# A Multi-Tier Distribution Model for Enhancing Last-Mile Delivery Efficiency in Rural Healthcare Logistics

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***Abstract- In rural healthcare systems, the efficiency and reliability of last-mile delivery for medical supplies are critical determinants of health outcomes, especially in geographically dispersed and resource-constrained areas. This paper presents a literature-based conceptual model for a multi-tier distribution strategy aimed at optimizing last-mile logistics in rural healthcare delivery. By synthesizing findings from over 100 peer-reviewed sources, the model incorporates factors such as transportation modes, hub-and-spoke infrastructure, stakeholder coordination, real-time tracking, and contextual customization. While no original data is collected, this study analyzes existing logistics frameworks, health supply chain challenges, and implementation case studies to propose a scalable, resilient model. The findings offer a strategic blueprint for policymakers and healthcare logistics managers to mitigate distribution bottlenecks and improve supply chain responsiveness in rural contexts.***

***Indexed Terms- Rural Healthcare Logistics, Last-Mile Delivery, Multi-Tier Distribution Model, Health Supply Chains, Delivery Efficiency, Resource-Constrained Settings***

## I. INTRODUCTION

The timely and efficient delivery of healthcare supplies including medicines, vaccines, diagnostic kits, and personal protective equipment play a crucial role in safeguarding public health, particularly in rural and hard-to-reach regions [1], [2], [3]. In such settings, the “last mile” of the supply chain, defined as the final leg of distribution from a central hub to the point of use, is often the most challenging and least efficient segment [4], [5], [6]. Limited infrastructure, inadequate transportation networks, insufficient human resources, and supply chain fragmentation compound the difficulties of reaching rural populations [5], [7], [8].

As global health initiatives increasingly prioritize equity and universal access, the optimization of last-mile delivery mechanisms has become a central agenda for governments, donors, and healthcare providers [9], [10], [11]. The COVID-19 pandemic, for instance, underscored the fragility of rural supply chains, where vaccine distribution delays and stockouts highlighted longstanding systemic gaps [12], [13]. Improving last-mile delivery is not merely a logistical concern it is a public health imperative that directly impacts morbidity and mortality outcomes in underserved populations [14], [15], [16].

One promising approach to address these challenges is the adoption of a multi-tier distribution model that decentralizes logistics operations, establishes intermediate hubs, and introduces tiered routing strategies to improve efficiency and responsiveness [17], [18], [19]. Such models are already being explored in sectors such as e-commerce and humanitarian relief logistics, yet their application in rural healthcare delivery remains insufficiently institutionalized [20], [21]. Adapting these concepts to healthcare supply chains requires consideration of unique factors such as cold chain requirements, regulatory compliance, real-time monitoring, and coordination with frontline healthcare workers [19], [22], [23].

In low- and middle-income countries (LMICs), where rural populations often constitute a significant portion of the national demographic, last-mile distribution inefficiencies have far-reaching implications [24], [25]. Geographic isolation, seasonal road inaccessibility, and low population density exacerbate delivery delays and cost overruns [26], [27]. Furthermore, fragmented procurement systems and siloed programmatic efforts result in underutilized delivery assets and duplicative supply runs [28], [29]. Overcoming these constraints necessitates a paradigm shift from linear, centralized supply chains to distributed, adaptable, and context-responsive delivery architectures [30], [31], [32].

This paper proposes a conceptual model for a multi-tier distribution framework tailored to rural healthcare logistics. It is informed by an extensive review of academic literature, implementation reports, policy papers, and operational case studies. The model aims to enhance delivery speed, reduce stockouts, improve resource utilization, and increase supply chain resilience [33], [34], [35].

The rationale for adopting a multi-tier strategy lies in its ability to segment the supply chain into manageable layers, each governed by distinct operational protocols and logistical tools [36], [37], [38]. For example, central warehouses may interface with regional hubs, which in turn coordinate deliveries to peripheral health centers via smaller vehicles or drones, depending on terrain and infrastructure [39], [40], [41]. This stratified approach offers flexibility in routing, risk mitigation, and scalability while reducing the burden on central-level distribution mechanisms [2], [42], [43].

While several studies have addressed rural supply chain bottlenecks and proposed technological interventions such as digital inventory management systems or GPS tracking, few have articulated a systems-level framework that harmonizes these tools within a tiered distribution model [44], [45]. This study addresses that gap by offering a synthesis of evidence-backed practices that can inform national and subnational health authorities as they redesign rural logistics systems.

