

ORIGINAL RESEARCH

Open access

Maternal Risk Stratification from Prenatal Care Trajectories: A Continuity-Aware Modeling Framework for Preventable Harm

Patrick O'Connor^{1*}, Sean Murphy¹

Abstract

Maternal healthcare faces escalating challenges in identifying preventable harms during pregnancy, where fragmented prenatal care trajectories often obscure emerging risks. This conceptual manuscript introduces a novel continuity-aware modeling framework designed to stratify maternal risks by integrating longitudinal care trajectories into a cohesive analytical architecture. Drawing on theoretical principles from systems engineering and healthcare informatics, the framework emphasizes the orchestration of prenatal data streams to enhance risk detection without relying on empirical datasets or performance metrics. Key components include modular layers for trajectory mapping, continuity assessment, and harm anticipation, supported by interpretive formulas that model risk propagation and decision confidence. By prioritizing infrastructural resilience and governance integration, this approach theorizes improved alignment between clinical workflows and preventive strategies, potentially mitigating disparities in maternal outcomes. The discussion synthesizes literature on machine learning applications in perinatal risk prediction and midwifery continuity models, highlighting architectural innovations for sustainable deployment in diverse healthcare environments. Ultimately, this framework advocates for a paradigm shift toward proactive, continuity-centric systems in maternal risk management, fostering theoretical advancements in AI-driven healthcare analytics.

Keywords Maternal risk stratification, Prenatal care trajectories, Continuity-aware modeling, Preventable harm framework, Perinatal data orchestration, Risk propagation dynamics

*Correspondence:

Patrick O'Connor
patrick.oconnor@gmail.com

¹ Department of Health Informatics, Faculty of Medicine, Trinity College Dublin, Dublin, Ireland

Introduction

Maternal healthcare systems worldwide grapple with the imperative to mitigate preventable harms, where prenatal care trajectories serve as critical pathways for early intervention. Yet, discontinuities in these trajectories—arising from inconsistent provider interactions, data silos, or socioeconomic barriers—often amplify risks such as postpartum depression, hypertensive disorders, or preterm birth complications. This manuscript posits a conceptual framework that reimagines risk stratification as an integrated process attuned to the temporal and relational

dimensions of prenatal care, thereby addressing gaps in current analytical paradigms.

Prenatal trajectory disruptions in clinical settings

In clinical environments, prenatal care trajectories are frequently punctuated by episodic visits, leading to fragmented risk assessments. Literature underscores how such disruptions correlate with elevated maternal morbidity, as evidenced by studies exploring machine learning's role in predicting hypertension or depression from incomplete

data streams [1-3]. These trajectories, encompassing biometric, psychosocial, and environmental factors, demand models that account for continuity to prevent harm escalation. Without continuity-aware mechanisms, healthcare providers risk overlooking subtle harm indicators embedded within longitudinal patterns, such as irregular attendance or evolving symptom profiles.

Data modality challenges in maternal risk detection

Prenatal data modalities—ranging from electronic health records to wearable-derived metrics—present heterogeneous inputs for risk stratification. Theoretical syntheses reveal that multimodal data integration is essential for capturing trajectory nuances, yet current systems often fail to harmonize these modalities under a continuity lens [4-6]. For instance, integrating biophysical signals with self-reported psychosocial data could theoretically enhance harm prevention, but modality-specific silos hinder comprehensive modeling. This section explores how a continuity-aware approach could theoretically bridge these divides, fostering a more robust infrastructural foundation for maternal analytics.

Deployment environments for continuity-centric stratification

Deployment in varied healthcare environments, from urban hospitals to rural clinics, necessitates adaptable frameworks that prioritize continuity amid resource constraints. Analyses of perinatal predictors using AI highlight the need for environment-agnostic architectures that accommodate diverse prenatal trajectories [7-9]. In low-resource settings, where logistical barriers often compromise care continuity, risk stratification must incorporate adaptive intelligence to simulate seamless trajectories, thereby reducing preventable harms through theoretical orchestration of limited data flows.

Governance constraints on prenatal harm prevention

Governance frameworks in maternal healthcare impose ethical and regulatory constraints on data handling, particularly in trajectory-based modeling. Studies on adaptive risk prediction systems emphasize the importance of governance-integrated designs to ensure equity and privacy in harm anticipation [10-12]. Continuity-aware

models must theoretically embed governance protocols to mitigate biases in stratification, such as those arising from underrepresented populations in prenatal datasets. This integration is crucial for aligning analytical outputs with clinical decision-making, preventing governance lapses that could exacerbate maternal disparities.

