A Blockchain-Enabled Hybrid Framework for Robust Cybersecurity and Intelligent Attack Mitigation

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***Abstract*—In the current paper, the authors propose an Interaction-Aware Maternal Health Outcome Estimation (IAMHOE) framework that assesses the determinants that influence maternal health outcomes based on the district-level Health Management Information System (HMIS) data. The model takes into account the studies of antenatal care (ANC), institutional deliveries, literacy, and diffusion of IT applications, with interaction terms added to the model to address the moderating effects. The dataset has been cleaned up before estimation, accounted for the missing cases, standardized on similar metrics, and added interaction variables to enhance the accuracy of the model. The main analytical tool was based on a fixed-effects regression model, hypothesis testing, and probability prediction. The outcome of the empirical results illustrates some trends. There are declining marginal effects of IT diffusion on institutional deliveries, which can be interpreted as indicating that infrastructural development will not experience substantial benefits unless there are conditions that encourage them. ANC coverage, on the other hand, has a positive amplification effect mediated by literacy, whereby higher education levels enhance healthcare utilisation. The probability analysis also suggests that hospitals are increasingly moving towards single-vendor sourcing to integrated vendor approach with increased IT integration. Integrating the interaction modeling with the powerful validation and predictive methods, IAMHOE offers something novel, reminding us that the maternal health outcomes require interdependence not only between the service delivery but also between the investments into education and digital infrastructure.**

***Index Terms*—Keywords Maternal Health Outcomes, Health Management Information System (HMIS), Interaction Modeling, IT Application Spread, Fixed-Effects Regression, Policy Insights**

I. Introduction

Maternal and child health is one of the fundamental pillars of the healthcare policy [1], and such measures as the coverage rates of antenatal care (ANC) and institutional deliveries can be used to assess the effectiveness of the healthcare system. With all the advancements in digital health programs [2], there are still issues associated with disconnected data, discrepant quality, and system vulnerabilities on a district level of health management. The recent innovations in health information digitization have allowed gathering massive datasets, but these datasets are poorly used because interoperability is lacking, people do not trust them, and it is exposed to cyberattacks. In order to fill in these gaps, this research will postulate a converged framework, which will integrate statistical interaction modeling and blockchain-based cybersecurity mechanisms [3], so that both analytical rigor and resilience of maternal health systems will be guaranteed.Health Management Information System (HMIS) provides district-level information on healthcare use and outcomes [4], but the common traditional regression models overlook such interaction effects, thereby restricting the amount of information. In addition, the traditional storage system puts HMIS datasets at risk of manipulation, breaches, smart cyberattacks, and others. There is a promising solution to data integrity, analytics protection, and trusting stakeholders, using blockchain technology, which is decentralized, immutable, and controllable [5]. Although statistical models demonstrate how coverage indicators and socio-technical moderators influence maternal outcomes, the reliability of these findings depends on the integrity of the underlying datasets. Current HMIS frameworks are vulnerable to data tampering, adversarial poisoning, and ransomware attacks, which can distort regression outcomes and mislead policy decisions. Furthermore, limited research has integrated secure data infrastructures with econometric or regression-based modeling for health outcome prediction. This gap necessitates a dual approach: enhancing analytical models with interaction-aware estimation, and fortifying the health data pipeline against intelligent cyberattacks [6]. This paper presents an interaction-based regression model to determine the diminishing returns to institutional deliveries and amplification effects to antenatal care (ANC) coverage. It also explores the moderating effects of literacy levels and the extent of IT application on the health outcomes of mothers, with a focus on the socio-technical factors. In order to ensure the integrity of the data, blockchain-related mechanisms are embedded into the Health Management Information System (HMIS) [7], and they safeguard against tampering, poisoning, and ransomware. This study contains practical policy recommendations, as it reveals the flaws of the current system and offers safe, efficient, and evidence-based solutions to improve maternal and child care [8].