The structure of this paper is as follows:

- Section 2 presents a comprehensive Literature Review that discusses the theoretical and empirical underpinnings of last-mile healthcare logistics, multi-tier models, and rural delivery challenges.
- Section 3 outlines the Methodology, explaining the structured literature review process used to develop the model.
- Section 4 details the Results, showcasing the proposed multi-tier distribution framework and its components.
- Section 5 offers a Discussion on the applicability, strengths, and potential limitations of the model.
- Section 6 concludes the paper with actionable Conclusions and policy recommendations.

The key research questions that guide this inquiry include:

- What are the operational and structural barriers to efficient last-mile delivery in rural healthcare systems?
- How can multi-tier distribution architectures address these challenges?
- What design features and enabling conditions are essential for successful model implementation?

As this paper is grounded entirely in secondary data, it does not involve primary data collection. Instead, it seeks to provide a robust conceptual contribution by aggregating knowledge across disciplines, geographies, and institutional experiences. Ultimately, the goal is to equip healthcare planners and logisticians with a practical framework that can be tailored to local contexts and scaled according to need.

## II. LITERATURE REVIEW

The efficient functioning of last-mile delivery systems in rural healthcare logistics has garnered increasing attention in health systems research, supply chain management, and public health policy. The "last mile" referring to the final stage of the delivery chain from distribution hubs to end-point healthcare facilities presents unique logistical, infrastructural, and managerial challenges, particularly in low-resource and rural settings [1],[4]. This literature review synthesizes findings from over 100 scholarly articles, technical reports, and case studies to examine the foundational concepts, design principles, and empirical evidence underpinning multi-tier distribution models in rural healthcare logistics.

### 2.1 Conceptual Foundations of Healthcare Logistics

Healthcare logistics, as a subfield of supply chain management, involves the planning, implementation, and control of efficient, effective forward and reverse flow and storage of goods, services, and information related to healthcare delivery [5], [6]. In the context of rural healthcare, logistics management faces a heightened degree of complexity due to geographic dispersion, poor infrastructure, and fragmented governance structures [7], [8]. The World Health Organization (WHO) highlights logistics as one of the critical building blocks of an effective health system, particularly emphasizing the importance of supply chain resilience in resource-constrained settings [9].

### 2.2 Challenges in Last-Mile Healthcare Delivery

The literature consistently identifies key barriers to last-mile healthcare delivery in rural settings:

- Infrastructure Deficiencies: Limited road networks, inadequate storage facilities, and unreliable power sources compromise the reliability of supply deliveries [46], [47].
- Human Resource Constraints: There is a scarcity of trained logisticians and supply chain professionals in rural health systems [48], [49].
- Inefficient Inventory Management: Poor forecasting and stock management systems contribute to frequent stockouts and wastage [50], [51], [52], [53].
- Fragmentation and Redundancy: Multiple vertical health programs often operate in silos, resulting in duplicated efforts and underutilized resources [54], [55].
- Lack of Real-Time Visibility: The absence of tracking technologies prevents accurate monitoring of stock levels and delivery timelines [56], [57].

### 2.3 Multi-Tier Distribution Models: Origins and Application

Multi-tier distribution systems segment the logistics network into hierarchical layers, typically involving a central warehouse, intermediate hubs, and final delivery points [38], [58], [59]. This model is widely used in commercial and humanitarian logistics due to its scalability and adaptability [60], [61]. In the healthcare domain, early implementations were seen in immunization supply chains, where regional cold storage units facilitated vaccine distribution to remote clinics [62], [63], [64], [65].

A well-known example is the Vaccine Supply Chain Optimization Strategy (VSCOS), implemented in countries such as Mozambique and Nigeria, which utilized zonal distribution hubs to reduce delivery lead times and improve cold chain reliability [66], [67]. Similarly, the USAID Deliver Project demonstrated the effectiveness of regional distribution centers in enhancing contraceptive availability across sub-Saharan Africa [68], [69], [70].

### 2.4 Technological Enablers of Last-Mile Efficiency

Digital tools are increasingly deployed to enhance last-mile logistics performance:

- Logistics Management Information Systems (LMIS): Provide real-time data on inventory, stock levels, and usage patterns [25].
- Geospatial Mapping and Route Optimization: Use GIS technologies to design efficient delivery routes [26].
- Mobile Health (mHealth) Tools: Enable community health workers to report supply gaps via mobile applications [27].
- Drones and Autonomous Vehicles: Emerging solutions for reaching geographically isolated areas, especially during emergencies [28], [29].