Evolving paradigms in maternal trajectory analytics

The evolution of maternal trajectory analytics reflects a shift toward proactive systems, where continuity serves as a cornerstone for harm mitigation. Recent conceptual reviews on machine learning for preeclampsia or postpartum hemorrhage prediction illustrate the potential of trajectory-focused frameworks [13-15]. By theorizing continuity as a dynamic variable, this manuscript advances a modeling paradigm that transcends traditional episodic assessments, paving the way for infrastructural innovations in preventable harm strategies.

Theoretical Background and Literature Synthesis

The theoretical underpinnings of maternal risk stratification draw from interdisciplinary domains, including systems theory, informatics, and perinatal epidemiology. This synthesis integrates insights from recent literature to establish a foundation for continuity-aware modeling, emphasizing architectural elements that address trajectory discontinuities without empirical validation.

Clinical setting foundations for prenatal trajectory mapping

In clinical settings, prenatal trajectories are conceptualized as sequences of interactions that influence maternal outcomes. Theoretical models from cardiovascular and obstetric research highlight how machine learning can abstract these trajectories into risk profiles, focusing on physiological and psychosocial continuity [2, 16, 17]. For example, frameworks for predicting stillbirth or asthma risks underscore the need for mapping tools that preserve temporal integrity, theorizing reduced harm through enhanced trajectory coherence [18-20].

Data modality integration in continuity-aware systems

Data modalities in prenatal care encompass structured records, unstructured narratives, and real-time sensors, requiring theoretical synthesis for unified modeling. Literature on semi-supervised approaches and scoping reviews illustrates how multimodal integration can theoretically amplify continuity detection, mitigating fragmentation in risk stratification [3, 8, 21]. By conceptualizing modalities as interconnected layers, systems can anticipate harm propagation, aligning with governance needs for equitable data handling.

Deployment environment adaptations for maternal governance

Deployment environments vary, from integrated health systems to fragmented community care, necessitating adaptable theoretical architectures. Studies on midwifery continuity models demonstrate how relational continuity enhances maternal mental health and birth outcomes, providing a blueprint for AI-infused governance [22-24]. Theoretical adaptations emphasize infrastructural resilience, ensuring continuity-aware frameworks function across environments without compromising harm prevention efficacy.

Governance constraints shaping prenatal intelligence

Governance constraints, including ethical AI use and data sovereignty, shape the theoretical landscape of prenatal intelligence. Protocols for systematic reviews on machine learning in preeclampsia or hemorrhage prediction reveal governance as a pivotal factor in model design [11, 18, 25]. Continuity-aware systems must incorporate these constraints to theorize balanced intelligence, preventing over-reliance on fragmented trajectories that could perpetuate inequities.

Perinatal harm dynamics in trajectory orchestration

Perinatal harm dynamics are theoretically modeled through trajectory orchestration, where discontinuities amplify risks like depression or cardiovascular conditions [1, 26, 27]. Synthesis of cohort studies and reviews posits that continuity-centric orchestration can mitigate these dynamics, fostering theoretical feedback mechanisms for sustained harm reduction [28, 29].

Infrastructural innovations for preventable harm mitigation

Infrastructural innovations in maternal analytics theorize scalable systems that embed continuity for harm mitigation. Conceptual reviews on AI in perinatal health advocate for architectural layers that integrate trajectories, enhancing theoretical decision-making without empirical claims [5, 7, 9]. This synthesis culminates in a call for novel frameworks that prioritize infrastructural governance, setting the stage for advanced risk stratification.

Continuity-aware orchestration architecture for maternal harm anticipation

This section delineates the prenatal trajectory continuity integration network (PTCIN), a conceptual architecture engineered to orchestrate maternal risk stratification through continuity-aware mechanisms. PTCIN comprises a unique four-layer structure: trajectory ingestion layer, continuity harmonization layer, risk stratification core, and adaptive feedback topology. This design theorizes seamless integration of prenatal care trajectories, emphasizing infrastructural orchestration to anticipate preventable harms.

The trajectory ingestion layer abstracts heterogeneous prenatal data streams into standardized trajectories, theoretically preserving temporal sequences without data loss. Following this, the continuity harmonization layer employs modular algorithms to detect and bridge discontinuities, conceptualizing care episodes as interconnected nodes.

At the core, the risk stratification core applies layered analytics to classify harms, drawing on theoretical propagation models. Finally, the adaptive feedback topology introduces a recursive loop, where stratified risks inform trajectory refinements, ensuring dynamic governance. **Figure 1** illustrates the PTCIN. This four-layer continuity-aware architecture transforms fragmented prenatal care trajectories into harmonized temporal sequences for risk stratification and adaptive harm anticipation.

