraints.

The same sources clearly state what helps and hinders integration. On the enabling side, PHEOC/IMS provides the standing products and cadence into which ensembles and scenarios can be dropped with minimal translation. Recent European and WHO guidance also elevates simulation exercises (SimEx) and after-action reviews (AARs) as the main tools to institutionalize the modeller–operator handshake [27]. Teams can rehearse thresholds, see whether forecasts actually change orders, and refine formats before the next activation.

On the barrier side, a 2023 scoping review finds recurrent gaps in data management, staffing, and information-sharing inside PHEOCs, along with product–process mismatches [5]. These findings explain why otherwise strong analyses have limited impact: without clear data plumbing and a place on the agenda, forecasts arrive too late or in the wrong shape. Recent work on exercise design offers practical remedies, clarifying objectives, standardizing artefacts, and embedding evaluation, so that integration is practised, not improvised [28].

Equity is another thread running through recent guidance that interacts directly with modelling. Hospital and system-level studies propose concrete ways to embed equity roles and metrics into HICS, from job action sheets to activation checklists [29]. These structures make it easier to translate model outputs about

coverage gaps among displaced or hard-to-reach groups into tasking [30]. This is especially relevant in Ukraine and host countries, where access barriers vary by location and status.

The extended evidence suggests a simple pattern. First, ensembles and structured scenarios, delivered on a fixed cadence and documented with clear assumptions, perform more reliably and are easier to use in command settings than bespoke single-model reports. Second, the fit to the decision matters: when outputs are linked explicitly to ICS/PHEOC products (incident objectives, resource checklists, job action sheets), uptake improves. Third, Ukraine's operating constraints, attacks on care, sustained displacement, and environmental disruption, shape both the parameters and the feasible options the models should test. The most useful simulations, therefore, combine displacement-aware catchment estimates, care-cascade stress tests, and WASH-sensitive scenarios, all embedded in the routine briefing rhythm of the response.

The literature is consistent on communication: decision makers respond better to probabilistic outputs with plain language caveats and a short statement of «what would change our advice», rather than to point estimates [31]. New guidance from WHO on communicating uncertainty in health emergencies and qualitative work with policy users reinforces this [32]. When these practices are institutionalized, a standard slide, a named liaison, and a decision log, simulation stops being an occasional input and becomes part of the program's operating system.

Table 1 presents a checklist that distils recent evidence on embedding epidemic simulation in crisis-management programs, focusing on conflict-affected settings such as Ukraine.

Table 1

Checklist

Action	Implementation	Why it matters
1	2	3
Anchor modelling inside the command structure	Place a modelling/analysis cell under Planning in the PHEOC/ICS org chart; pre-define activation levels and reporting lines.	PHEOCs are designed to coordinate analysis into action. Explicitly placing modelling in the workflow improves uptake.
Adopt a fixed cadence & standard products	Issue a one-page briefing on a set schedule (e.g., weekly forecasts; monthly scenarios) with assumptions, uncertainty bands, and «what would change the advice».	Forecast/scenario hubs show higher policy use when outputs are routinized and standardized.

Continuation of the Table 1

1	2	3
Prefer ensembles & hubs for operations	Use an ensemble for near-term indicators; use multi-team scenario hubs for horizon scanning.	Ensembles are better calibrated on average; scenario hubs support comparative planning when assumptions are explicit.
Map outputs directly to ICS artifacts	Tie thresholds to ICS-202 (Incident Objectives); turn options into ICS-204 (Assignments); log rationale in ICS-214 (Activity Log).	Direct mapping turns numbers into orders without reformatting.
Specify the minimum viable data feeds	Maintain live feeds for: surveillance/labs; immunization & stocks; facility capacity; displacement/mobility; WASH/env.	Guidance identifies these as core information streams for effective PHEOC operations.
Triangulate displacement & access	When registries lag, combine Meta ads, GPS/mobile mobility, and satellite car counts to refine catchments and outreach.	Recent Ukraine studies validate each proxy and their complementarity for subnational nowcasting.
Stress-test WASH-sensitive scenarios	Include safe-water, surveillance, and vector-control options under different access/supply constraints.	UNEP rapid assessment and peer-reviewed analyses document contamination risks and hydrologic disruption after the dam breach.
Build an equity checkpoint into every cycle	Name an Equity Lead in HICS/PHEOC; add an «equity impact» line to each modelling brief and ICS-202.	Empirical and review work shows practical ways to embed equity roles and metrics into HICS.
Use plain-language uncertainty	Report probabilistic ranges; state key assumptions and explicit triggers for revision; align with RCCE principles.	Clear uncertainty communication increases trust and actionability in emergencies.
Exercise the interface; learn from it	Run SimEx that rehearse how forecasts change orders; conduct AARs to check timeliness, comprehension, and impact.	WHO/EU guidance and recent SimEx reports highlight SimEx/AARs as key institutional levers.
Record decisions & rationale	Keep a decision log linked to the modelling brief and ICS-214.	Standardized activity logs support accountability and rapid updates.
Plan data plumbing & governance	Document owners, sharing agreements, refresh rates, and fallbacks; resource the information function.	PHEOC assessments cite data management and staffing as recurrent gaps.
Define roles & liaisons	Assign a Modelling Liaison to Planning/Incident Commander; pair with Risk-Comms lead for joint briefings.	Formal role definitions reduce friction and align products with decisions.
Match questions to methods	Use ensembles for staffing/supply in the next 1–4 weeks; scenarios to compare strategic options; nowcasting for situational awareness.	Different decision horizons require different tools; CDC articulates the scenario role, and recent ensemble work supports near-term use.
Close the loop with evaluation	Add a standing «Was this useful?» item to planning meetings; track actions linked to modelling in AAR.	Continuous evaluation is embedded in current preparedness and exercise guidance.