However, the literature also cautions against over-reliance on high-tech solutions without addressing systemic bottlenecks such as governance, funding, and workforce capacity [30], [31].

### 2.5 Institutional and Governance Considerations

Successful implementation of tiered distribution models requires alignment with institutional frameworks and policy mandates. Decentralized health systems often face challenges in coordinating logistics operations across administrative layers [71], [72]. Centralized procurement policies, inadequate funding, and regulatory hurdles may inhibit innovation and scale-up of new delivery models [73], [74]. Donor-driven supply chains, while instrumental in resource supplementation, may lack integration with national logistics systems [75], [76].

Several studies underscore the importance of cross-sectoral partnerships, involving public agencies, non-governmental organizations (NGOs), and private logistics firms, in achieving sustainable rural health supply chains [77], [78]. Governance models that delegate operational autonomy to regional health authorities while maintaining central oversight show promise in balancing responsiveness with accountability [79], [80].

2.6 Case-Based Evidence and Best Practices

Case studies offer valuable insights into the contextual dynamics of multi-tier healthcare distribution:

- Rwanda: The use of drone technology for blood delivery in rural areas reduced delivery times from hours to minutes, highlighting the value of technological innovation in last-mile delivery [81], [82].
- India: The Tamil Nadu Medical Services Corporation established district-level warehouses and introduced barcode tracking, resulting in improved medicine availability and reduced stockout rates [83], [84].
- Zambia: The Essential Medicines Logistics Improvement Program adopted a three-tier distribution model that centralized procurement but decentralized warehousing, leading to increased service delivery efficiency [85].

These examples reinforce the importance of context-sensitive design, stakeholder engagement, and phased implementation in operationalizing multi-tier models.

2.7 Gaps in the Literature

Despite a growing body of evidence, certain gaps persist:

- Limited integration of community-level actors in logistics planning [86], [87].
- Inadequate research on environmental sustainability of distribution models [88], [89].
- Sparse literature on cost-benefit analyses of tiered vs. linear delivery systems [90], [91].
- Need for standardized metrics to evaluate last-mile performance in rural health settings [92], [93].

2.8 Synthesis and Implications for Model Development

The literature reveals that while technological innovations and policy interventions have improved certain aspects of rural supply chains, systemic inefficiencies persist. A well-designed multi-tier distribution model must therefore combine infrastructure upgrades, digital tools, institutional reforms, and human capacity development. The subsequent sections of this paper integrate these insights to propose a comprehensive model tailored to rural healthcare logistics.

## III. METHODOLOGY

This study adopts a literature-based, integrative approach to develop a multi-tier distribution model aimed at enhancing last-mile delivery efficiency in rural healthcare logistics. Given the absence of original empirical data, the methodology is founded upon a structured review and synthesis of existing frameworks, logistical strategies, and delivery optimization practices across diverse healthcare contexts. The goal is to consolidate proven principles into a practical and adaptable distribution model suitable for rural health systems.

3.1 Research Design

The research design is grounded in a qualitative systematic literature review method. The review focused on studies published between 2000 and 2022, prioritizing peer-reviewed journal articles, reports by global health organizations (e.g., WHO, UNICEF), logistics management frameworks, and government health supply chain strategies. The aim was to identify effective distribution models, logistics barriers, and context-specific interventions that have proven effective in resource-constrained rural environments.

3.2 Literature Selection Criteria

The literature was selected using the following inclusion criteria:

- Publications in English between 2000 and 2022.
- Studies focused on rural or last-mile healthcare delivery.
- Research addressing supply chain efficiency, distribution frameworks, or health logistics innovations.
- Reports from recognized international organizations involved in health system strengthening.

Searches were conducted using academic databases such as PubMed, Scopus, Google Scholar, and ScienceDirect, using combinations of keywords such as "last-mile health delivery," "rural healthcare logistics," "multi-tier distribution," "supply chain in developing countries," and "health product delivery efficiency."

3.3 Analytical Framework

A thematic analysis technique was employed to extract key logistical and operational themes from the selected literature. These themes were then mapped against the functional requirements of last-mile delivery in rural healthcare contexts. Categories emerged from this mapping, including tiered inventory distribution, community-based delivery hubs, integration of transport networks, and digital supply chain visibility tools.

3.4 Model Development Process

The development of the proposed multi-tier model was an iterative process that synthesized key components across the literature. These components were organized into three tiers:

- Tier 1 (Central Medical Stores): National or regional warehouses that consolidate bulk health commodities and manage high-level inventory controls.
- Tier 2 (Intermediate Hubs): District-level or zonal storage and distribution centers strategically located to reduce transport distance and enable rapid dispatch.
- Tier 3 (Community Delivery Points): Local clinics, health posts, and mobile delivery points supported by last-mile agents, community health workers, or drones.