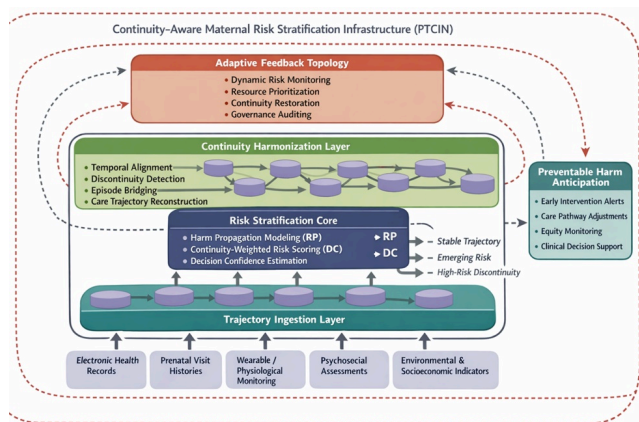


Figure 1. Prenatal trajectory continuity integration network (PTCIN): Continuity-aware architecture for maternal risk stratification

To interpret system dynamics, consider the following conceptual formulas:

1. Risk propagation (RP): $RP = \frac{TC_i * HF_j}{CL}$, where TC_i denotes trajectory continuity index for episode i , HF_j represents harm factor j , and CL is continuity load, theorizing amplified risks from fragmented trajectories.

2. Decision confidence (DC): $DC = 1 - \left(\frac{DS}{TM}\right)$, where DS is drift sensitivity, and TM is trajectory maturity, capturing theoretical confidence erosion due to discontinuities.

3. Governance load (GL): $GL = \int (RD_k * EC_l) dt$, where RD_k is resource demand k and EC_l is an ethical constraint l over time t , modeling cumulative burden in continuity-aware deployments.

Table 1 delineates the functional architecture of PTCIN by mapping each computational layer to its continuity role, maternal risk signal generation, and governance interaction.

Table 1. Structural functions of the PTCIN layers

Architectural layer	Primary analytical function	Continuity role	Maternal risk signal produced
Trajectory ingestion layer	Aggregates heterogeneous prenatal data streams into temporally ordered care trajectories	Preserves the chronological integrity of prenatal events	Raw trajectory continuity indicators
Continuity harmonization layer	Detects and reconciles fragmented care episodes through temporal alignment algorithms	Bridges discontinuities across prenatal visits and data modalities	Continuity coherence metrics
Risk stratification core	Applies propagation modeling to classify emerging maternal risks	Weighs trajectory coherence in risk scoring mechanisms	Stratified risk tiers (stable, emerging, and high risk)
Adaptive feedback topology	Dynamically recalibrates monitoring intensity and analytic priorities	Reinforces stable trajectories while amplifying oversight for discontinuities	Predictive monitoring signals and resource allocation triggers

Trajectory ingestion layer	Aggregates heterogeneous prenatal data streams into temporally ordered care trajectories	Preserves the chronological integrity of prenatal events	Raw trajectory continuity indicators
Continuity harmonization layer	Detects and reconciles fragmented care episodes through temporal alignment algorithms	Bridges discontinuities across prenatal visits and data modalities	Continuity coherence metrics
Risk stratification core	Applies propagation modeling to classify emerging maternal risks	Weighs trajectory coherence in risk scoring mechanisms	Stratified risk tiers (stable, emerging, and high risk)
Adaptive feedback topology	Dynamically recalibrates monitoring intensity and analytic priorities	Reinforces stable trajectories while amplifying oversight for discontinuities	Predictive monitoring signals and resource allocation triggers

Dynamics of preventable harm reduction in trajectory-integrated infrastructures

The PTCIN architecture theorizes profound shifts in maternal risk stratification by embedding continuity as a core infrastructural element, thereby influencing the dynamics of preventable harm reduction. This section examines the conceptual consequences of such integration, focusing on how trajectory orchestration could alter clinical decision pathways, resource distributions, and equity in perinatal care systems. Without empirical validation, these dynamics are explored through theoretical lenses, drawing on systems resilience and informatics principles to anticipate infrastructural impacts.

Trajectory coherence effects on clinical decision pathways

In theoretical terms, enhancing trajectory coherence via PTCIN's harmonization layer could streamline clinical decision pathways, reducing the cognitive load on providers. Literature on machine learning for maternal morbidity prediction suggests that fragmented trajectories often lead to delayed interventions, as seen in models for hypertensive disorders or postpartum readmissions [3, 13, 16]. By conceptualizing continuity as a stabilizing factor, PTCIN theorizes accelerated harm detection, where decision pathways evolve from reactive to anticipatory modes. This shift could theoretically minimize the escalation of risks like preeclampsia, fostering a more fluid integration of prenatal data into real-time clinical workflows.

Table 2 conceptualizes how different forms of prenatal trajectory disruption influence risk propagation dynamics and trigger continuity-aware governance responses within PTCIN.