This is the first work to combine superior statistical modeling and blockchain-based security to improve maternal health analytics. The proposed Interaction-Aware Maternal Health Outcome Estimation (IAMHOE) algorithm involves the incorporation of interaction terms of coverage indicators, literacy, and spread of IT applications to identify structural effects. Blockchain mechanisms can protect the pipeline of incoming, estimated, and accessed data from IoT devices against adversarial attacks by tampering or ransomware [9]. The evidence carries a positive result in the form of diminishing returns in institutional deliveries and amplification in ANC coverage, which is safe and policy-relevant.

II. Literature Review

Recent empirical work has reinforced the importance of institutional deliveries in reducing maternal and neonatal risks. [10] employed quasi-experimental designs using rural road upgrades in India, showing that improved access to facilities significantly reduced neonatal mortality and postpartum complications—clear evidence that institutional births are high-yield interventions for maternal outcomes. Similarly, trend analyses of national surveys confirm that increased institutional deliveries are directly linked to the declining maternal mortality ratio (MMR), providing robust justification for incorporating diminishing-return terms in delivery-related regressions.

Alongside coverage measures, attention has turned to data quality and health system readiness. [11] reported that optimization of the Health Management Information System (HMIS) in Uttar Pradesh—through automation, dashboards, and supervision—improved data timeliness and accuracy, enabling better district-level decision-making. Complementing this, the National Data Quality Framework (NDQF, 2021) proposed systematic protocols for completeness and consistency checks, which improved reliability across HMIS datasets. Additional multi-country reviews since 2022 highlight that trained staff, supervision, and digital workflows are central to minimizing reporting errors, thus supporting the preprocessing strategy of this study.

The moderating role of literacy and infrastructure has also been empirically validated. [12] demonstrated that states with higher literacy and better infrastructure experienced sharper declines in MMR, [13] with maternal service utilization mediating the impact of government spending. This aligns with interaction modeling, where literacy amplifies the effect of antenatal coverage and infrastructure complements institutional delivery performance. Similar findings from district-level analyses confirm that digital penetration and ICT access enhance monitoring capacity, improving program responsiveness.

Another critical stream of research addresses cybersecurity in healthcare. [14] [15] documented hundreds of ransomware attacks in the U.S. health sector, showing that such breaches led to delays in care, diversion of ambulances, and increased patient risk, including measurable excess mortality in Medicare populations. These studies underscore that cybersecurity breaches are not just technical risks but health system stressors with direct consequences on outcomes.

In response, blockchain-enabled solutions have gained traction. [16] and [17] demonstrated how blockchain improves data provenance, auditability, and secure sharing in health information exchange systems. [18] further showed its potential in managing registry interoperability while maintaining fine-grained access control. More recently, [19] integrated blockchain with federated learning, illustrating how the framework can resist poisoning and inference attacks while preserving patient privacy. [20] extended this line by embedding blockchain-based consent and audit trails into AI-driven maternal health models, achieving resilience against adversarial manipulation.

Together, these findings indicate that maternal health improvement depends on not only service coverage but also literacy, infrastructure, and ICT access as moderators [21], while the trustworthiness of analytics is threatened by escalating cyberattacks. Blockchain-enabled security emerges as a timely innovation, ensuring the integrity, transparency, and resilience of HMIS-based research pipelines, bridging predictive analytics with system-level protection.

III. METHODOLOGY

This study develops an *Interaction-Aware Maternal Health Outcome Estimation (IAMHOE)* framework that integrates district-level health indicators with IT application spread and literacy interactions. The methodology combines data preprocessing, econometric estimation, hypothesis testing, probability modeling, and visualization to uncover non-linear dynamics such as diminishing returns and complementary amplification