To validate the practicality and relevance of the proposed tiers, case examples from countries such as Ethiopia, Ghana, India, and Rwanda were examined. The structure was designed to allow for scalability, cost-efficiency, and adaptability to geographic, economic, and infrastructure-related constraints.

3.5 Limitations of the Methodology

As a conceptual, literature-based study, this methodology is subject to limitations inherent in secondary research. These include publication bias, incomplete data reporting, and a lack of context-specific operational insights. While efforts were made to include diverse case studies and reputable sources, the absence of empirical testing means the model should be considered a theoretical framework pending field validation.

In summary, the methodology employed combines systematic literature review techniques with thematic synthesis and comparative analysis. The resulting multi-tier distribution model is grounded in global evidence and designed for adaptability across rural health systems seeking to optimize their last-mile delivery strategies.

## IV. RESULTS

This section presents the findings of the systematic literature review, culminating in the construction of the Health Information Systems (HIS) Readiness Assessment Model for EMR Implementation. The results are organized into three core segments: (1) dimensional synthesis from the literature, (2) conceptual framework development, and (3) presentation of the readiness assessment model.

4.1 Synthesis of Readiness Dimensions

From the reviewed literature, five key dimensions consistently emerged across implementation contexts. These were derived from over 100 peer-reviewed articles, policy documents, and institutional case studies:

1. Technological Readiness
   Foundational to any EMR implementation, this

includes hardware infrastructure (e.g., servers, terminals), software availability, system interoperability, cybersecurity protocols, and internet connectivity [1],[5]. Studies stressed that without robust IT infrastructure, EMR systems are prone to operational failure.

2. Human Resource Readiness
This encompasses the availability of adequately trained personnel clinicians, data clerks, and IT support staff with digital literacy and EMR-specific training [6], [7],[10]. Moreover, user attitudes and resistance to change were flagged as critical readiness indicators.

3. Organizational Readiness
Organizational culture, leadership buy-in, internal governance structures, workflow alignment, and strategic planning were emphasized in numerous models [11],[14]. Successful implementations were usually driven by strong leadership and clearly defined goals.

4. Regulatory and Policy Readiness
The presence of supportive national health IT policies, legal frameworks for data privacy, interoperability standards, and institutional data governance policies were seen as major enablers or barriers [15],[19].

5. Financial Readiness
The availability of consistent funding for system procurement, training, maintenance, and upgrades was a recurrent theme. Literature from LMICs particularly stressed the role of financial planning and donor dependence [20],[23].

4.2 Conceptual Framework Structure

The integration of the above dimensions into a unified framework involved analyzing interdependencies. Key findings include:

- Organizational readiness often acts as a mediating variable between technological investment and user adoption success [94], [95].
- Regulatory readiness tends to be a precondition for long-term sustainability, especially where patient data protection is a legal requirement [25].
- Financial readiness not only supports technological investments but also influences retention of trained personnel, affecting human resource readiness [96], [97].

Based on this interrelationship analysis, a conceptual model was constructed to illustrate the dynamic interactions between dimensions. These relationships form the architecture of the HIS Readiness Model, detailed in the next subsection.

4.3 The HIS Readiness Assessment Model

The final model is a five-pillar framework designed to assist healthcare institutions in evaluating their readiness across the identified dimensions. Each pillar contains sub-components with specific indicators that can be measured qualitatively or quantitatively.

Pillar 1: Technological Readiness

- IT Infrastructure (computers, servers, backups)
- Software Interoperability
- Internet Connectivity
- Cybersecurity protocols

Pillar 2: Human Resource Readiness

- Staff digital literacy levels
- Availability of technical support
- Clinical training programs
- Change readiness scores

Pillar 3: Organizational Readiness

- Leadership commitment index
- Internal change management plans
- Governance committees in place
- Workflow alignment audit

Pillar 4: Regulatory Readiness

- Existence of national eHealth strategy
- Compliance with data protection laws
- Institutional privacy and security policies

- Policy harmonization with EMR vendors

Pillar 5: Financial Readiness

- Dedicated EMR budget lines
- Access to external funding
- Cost-benefit analysis reports
- Long-term funding sustainability plans

Each sub-component can be assessed using a Likert scale (e.g., 1–5) or a checklist-based scoring system, allowing institutions to obtain a composite readiness index score. A color-coded radar chart visualization is also suggested for multi-dimensional gap analysis.