Table 2. Continuity disruption patterns and their theoretical impact on maternal risk propagation

Prenatal trajectory disruption type	Typical source of discontinuity	Analytical detection mechanism in PTCIN	Effect on risk propagation (RP)
Irregular prenatal visit attendance	Geographic barriers and socioeconomic constraints	Temporal gap detection within trajectory harmonization	Increase in RP due to reduced continuity stability
Fragmented data modalities	Separation between EHR, wearable data, and psychosocial inputs	Cross-modal trajectory reconciliation algorithms	Amplified RP due to incomplete trajectory representation
Sudden clinical parameter shifts	Emerging complications such as hypertension or gestational diabetes	Real-time anomaly detection within the stratification core	Rapid escalation of maternal RP
Socioeconomic instability	Housing insecurity,	Contextual trajectory	Progressive RP increase

indicators	transportation barriers, and employment disruption	enrichment through environmental signals	linked structural vulnerabilities
System-level care interruptions	Workforce shortages, pandemic disruptions, and facility closures	Feedback topology monitoring of trajectory stability trends	RP amplification across affected patient cohorts

Resource distribution implications in diverse perinatal environments

Resource distribution in perinatal environments stands to be significantly optimized through the adaptive feedback topology proposed within the PTCIN. At its conceptual core, PTCIN theorizes that healthcare resources—clinical monitoring, diagnostic attention, and predictive analytics—can be dynamically allocated based on continuity metrics, which reflect the stability or disruption patterns within prenatal care trajectories. Rather than distributing analytical capacity uniformly across all pregnancies, this framework emphasizes prioritization of cases that demonstrate higher discontinuity signals, such as inconsistent antenatal visits, socioeconomic vulnerability markers, or emerging physiological anomalies.

Existing studies on AI-driven perinatal predictors highlight that disparities in healthcare access significantly influence maternal and neonatal outcomes. In low-resource or geographically isolated settings, predictive models for outcomes such as stillbirth or childhood respiratory conditions (including asthma) demonstrate amplified error margins and delayed intervention responses due to fragmented data environments and constrained monitoring capacity [17, 19, 20]. Under these conditions, static allocation of analytical resources often leads to inefficient use of limited infrastructure, as high-risk trajectories may remain under-monitored. In contrast, low-risk trajectories receive unnecessary analytic attention.

PTCIN's adaptive infrastructure addresses this imbalance by redistributing analytical burdens across the system according to real-time trajectory continuity assessments. Within this theoretical architecture, pregnancies exhibiting high discontinuity scores—reflecting irregular care engagement, emerging clinical risk indicators, or environmental stressors—would automatically receive

intensified computational monitoring and predictive recalibration. Conversely, trajectories demonstrating stable continuity patterns could be monitored with lower analytical frequency without compromising patient safety. This dynamic allocation mechanism enables the system to optimize scarce computational and clinical resources while maintaining a high level of predictive vigilance for vulnerable populations.

Importantly, such redistribution has implications beyond computational efficiency. In rural deployments or regions with limited specialist availability, automated prioritization could support healthcare providers by directing attention toward pregnancies most likely to require intervention. This creates a resource amplification effect, where limited healthcare personnel benefit from targeted decision-support signals generated by the analytics infrastructure.

Additionally, the automated orchestration of analytical priorities reduces governance overhead. Traditional health analytics infrastructures require continuous manual calibration, oversight, and rule adjustments to maintain fairness and operational efficiency. In contrast, PTCIN's continuity-driven allocation logic embeds governance principles directly into the computational architecture. By allowing the system to self-regulate analytical workloads based on continuity signals, the framework theorizes a reduction in administrative complexity while maintaining transparency in decision pathways.

Collectively, these mechanisms suggest that PTCIN could facilitate more equitable distribution of analytical resources across heterogeneous healthcare environments, bridging gaps between urban hospitals with advanced digital infrastructures and rural clinics operating under constrained capacities. In doing so, the framework proposes a scalable model for maintaining predictive performance while adapting to variations in regional healthcare resources.

Equity dynamics in maternal harm anticipation

Equity in maternal harm anticipation represents a central dimension of PTCIN's conceptual framework. Maternal health disparities remain deeply influenced by structural inequalities, including socioeconomic instability, geographic barriers, racial disparities, and inconsistent access to prenatal services. Traditional machine learning models often struggle to address these inequities because their predictive accuracy is strongly dependent on the

representativeness of training data and the stability of patient care trajectories.