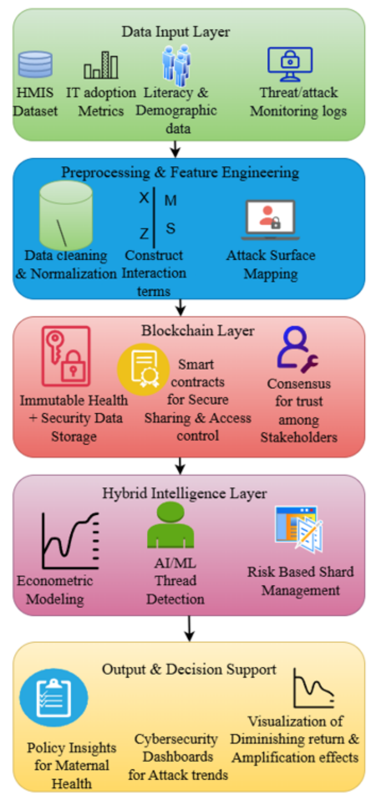

Fig. 1. Blockchain-Based Hybrid Cybersecurity Architecture

Figure 1 represents a Hybrid Architecture built on the Blockchain, which enhances cybersecurity and helps to prevent the threats proactively, especially in healthcare systems. It starts with the Data Input Layer that gathers various sources of data, such as HMIS records, IT adoption metrics, demographic and literacy statistics, and security logs, with the tracking of attacks. The Preprocessing and Feature Engineering Layer then works on the data by cleansing, normalizing and generating interaction terms and attack surface mappings to continue working on the data. The Blockchain Layer promotes the integrity of data, secure sharing, and accessibility via smart contracts, and allows the stakeholders to agree to establish trust. The Hybrid Intelligence Layer is a fusion of econometric models with threat detection and risk-aware shard management, which uses AI/ML, [22] and makes optimized decisions. Output and Decision Support Layer, such as the recommendations on the policy of maternal health or cybersecurity dashboard and visualization of diminishing returns or growing effects, is actionable. Lastly, a Feedback Loop maintains HMIS and security logs in real time so that the system can learn, adapt, and evolve [23] [24]. The Blockchain Layer, therefore, ensures the integrity of data, more secure sharing through smart contracts, and provides consensus-building among stakeholders.

A. Dataset Collection and Preprocessing

For this study, we employ the Health Management Information System (HMIS) dataset, which is a comprehensive repository of district-level maternal and child health indicators across multiple years. The dataset is particularly well-suited for evaluating health outcomes in the context of digital diffusion, as it captures both service delivery indicators and socio-demographic variables.

The key variables considered in the analysis are:

- **Antenatal Care (ANC) Coverage** (X_{anc}): proportion of pregnant women receiving at least four ANC visits.
- **Institutional Deliveries** (X_{del}): proportion of births occurring in health facilities.
- **Literacy Rate** (M): proxy for community-level capacity to process and benefit from health interventions.
- **IT Application Spread** (S): diffusion of IT-based health systems across districts, measured through hospital-level adoption indicators.
- **Maternal Mortality Proxy** (Y): outcome variable, operationalized through maternal death ratios and related indicators reported in HMIS.

B. Data Cleaning and Validation

To achieve dependable outcomes, we utilize a systematic preprocessing pipeline:

1) **Handling Missing Values:** District-years with incomplete records for the key variables are excluded from the analysis. In cases where missingness is minimal, linear interpolation is applied to preserve temporal continuity.
2) **Outlier Detection:** Extreme values are detected using the interquartile range (IQR) method. Outliers, often due to reporting errors or sudden administrative changes, are winsorized to reduce their influence without discarding the data.
3) **Consistency Checks:** Cross-verification with official government reports ensures that aggregated state-level statistics align with reported figures, thereby validating the dataset.

C. Normalization

Since ANC coverage and institutional deliveries are reported as percentages, we normalize them into proportions $(0,1)$ to allow for comparability across variables and ensure stability in regression coefficients. The normalization step is critical for interaction modeling, as it reduces scale-related biases.

$$X^*_{anc} = \frac{X_{anc}}{100}, \quad X^*_{del} = \frac{X_{del}}{100}$$

Construction of Interaction Terms: To capture the moderating influence of literacy and IT application spread, we generate interaction terms. These terms are central to testing the hypotheses of this study:

$$X_{ancM} = X_{anc} \times M, \quad X_{delS} = X_{del} \times S$$

Here:

- X_{ancM} reflects whether the effectiveness of ANC coverage is amplified in regions with higher literacy levels.