Discussion

Our results show that simulation becomes useful when it is delivered at the same points where command teams make choices, during planning, operations, logistics, and briefings, and on a regular cadence. This placement is not incidental: PHEOC/IMS guidance is built around recurring products (situation assessments, incident objectives, resource requests) and a meeting rhythm that converts information into tasking. Aligning model outputs to that rhythm lowers the cost of use. It explains why programs that treat simulation as a standing input, rather than an occasional report, see more consistent uptake. Recent WHO materials on EOC practice, and national handbooks derived from them, reinforce this operational logic [14].

The evidence is strongest for two model types serving different horizons. First, near-term ensembles offer more stable accuracy than individual models for the one-to-four-week window that operations sections care about [33]. Evaluations of the US Forecast Hub repeatedly show better calibration and fewer large errors when teams are combined [34]. Second, scenario hubs can inform planning several months out when the big drivers are stated upfront and versioned, a point underscored by the formal assessment of the US Scenario Modelling Hub [3]. These findings support a dual track in crisis programs: ensembles for staffing, beds, and supplies, scenarios for strategy and contingency planning.

The Ukraine case adds concrete constraints that shape how those tools should be used. Sustained attacks on health care have reduced facility availability and disrupted routine data flows; at the same time, displacement has remained large and mobile, shifting catchments and denominators. Under such conditions, the value of simulation lies less in precise point prediction and more in converting noisy inputs into threshold-based options that map to incident objectives and orders. Documented counts of attacks and current displacement totals indicate this is not a transient problem. Hence, making simulation a routine part of PHEOC planning is a practical response rather than a research ideal.

Interpreting our results from data sources, we see that the literature supports a pragmatic triangulation strategy. Social media advertising data, mobile device mobility traces, and satellite-based car counts introduce bias. However, when combined, they move faster than registries and can track subnational population change closely enough to steer outreach and staging. The implication for practice is not to replace administrative data but to treat these feeds as early signals that are folded into the PHEOC information function with explicit caveats and periodic checks against surveys or official tallies.

Our results also indicated that disease risks around Ukraine pull in different directions: a surge of measles across the WHO European Region in 2024 demands catch-up vaccination and outreach, while the formal closure of Ukraine's 2021 cVDPV2 polio outbreak shows that targeted campaigns can succeed even during conflict. Rather than contradicting each other, these signals point to modular use of simulation: short-term demand forecasts and micro-planning support for measles; monitoring and contingency scenarios to maintain polio immunity in mobile populations.

For tuberculosis, our results suggest shifting the modelling question from «how many infections?» to «where does the care cascade break under strain?». Regional surveillance highlights the continued burden of MDR/RR-TB and the risk posed by treatment interruptions [35]. In that context, scenario comparisons that test adherence support, drug supply continuity, and cross-border referral are more decision-relevant than transmission-only outputs.

Environmental disruption after the Kakhovka Dam breach sharpens this orientation toward scenarios. Studies document altered hydrology and likely mobilization of contaminants, but the operational issue is whether current WASH measures and surveillance remain adequate under different access constraints. The results, therefore, support embedding WASH-sensitive scenarios, safe-water distribution, vector control, and intensified testing into the planning cycle for the affected oblasts.

The enablers and barriers we identified also interpret the results in practical terms. Scoping reviews of PHEOCs consistently flag data management, staffing, and information-sharing as limiting factors; our mapping to ICS artefacts directly responds to those gaps, making it easier for numbers to become orders. Likewise, the prominence of simulation exercises and after-action reviews in current ECDC and WHO guidance matches the result that integration improves when teams rehearse thresholds and hand-offs before activation.

The results on communication argue for disciplined uncertainty practices. WHO's 2024–2025 guidance clearly states that confidence grows when leaders and the public hear what is known, what is unknown, and what would change the advice. Translating that into one-page briefs for the Planning meeting, paired with a decision log, turns a general principle into a repeatable habit that supports accountability and rapid revision.

Conclusions

This chapter shows that epidemic simulation has the greatest impact when treated as a routine input to command work rather than an occasional technical add-on. This framing is feasible and necessary in the Ukraine context, marked by attacks on health care, sustained displacement, and environmental shocks: near-term ensembles support operations. At the same time, scenario exercises guide strategy under shifting constraints.

The paper consolidates recent literature into a coherent, operational integration template for crisis programs. It contributes a dual-track approach that pairs short-horizon ensembles with medium-term scenario hubs; a displacement-aware data strategy that triangulates social media, mobility, and satellite signals; an explicit equity checkpoint embedded in ICS/PHEOC cycles; and a direct mapping of model outputs to incident artefacts.

The evidence-informed checklist can be adopted immediately: designate a modelling liaison in Planning, issue weekly one-page ensemble briefs, run scheduled scenario cycles linked to triggers, maintain a decision log, and stand up minimum data feeds for surveillance, capacity, displacement, and WASH. These steps reduce the friction between analysis and orders, improve accountability, and are transferable to other high-constraint settings. Future work should evaluate how these practices change decisions and outcomes and standardise reporting for operational modelling.

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