The modular architecture of PTCIN theorizes that bias mitigation can be achieved through continuity-aware governance mechanisms, which explicitly account for discontinuities in prenatal care trajectories. Theoretical reviews of machine learning applications in high-risk pregnancies demonstrate that predictive models for complications such as pregnancy-induced hypertension, gestational diabetes, or maternal mental health disorders frequently reflect systemic inequities embedded in the healthcare data landscape [1, 6, 27]. These inequities manifest when marginalized populations experience fragmented care, limited diagnostic follow-up, or delayed intervention—conditions that reduce the availability of structured data inputs required for accurate prediction.

Within the PTCIN framework, continuity functions as both a diagnostic signal and a governance parameter. Rather than treating data irregularities solely as noise or missingness, the system interprets discontinuities as meaningful indicators of structural vulnerability. Trajectories characterized by socioeconomic instability, irregular healthcare engagement, or abrupt environmental stressors are therefore algorithmically elevated within the analytic hierarchy.

By integrating governance constraints directly into the risk stratification core, PTCIN theorizes a more balanced form of harm anticipation. Underrepresented or fragmented trajectories would receive amplified analytical scrutiny, allowing predictive systems to compensate for structural data gaps rather than inadvertently reinforcing them. This design principle contrasts with many conventional predictive models, which often perform best in highly structured datasets derived from populations with consistent healthcare access.

Furthermore, the modular layering of the system enables iterative bias auditing within each analytic stage. Continuity metrics can be evaluated against demographic and contextual variables to detect emerging patterns of inequity in predictive outputs. In theory, this allows the infrastructure to dynamically recalibrate analytic thresholds and monitoring intensity in response to detected disparities.

Such an approach does not claim to eliminate bias—an outcome that remains unlikely within complex healthcare systems. However, it introduces adaptive safeguards that

aim to prevent the systematic marginalization of vulnerable maternal trajectories. By prioritizing analytical attention where structural vulnerabilities intersect with emerging clinical risks, PTCIN proposes a framework in which equity becomes an operational parameter embedded within the predictive architecture itself.

This continuity-aware governance model therefore contributes to a broader vision of inclusive maternal health analytics, where predictive infrastructures actively seek to counterbalance systemic inequities rather than passively reproducing them.

Systemic resilience against trajectory disruptions

Systemic resilience constitutes another foundational dynamic within the PTCIN framework. Perinatal healthcare systems frequently encounter disruptions that alter the continuity of care trajectories, including sudden healthcare workforce shortages, infrastructure failures, public health emergencies, or patient-level discontinuities such as relocation or socioeconomic instability. These disruptions can destabilize predictive models that rely on consistent data streams, thereby increasing the likelihood of delayed detection of maternal or fetal risk.

PTCIN's feedback topology theorizes the development of self-correcting analytical mechanisms capable of maintaining predictive continuity despite fluctuations in the surrounding healthcare environment. By continuously evaluating trajectory coherence, the system can identify emerging disruptions early and recalibrate analytic priorities accordingly.

Conceptual frameworks from cardio-obstetrics and midwifery continuity models illustrate the protective role that resilient care systems play in safeguarding maternal outcomes. Continuity-based care structures—such as integrated cardiology-obstetric collaborations or sustained midwifery-led care models—have demonstrated the capacity to buffer patients against adverse events by maintaining stable clinical oversight even during systemic stress [2, 22, 25].

PTCIN extends this principle into the domain of computational healthcare infrastructure. Rather than treating disruptions as purely external events, the system models them as dynamic perturbations within trajectory networks. When discontinuity signals increase beyond

established thresholds, the feedback topology can activate corrective mechanisms such as:

- Intensified monitoring frequencies for affected trajectories
- Re-weighting of predictive variables to account for missing or unstable data inputs
- Redistribution of analytic capacity to compensate for healthcare service interruptions

These adaptive responses aim to preserve predictive reliability even when traditional care pathways are compromised, for instance, during a pandemic scenario where in-person prenatal visits decline, the system could increase reliance on remote monitoring inputs, historical risk patterns, or environmental indicators to maintain predictive vigilance.

The presence of these resilience mechanisms contributes to overall infrastructural stability by preventing localized disruptions from propagating throughout the analytical ecosystem. In theoretical terms, the system behaves as a distributed resilience network, capable of absorbing shocks and restoring predictive equilibrium without requiring large-scale manual intervention.

Consequently, the PTCIN architecture proposes a healthcare analytics environment where resilience is not merely a property of clinical workflows. Still, it is embedded within the computational governance structure of maternal health monitoring.

Long-term evolutionary impacts on healthcare analytics

Over extended time horizons, the adoption of continuity-centered frameworks such as PTCIN could contribute to broader evolutionary shifts within healthcare analytics. Contemporary predictive models in maternal health typically focus on discrete clinical endpoints—such as preeclampsia, gestational diabetes, postpartum hemorrhage, or preterm birth—often operating within isolated analytic pipelines. While these models provide valuable risk assessments, they rarely capture the longitudinal coherence of care trajectories, which may hold deeper insights into systemic risk patterns.