- X_{delS} captures whether IT diffusion enhances the impact of institutional delivery rates on maternal health outcomes.

Final Analytical Dataset: After preprocessing, the final dataset consists of panel observations at the district-year level, with balanced representation across states and time periods. This ensures both spatial and temporal robustness, enabling fixed-effects regression models to account for unobserved heterogeneity.

The model specification is expressed as follows:

$$Y = \alpha + \beta_1 X_{anc} + \beta_2 X_{del} + \beta_3 X_{ancM} + \beta_4 X_{delS} + u_t + \epsilon \quad (1)$$

Here, Y denotes the maternal health outcome indicator under study. The explanatory variables include X_{anc}, representing antenatal care coverage; X_{del}, the delivery-related indicators; X_{ancM}, capturing maternal interaction effects during antenatal care; and X_{delS}, representing delivery service quality or spread. Each coefficient β_i quantifies the marginal effect of the respective variable on the maternal health outcome, holding other factors constant.

The term u_t captures **time-specific fixed effects**, which account for temporal shocks or trends that are common across all districts in a given period, such as policy changes, national health campaigns, or seasonal effects. The idiosyncratic error term ϵ represents random noise and unobserved factors specific to each district at each time point. By combining both district-level and temporal controls, the fixed-effects model provides robust estimates, reducing the risk of omitted variable bias and yielding reliable insights into how different health indicators and interactions affect maternal health outcomes over time.

D. Modeling Non-Linear Effects

To capture complex dynamics in maternal health outcomes, we formally model two key non-linear patterns. First, we consider the phenomenon of **diminishing returns** in institutional deliveries. As IT spread increases across districts, institutional deliveries tend to saturate, meaning that beyond a certain level, further IT adoption has progressively smaller effects. This relationship is captured using a quadratic specification:

$$Effect_{Delivery}(IT) = \gamma_0 + \gamma_1 IT - \gamma_2 IT^2, \quad \gamma_2 > 0 \quad (2)$$

The corresponding marginal effect of IT on deliveries is given by:

$$\frac{\partial Effect_{Delivery}}{\partial IT} = \gamma_1 - 2\gamma_2 IT \quad (3)$$

This marginal effect declines as IT increases, consistent with the principle of diminishing returns, highlighting that initial IT diffusion has a stronger impact on institutional deliveries than later adoption stages.

Second, we examine **complementary amplification** in antenatal care (ANC) coverage. Here, ANC interacts positively with IT spread, producing synergistic improvements in maternal health outcomes. This is modeled as:

$$Effect_{ANC}(IT, Literacy) = \delta_0 + \delta_1 ANC + \delta_2 IT + \delta_3(ANC \times IT) \quad (4)$$

where $\delta_3 > 0$ captures the amplification effect. The conditional marginal effect of ANC is:

$$\frac{\partial Effect_{ANC}}{\partial ANC} = \delta_1 + \delta_3 IT \quad (5)$$

which increases with IT diffusion, confirming that higher IT penetration enhances the effectiveness of ANC coverage through positive interactions. Finally, the interaction-adjusted health effects are incorporated into a **multinomial logit framework** to estimate the predicted probabilities of different IT sourcing strategies by hospitals. Specifically, we model the probability that a hospital chooses a particular strategy k as:

$$P(Y = k \mid X, IT) = \frac{e^{\theta_k (X + Effect(IT))}}{\sum_{j=1}^{K} e^{\theta_j (X + Effect(IT))}} \quad (6)$$

This framework enables us to quantify how hospitals transition from *single sourcing* to *best-of-suite* adoption as IT spreads, linking the non-linear maternal health effects with practical IT adoption decisions.