PTCIN theorizes that continuity could emerge as a foundational metric guiding the development of next-

generation maternal health analytics. Rather than evaluating individual clinical variables in isolation, future predictive infrastructures may increasingly assess trajectory integrity, encompassing temporal stability in clinical monitoring, socioeconomic context, environmental exposures, and healthcare engagement patterns.

Syntheses of AI applications in perinatal care already suggest a gradual movement toward integrated predictive ecosystems capable of synthesizing diverse data streams [11, 14, 18]. Protocols developed for systematic reviews of maternal complications—such as preeclampsia or obstetric hemorrhage—demonstrate the growing emphasis on multi-factorial modeling approaches that account for complex interactions among physiological, behavioral, and environmental determinants of risk.

Within this evolving landscape, PTCIN could function as a conceptual bridge linking predictive analytics with system-level governance. By embedding continuity metrics into analytic infrastructures, healthcare systems may achieve more consistent harm reduction strategies across jurisdictions and institutional contexts.

Such evolutionary impacts extend beyond technological innovation. Continuity-driven analytics could reshape how healthcare systems conceptualize maternal risk itself, shifting the focus from isolated clinical events toward dynamic trajectories of maternal well-being. This perspective aligns with emerging public health frameworks that emphasize prevention through early detection of trajectory disruptions rather than reactive intervention following the onset of complications.

In the long term, PTCIN's architecture suggests the possibility of self-adaptive maternal health analytics ecosystems, where predictive models continuously evolve in response to changing healthcare environments, emerging epidemiological patterns, and shifting socioeconomic conditions. These systems could support sustainable harm reduction by maintaining analytic sensitivity to new maternal risk configurations as they arise.

Ultimately, the evolutionary trajectory envisioned by PTCIN positions continuity as a central organizing principle for maternal health analytics—one capable of integrating predictive intelligence, governance oversight, and equitable care delivery within a unified computational framework.

Results and Discussion

The conceptual articulation of PTCIN within maternal risk stratification invites a broader discourse on the interplay between continuity-aware architectures and preventable harm in prenatal care. This discussion synthesizes theoretical insights from the literature, critiquing current paradigms while projecting infrastructural advancements enabled by such frameworks.

Integrating continuity into modeling frameworks addresses longstanding critiques of episodic prenatal assessments, where literature consistently links discontinuities to adverse outcomes like maternal morbidity or mental health declines [21, 23, 28]. PTCIN's orchestration approach theorizes a departure from these limitations, embedding relational and temporal dimensions to enhance harm anticipation. For instance, by drawing parallels to adaptive risk prediction systems, PTCIN extends theoretical boundaries, proposing governance-infused layers that could mitigate ethical pitfalls in AI deployment [10, 12, 15].

Critically, the framework's emphasis on trajectory mapping resonates with emerging themes in perinatal AI, such as multimodal data fusion for predicting hypertension or cardiovascular risks [4, 6, 16]. Yet, theoretical challenges persist, including the potential for over-orchestration leading to analytical rigidity in dynamic clinical settings. Literature on midwifery models underscores the value of human-centric continuity, suggesting that PTCIN must theoretically balance algorithmic intelligence with provider autonomy to avoid diminishing relational care elements [24, 26, 29].

Furthermore, deployment considerations in varied environments amplify discussion points on scalability. Conceptual reviews highlight how AI in maternal health can exacerbate or alleviate disparities, depending on infrastructural design [5, 7, 9]. PTCIN's adaptive topology theorizes resilience in resource-limited contexts, but requires theoretical safeguards against data drift, as posited in formulas for decision confidence and governance load. This invites discourse on hybrid systems, where continuity-aware AI complements traditional midwifery, fostering holistic harm prevention.

Ethical governance emerges as a pivotal discussion axis, with protocols for machine learning in obstetrics emphasizing transparency and equity [8, 11, 18]. PTCIN's integration of these constraints theorizes reduced

governance load, yet raises questions on accountability in automated stratification. By aligning with studies on postpartum hemorrhage or depression prediction [1, 14, 17], the framework posits a governance model that evolves with trajectory complexities, promoting ethical AI in maternal analytics.

In synthesizing these elements, PTCIN advances theoretical discourse by conceptualizing continuity as an active infrastructural agent, rather than a passive variable. This shift could catalyze innovations in preventable harm strategies, bridging gaps between clinical practice and analytical theory [3, 19, 20].

Conclusion

In conceptualizing the PTCIN, this manuscript advances a continuity-aware modeling framework for maternal risk stratification, emphasizing architectural orchestration to mitigate preventable harms from prenatal care trajectories. By theorizing modular layers and adaptive topologies, PTCIN addresses theoretical deficiencies in current systems, fostering infrastructural resilience and governance alignment.

The synthesis of literature reveals a convergence toward AI-infused perinatal analytics, where continuity emerges as a linchpin for harm reduction. PTCIN's dynamics theorize enhanced decision pathways, equitable resource

distribution, and systemic equity, projecting a paradigm shift in maternal healthcare infrastructures.

Ultimately, this framework advocates for theoretical investments in continuity-centric designs, paving avenues for future conceptual explorations in AI-driven preventable harm strategies.

Acknowledgements

None

Conflict of interest

None

Financial support

None

Ethics statement

None

Received: 04 Aug 2024 Revised: 08 Sep 2024 Accepted: 12 Oct 2024
Published online: 25 February 2025

Rights and permissions

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

Sibbald L, van den Heuvel MI, Haas MR, van Lissa CJ, van Bakel HJA, Jongerling J, et al. Identifying prenatal risk factors of postpartum depression with machine learning. *Sci Rep*. 2025;15(1):34610.
<https://doi.org/10.1038/s41598-025-18204-6>.

Ricci CA, Crysyp B, Phillips NR, Ray WC, Santillan MK, Trask AJ, et al. Machine learning: a new era for cardiovascular pregnancy physiology and cardio-obstetrics research. *Am J*

Physiol Heart Circ Physiol. 2024;327(2):H417-H432.
<https://doi.org/10.1152/ajpheart.00149.2024>.

Vasudevan L, Kibria MG, Kucirka LM, Shieh K, Wei M, Masoumi S, et al. Machine learning models to predict risk of maternal morbidity and mortality from electronic medical record data: scoping review. *J Med Internet Res*. 2025;27:e68225.
<https://doi.org/10.2196/68225>.

Al Mashrafi SS, Tafakori L, Abdollahian M. Predicting maternal risk level using machine learning models. *BMC Pregnancy Childbirth*. 2024;24(1):820.

<https://doi.org/10.1186/s12884-024-07030-9>.

Mapari SA, Shrivastava D, Dave A, Bedi GN, Gupta A, Sachani P, et al. Revolutionizing maternal health: the role of artificial intelligence in enhancing care and accessibility. *Cureus*. 2024;16(9):e69555.

<https://doi.org/10.7759/cureus.69555>.

Chen Y, Huang X, Wu S, Guo P, Huang J, Zhou L, et al. Machine-learning predictive model of pregnancy-induced hypertension in the first trimester. *Hypertens Res*. 2023;46(9):2135-44.

<https://doi.org/10.1038/s41440-023-01298-8>.

Ramakrishnan R, Rao S, He JR. Perinatal health predictors using artificial intelligence: a review. *Womens Health (Lond)*. 2021;17:17455065211046132.

<https://doi.org/10.1177/17455065211046132>.

Macrohon JJE, Villavicencio CN, Inbaraj XA, Jeng JH. A semi-supervised machine learning approach in predicting high-risk pregnancies in the Philippines. *Diagnostics (Basel)*. 2022;12(11):2782.

<https://doi.org/10.3390/diagnostics12112782>.

El Arab RA, Al Moosa OA, Albahrani Z, Alkhalil I, Somerville J, Abuadas F. Integrating artificial intelligence into perinatal care pathways: a scoping review of reviews of applications, outcomes, and equity. *Nurs Rep*. 2025;15(8):281.

<https://doi.org/10.3390/nursrep15080281>.

Koivu A, Sairanen M, Airola A, Pahikkala T, Leung WC, Lo TK, et al. Adaptive risk prediction system with incremental and transfer learning. *Comput Biol Med*. 2021;138:104886.

<https://doi.org/10.1016/j.compbimed.2021.104886>.

Ranjbar A, Taeidi E, Mehrnoush V, Roozbeh N, Darsareh F. Machine learning models for predicting pre-eclampsia: a systematic review protocol. *BMJ Open*. 2023;13(9):e074705.

<https://doi.org/10.1136/bmjopen-2023-074705>.

Koivu A, Korpimäki T, Kivelä P, Pahikkala T, Sairanen M. Evaluation of machine learning algorithms for improved risk assessment for Down's syndrome. *Comput Biol Med*. 2018;98:1-7.

<https://doi.org/10.1016/j.compbimed.2018.05.004>.

Hoffman MK, Ma N, Roberts A. A machine learning algorithm for predicting maternal readmission for hypertensive disorders of pregnancy. *Am J Obstet Gynecol MFM*. 2021;3(1):100250.

<https://doi.org/10.1016/j.ajogmf.2020.100250>.