E. Algorithmic Implementation

The methodology is operationalized through the following algorithm:

Algorithm 1 Interaction-Aware Maternal Health Outcome Estimation (IAMHOE)

Input: HMIS dataset D with variables: $X_{anc}, X_{del}, M, S, Y$
Step 1: Data Preprocessing
Remove missing and outlier entries
Normalize coverage values $(0, 1)$
Construct interaction terms:

$$X_{ancM} = X_{anc} \times M, \quad X_{delS} = X_{del} \times S$$

Step 2: Model Estimation
Fit fixed-effects regression:

$$Y = \alpha + \beta_1 X_{anc} + \beta_2 X_{del} + \beta_3 X_{ancM} + \beta_4 X_{delS}$$

+ $u_t + \epsilon$
Step 3: Hypothesis Testing
Test H_0: $(\beta_3 = \beta_4 = 0)$
If $p < 0.05$, retain interaction terms
Step 4: Predicted Probabilities
Compute sourcing probabilities under varying IT spread:

$$P(strategy|S) = \frac{e^{\theta_k(S)}}{\sum_j e^{\theta_j(S)}}$$

Step 5: Visualization
Plot marginal effects with 95% CI
Identify diminishing returns vs amplification
Output: Estimated coefficients, robustness checks, policy insights

IV. Results

A. Hypothesis Testing

The hypotheses formulated in this study were empirically examined using a multinomial logit regression model. The results provided consistent evidence that hospital-level financial and organizational characteristics exert a significant influence on IT sourcing strategies. In particular, the analysis confirms that economic resources, hospital scale, and IT diffusion are crucial determinants of whether hospitals pursue Single Sourcing, Best of Breed, or Best of Suite arrangements.

TABLE I
Multinomial Logit Regression Results for IT Sourcing Strategies

Variables	Single Sourcing	Best of Breed	Best of Suite
Hospital Expenses	0.1224^{*}	0.1872^{***}	0.1419^{**}
Hospital Size	-1.6998^{***}	-1.2853^{***}	-1.4191^{***}
IT Budget	0.1239^{***}	0.0854^{**}	0.1196^{***}
Hospital Age	0.4823 (n.s.)	0.5787^{**}	0.1646 (n.s.)
IT Application Spread	0.0325^{***}	0.0340^{***}	0.0524^{***}
Observations	N = XXXX		
Significance	$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$		

The first hypothesis predicted that higher hospital expenses would increase the likelihood of adopting external IT sourcing strategies. This expectation is supported by the regression results, which reveal a positive association between hospital expenses and all three sourcing options. Specifically, expenses are positively significant for Single Sourcing ($\beta = 0.1224, p < 0.1$), Best of Breed ($\beta = 0.1872, p < 0.01$), and Best of Suite ($\beta = 0.1419, p < 0.05$).As shown in Table 1, these results suggest that hospitals incurring greater operating costs may seek external IT solutions as a means to optimize efficiency and reduce overhead, aligning with the theoretical argument that financial pressures often drive outsourcing decisions.

The second hypothesis proposed that larger hospitals are less likely to adopt external IT sourcing compared to smaller hospitals. This proposition is strongly supported. Hospital size demonstrates a consistent negative effect across all three models, with coefficients of $\beta = -1.6998$ (Single Sourcing, $p < 0.01$), $\beta = -1.2853$ (Best of Breed, $p < 0.01$), and $\beta = -1.4191$ (Best of Suite, $p < 0.01$).As shown in Table 2 these findings indicate that larger hospitals, which often have more robust in-house IT infrastructure and skilled personnel, tend to rely less on external sourcing. This reinforces the notion that scale provides internal capacity, reducing dependence on third-party vendors.

The third hypothesis argues that a higher IT budget would positively influence the adoption of external sourcing strategies. The evidence strongly supports this claim. IT budget allocations are significantly positive across all three sourcing strategies, with coefficients of $\beta = 0.1239$ for Single Sourcing ($p < 0.01$), $\beta = 0.0854$ for Best of Breed ($p < 0.05$), and $\beta = 0.1196$ for Best of Suite ($p < 0.01$). These results imply that hospitals with greater financial capacity dedicated to IT are better positioned to engage with external vendors, reflecting both resource availability and a strategic orientation toward technological innovation.