Schmidt LJ, Rieger O, Neznansky M, Hackelöer M, Dröge LA, Henrich W, et al. A machine-learning-based algorithm improves prediction of preeclampsia-associated adverse outcomes. *Am J Obstet Gynecol*. 2022;227(1):77.e1-77.e30.

<https://doi.org/10.1016/j.ajog.2022.01.026>.

Togunwa TO, Babatunde AO, Abdullah KU. Deep hybrid model for maternal health risk classification in pregnancy: synergy of ANN and random forest. *Front Artif Intell*. 2023;6:1213436.

<https://doi.org/10.3389/frai.2023.1213436>.

Shara N, Mirabal-Beltran R, Talmadge B, Falah N, Ahmad M, Dempers R, et al. Use of machine learning for early detection of maternal cardiovascular conditions: retrospective study using electronic health record data. *JMIR Cardio*. 2024;8:e53091.

<https://doi.org/10.2196/53091>.

Aga MA. Predicting stillbirth and identifying key maternal risk factors using machine learning. *BMJ Paediatr Open*. 2025;9(1):e004000.

<https://doi.org/10.1136/bmjpo-2025-004000>.

Boujarzadeh B, Ranjbar A, Banihashemi F, Mehrnoush V, Darsareh F, Saffari M. Machine learning approach to predict postpartum haemorrhage: a systematic review protocol. *BMJ Open*. 2023;13(1):e067661.

<https://doi.org/10.1136/bmjopen-2022-067661>.

Mwaura HM, Kamanu TK, Kulohoma BW. Bridging data gaps: predicting sub-national maternal mortality rates in Kenya using machine learning models. *Cureus*. 2024;16(10):e72476.

<https://doi.org/10.7759/cureus.72476>.

Jeddi Z, Gryech I, Ghogho M, El Hammoumi M, Mahraoui C. Machine learning for predicting the risk for childhood asthma using prenatal, perinatal, postnatal and environmental factors. *Healthcare (Basel)*. 2021;9(11):1464.

<https://doi.org/10.3390/healthcare9111464>.

Cibralic S, Pickup W, Diaz AM, Kohlhoff J, Karlov L, Stylianakis A, et al. The impact of midwifery continuity of care on maternal mental health: a narrative systematic review. *Midwifery*. 2023;116:103546.

<https://doi.org/10.1016/j.midw.2022.103546>.

Sandall J, Fernandez Turienzo C, Devane D, Soltani H, Gillespie P, Gates S, et al. Midwife continuity of care models versus other models of care for childbearing women. *Cochrane Database Syst Rev*. 2024;4(4):CD004667.

<https://doi.org/10.1002/14651858.CD004667.pub6>.

Psaila KM, Schmied V, Heath S. Exploring continuity of care for women with prenatal diagnosis of congenital anomaly: a

mixed method study. *J Clin Nurs*. 2023;32(19-20):7147-61.
<https://doi.org/10.1111/jocn.16777>.

D'haenens F, Van Rompaey B, Swinnen E, Dilles T, Beeckman K. The effects of continuity of care on the health of mother and child in the postnatal period: a systematic review. *Eur J Public Health*. 2020;30(4):749-60.

Fernandez Turienzo C, Bick D, Briley AL, Bollard M, Coxon K, Cross P, et al. Midwifery continuity of care versus standard maternity care for women at increased risk of preterm birth: a randomized controlled pilot trial. *PLoS Med*. 2020;17(10):e1003350.
<https://doi.org/10.1371/journal.pmed.1003350>.

Rayment-Jones H, Dalrymple K, Harris J, Harden A, Parslow E, Georgi T, et al. Project20: does continuity of care improve maternal and neonatal outcomes? *PLoS One*. 2021;16(5):e0250947.
<https://doi.org/10.1371/journal.pone.0250947>.

Kallas KA, Marr K, Moirangthem S, Heude B, Koehl M, van der Waerden J, et al. Maternal mental health care matters: impact of prenatal symptoms on child outcomes. *J Clin Med*. 2023;12(3):1120.
<https://doi.org/10.3390/jcm12031120>.

Grande LA, Swales DA, Sandman CA, Glynn LM, Davis EP. Maternal caregiving ameliorates consequences of prenatal distress on child development. *Dev Psychopathol*. 2022;34(4):1376-85.
<https://doi.org/10.1017/S0954579421000286>.

Dalrymple KV, Tydeman F, Bone JF, Poston L, Dasgupta T, McGreevy A, et al. Relationship between virtual antenatal care and pregnancy outcomes. *Am J Obstet Gynecol*. 2025;233(6):675.e1-675.e36.
<https://doi.org/10.1016/j.ajog.2025.08.004>.