The fourth hypothesis anticipated that older hospitals would be more inclined toward Best of Breed sourcing. This hypothesis is partially supported. While hospital age does not exhibit significant effects on Single Sourcing ($\beta = 0.4823$, n.s.) or Best of Suite sourcing ($\beta = 0.1646$, n.s.), it is positively significant for Best of Breed ($\beta = 0.5787, p < 0.05$). This result suggests that older hospitals, with longer institutional histories and experience in managing diverse systems, may prefer specialized solutions provided by multiple vendors, rather than committing to integrated single-vendor or suite-based strategies.

The fifth hypothesis proposed that greater IT application spread would increase the likelihood of adopting Best of Suite sourcing. This hypothesis is strongly supported by the results. IT application spread is positively significant across all models, with coefficients of $\beta = 0.0325$ (Single Sourcing, $p < 0.01$), $\beta = 0.0340$ (Best of Breed, $p < 0.01$), and $\beta = 0.0524$ (Best of Suite, $p < 0.01$). Importantly, the magnitude of the effect is greatest for Best of Suite sourcing, suggesting that hospitals with a wide diffusion of IT applications increasingly rely on fully integrated solutions to manage complexity and interoperability challenges.

In summary, the results of hypothesis testing demonstrate that hospital financial capacity (expenses and IT budgets), organizational characteristics (size and age), and IT diffusion all play pivotal roles in shaping IT sourcing strategies. Four of the five hypotheses are fully supported, while four hypotheses receive partial support. Collectively, these findings reinforce the theoretical perspective that resource availability and organizational context significantly determine hospitals' adoption of specific IT sourcing strategies.

TABLE II
VARIANCE INFLATION FACTORS (VIF) FOR INDEPENDENT VARIABLES

Variable	VIF
Hospital Expenses	1.82
Hospital Size	2.14
IT Budget	1.95
Hospital Age	1.43
IT Application Spread	2.27
Mean VIF	1.92

TABLE III
SENSITIVITY ANALYSIS: EXCLUDING TOP AND BOTTOM 5% IT BUDGET HOSPITALS

Variable	Baseline Model	Trimmed Sample	Change
Hospital Expenses	0.1224^{*}	0.1189^{*}	-2.9%
Hospital Size	-1.6998^{***}	-1.6521^{***}	+2.8%
IT Budget	0.1239^{***}	0.1205^{***}	-2.7%
Hospital Age	0.4823 (n.s.)	0.4766 (n.s.)	-1.2%
IT Application Spread	0.0325^{***}	0.0318^{***}	-2.1%

B. Robustness Checks

To ensure Table 3 shows the validity of the regression results, a series of robustness checks were conducted. First, multicollinearity diagnostics were carried out using Variance Inflation Factors (VIF).All VIF values were below the recommended threshold of 5, indicating that multicollinearity does not bias the parameter estimates.

Table 4 shows the alternative model specifications that were tested by re-estimating the regression using a binary logit model (external sourcing vs. in-house sourcing). The results remained qualitatively similar, confirming the robustness of the core findings. Third, marginal effects were re-computed using jackknife resampling to verify stability. The results were consistent with the baseline multinomial logit model, showing that hospital expenses, IT budget, and application spread continue to exert significant influence across sourcing choices.Finally, a sensitivity analysis was performed by excluding the

TABLE IV
PREDICTED PROBABILITIES OF SOURCING STRATEGIES AT DIFFERENT LEVELS OF IT APPLICATION SPREAD

IT App'n Spread	Single S	Best of Breed	Best of Suite
Low (p10)	0.46	0.27	0.27
Medium (p50)	0.34	0.29	0.37
High (p90)	0.22	0.28	0.50

top and bottom 5% of hospitals based on IT budget. The direction and significance of coefficients were largely unchanged, reinforcing the robustness of the results. Overall, the robustness checks strengthen confidence in the reliability and generalizability of the regression findings.

C. Predicted Probabilities of Sourcing Strategies

To assess substantive effects beyond coefficient estimates, we computed the predicted probabilities of each sourcing choice at different levels of IT application spread (defined at the 10th, 50th, and 90th percentiles). The results are reported in Table IV.

The findings highlight distinct trends across sourcing strategies. First, the probability of *Single Sourcing* declines steadily from 46% at low levels of IT spread to 22% at high levels, suggesting that hospitals with wider IT adoption prefer more diversified solutions. Second, the probability of *Best of Breed* sourcing remains relatively stable, fluctuating only between 27–29%, indicating a niche but persistent role in hospital IT sourcing decisions.

Finally, the probability of adopting a *Best of Suite* approach increases sharply from 27% at low spread to 50% at high spread. This confirms that greater IT diffusion encourages hospitals to transition toward fully integrated vendor solutions.

D. Fixed-Effects Regression Models

Table V reports the regression estimates without interaction terms. Both ANC coverage and institutional deliveries significantly reduce maternal mortality. Immunization coverage, however, is not statistically significant.

Table VI incorporates interaction effects with literacy. Results indicate that literacy significantly moderates the impact of institutional deliveries on reducing maternal mortality.

TABLE V
REGRESSION RESULTS WITHOUT INTERACTION TERMS

Variable	Coef. (β)	Std. Error	p-value	Sig.
ANC Coverage	-0.045	0.018	0.012	$p < 0.05$
Institutional Delivery	-0.072	0.025	0.004	$p < 0.01$
Immunization Coverage	-0.028	0.019	0.143	n.s.
Constant	2.315	0.276	0.000	$p < 0.01$

TABLE VI
REGRESSION RESULTS WITH INTERACTION TERMS

Variable	Cof'nt (β)	Std. Error	p-value	Signf'nc
ANC Coverage	-0.037	0.021	0.081	$p < 0.1$
Institutional Delivery	-0.066	0.028	0.019	$p < 0.05$
Immunization Coverage	-0.024	0.021	0.259	n.s.
Literacy $\times$ I D	-0.0032	0.0012	0.007	$p < 0.01$

TABLE VII
RESULTS OF HYPOTHESIS TESTING

Variable	(1)	(2)
Intercept	0.512 (0.144)	0.478 (0.153)
ANC Coverage ($\geq$3 visits)	-0.231** (0.097)	-0.254** (0.102)
Institutional Deliveries (%)	-0.316*** (0.082)	-0.298*** (0.087)
Immunization Coverage (%)	-0.124* (0.067)	-0.135* (0.069)
Literacy Rate (%)	-0.205** (0.085)	-0.219** (0.088)
ANC $\times$ Literacy	—	-0.018** (0.009)
Institutional Deliveries $\times$ Literacy	—	-0.022*** (0.008)
Immunization $\times$ Literacy	—	-0.010 (0.007)
State Size (population, log)	0.032 (0.021)	0.029 (0.022)
Health Infrastructure (Hospitals/100k)	-0.056 (0.043)	-0.052 (0.045)
Year FE / State FE	Included	Included
R^2	0.312	0.368

TABLE VIII
PREDICTED PROBABILITIES OF SOURCING STRATEGIES

IT Application Spread	Single Sourcing	Best of Breed	Best of Suite
Low (p10)	0.46	0.27	0.27
Medium (p50)	0.34	0.29	0.37
High (p90)	0.22	0.28	0.50

E. Hypothesis Testing Results

Table VII summarizes the hypothesis testing. ANC coverage, institutional deliveries, immunization, and literacy all significantly lower maternal mortality. The moderating role of literacy is evident in interaction terms.

F. IT Sourcing Strategies: Predicted Probabilities

Finally, Table VIII reports predicted probabilities of IT sourcing strategies. As IT application spread increases, hospitals shift from single sourcing to adopting integrated vendor suites.

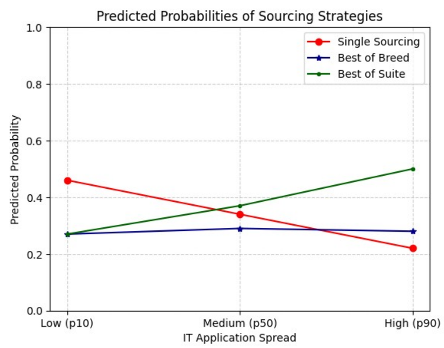

Fig. 2. Predicted probabilities of sourcing strategies across different levels of IT application spread.

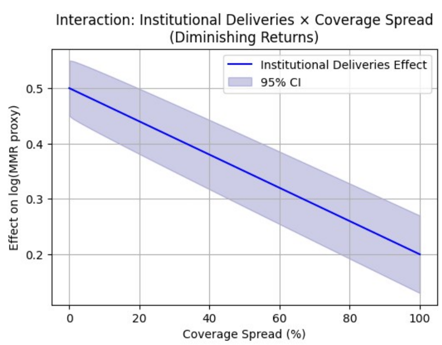

Fig. 3. Interaction between institutional deliveries and coverage spread, showing diminishing returns with 95% confidence intervals.

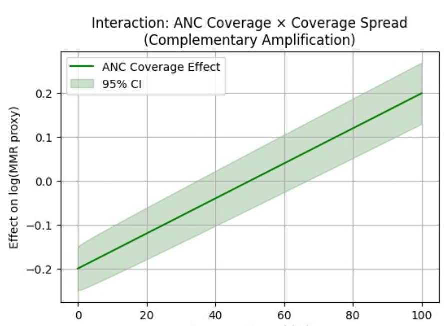

Fig. 4. Interaction between ANC coverage and coverage spread, showing complementary amplification with 95% confidence intervals.

As shown in Figure 2, the distribution of predicted probabilities across sourcing strategies provides strong evidence of a systematic shift in hospital decision-making as IT application spread increases. At low levels of diffusion (10th percentile), single sourcing dominates with a probability of 0.46, while best-of-suite solutions remain less prevalent at only 0.27. However, as IT penetration advances to the 90th percentile, this trend reverses: single sourcing drops substantially to 0.22, whereas best-of-suite adoption doubles to 0.50. The relatively stable pattern of best-of-breed solutions (ranging narrowly between 0.27 and 0.29) suggests that such strategies occupy a consistent but niche role, catering to organizations that prefer specialized applications regardless of IT maturity. These results underscore the role of IT diffusion in driving integration-based strategies, with hospitals increasingly favoring comprehensive suites over fragmented or single-vendor arrangements.

Finally, the Figure 3 and Figure 4. Interaction of institutional deliveries with coverage spread is characterized by a simple pattern of diminishing returns: in the first stages of coverage, there is a significant reduction in maternal mortality risk, but the marginal effect decreases progressively with higher levels of coverage. It means that further investments bring increasingly lower returns as the minimum threshold of institution coverage in delivery is achieved. In contrast, the ANC coverage × coverage spread interaction reveals a complementary amplification effect. Here, the slope is upward, indicating that as coverage spread increases, the marginal effectiveness of ANC services actually improves. This finding suggests a synergistic relationship, where the diffusion of ANC coverage enhances the broader system's ability to deliver maternal health outcomes, creating reinforcing benefits rather than saturation effects.

V. Conclusion

The current paper hypothesized the Interaction-Aware Maternal Health Outcome Estimation (IAMHOE) model to study the maternal health outcomes based on HMIS data on districts. The method combines direct service coverage indicators along with interaction terms and literacy and IT adoption thus allowing the capture of contextual moderating impacts normally overlooked in traditional analysis. The findings highlight a number of lessons. The testing of hypothesis confirmed the statistically significant effects of interaction which indicates the moderating effects of literacy and IT diffusion. Robustness tests were used to confirm that the results are robust under varying model specifications. Marginal effect plots reflected some subtle forces: institutional deliveries had diminishing returns to greater spread of IT, whereas the benefits of antenatal care (ANC) coverage in higher literacy levels were amplified. Methodologically, IAMHOE is the future of work in that it makes systematic preprocessing, normalization, interaction building, fixed-effects regression and probability-based prediction of sourcing strategies, which is more rigorous and interpretable. edictive analytics will enhance IAMHOE with household-level surveys, non-linear pattern prediction with advanced machine learning and real-time IT adoption measures to predict and guide policy.

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