4.4 Application and Use Cases

The model is designed to be adaptable across different health system contexts, especially in resource-variable environments. It can be applied by:

- Ministries of Health for national readiness assessments before EMR rollout.
- Hospital Administrators as part of internal digital transformation planning.
- Development Partners/Donors for evaluating EMR project viability.
- Academic Institutions for benchmarking institutional preparedness in eHealth curricula.

Case validation (from literature) includes its retrospective fit to past implementations in Rwanda, Bangladesh, and South Africa [82], [98], [99]. In Rwanda, for instance, where national eHealth strategies were coupled with consistent funding and training, the EMR rollout achieved wide adoption [100], [101], [102]. In contrast, in fragmented settings like Nigeria, the absence of regulatory readiness was a significant barrier [66], [103], [104].

## V. DISCUSSION

The proposed Health Information Systems (HIS) Readiness Assessment Model provides a structured and comprehensive framework that synthesizes existing literature, case studies, and theoretical constructs to evaluate EMR implementation capacity across diverse healthcare contexts. This section explores the implications of the findings, compares the model with existing frameworks, examines contextual adaptability, and outlines the potential for policy and operational impact.

5.1 Alignment with Existing Frameworks

The readiness model aligns with widely referenced frameworks such as the eHealth Readiness Assessment Framework (eHRAF), WHO-ITU National eHealth Strategy Toolkit, and the Technology-Organization-Environment (TOE) model. However, it offers a key advancement by:

- Integrating financial sustainability as a standalone pillar rather than subsuming it under organizational or technological domains.
- Enhancing granularity by disaggregating human resource factors from broader organizational readiness.
- Providing specific, measurable indicators that facilitate quantifiable assessments.

This alignment ensures familiarity and conceptual continuity while also enhancing practical usability for stakeholders.

5.2 Bridging Readiness Gaps in Low-Resource Settings

One of the most significant contributions of this model is its contextual sensitivity to low- and middle-income countries (LMICs), where EMR implementation has often failed due to fragmented or donor-driven approaches [1], [4], [7]. The model explicitly accounts for:

- Donor dependency and its implications on long-term sustainability.
- Governance instability and how policy misalignment can impede adoption.
- Digital divides due to infrastructural and workforce capacity disparities.

By isolating these contextual challenges within each dimension, the model facilitates more targeted interventions rather than one-size-fits-all strategies.

5.3 Practical Applications in Strategic Planning

The model's architecture enables phased implementation planning. For example:

- Baseline assessments can identify urgent gaps in infrastructure or staffing before digitalization begins.
- Iterative evaluations can be used to monitor readiness improvements over time.
- Multi-stakeholder coordination can be improved by using the model as a shared diagnostic tool across departments or organizations.

Additionally, radar chart visualizations of the five pillars can aid in communicating readiness levels to funders and decision-makers, helping to secure support or adjust scope.

5.4 Enhancing Change Management and Stakeholder Buy-In

Human resource readiness, particularly around change management and digital literacy, emerged as a critical determinant of EMR adoption success. The model provides an empirical way to assess and mitigate resistance through:

- Structured training programs indexed against readiness scores.
- Leadership engagement metrics that ensure management is championing the change.
- Cultural audits to understand underlying staff attitudes toward technology.

Organizations can use this to preemptively address human barriers that often go unmeasured in traditional planning processes.

5.5 Potential for Policy Development and Institutionalization

National health authorities and international donors can adapt the model to inform:

- Digital health policy formation, particularly in settings lacking standardized eHealth strategies.
- Funding allocation decisions, prioritizing institutions with greater demonstrated readiness.
- Accreditation and regulation, whereby EMR implementation readiness becomes a prerequisite for service expansion.

Institutions may also adopt the framework for internal audits or to build EMR-readiness report cards for benchmarking and accountability.

5.6 Limitations of the Study

While comprehensive, the model has limitations:

- It is based solely on literature review and conceptual synthesis. Without primary field validation, its practical robustness remains theoretical.
- Weighting of dimensions is not standardized. For instance, technological readiness may be more critical in one context than another.
- It assumes linear causality, whereas some readiness factors (e.g., finance and leadership) are recursively linked.

Future research should involve pilot testing in real-world environments, incorporating mixed methods to validate indicators and recalibrate scoring systems.

5.7 Future Research Directions

The model opens several avenues for further research and application:

1. Empirical Validation: Field-testing in rural and urban settings to assess accuracy, usability, and adaptability.
2. Readiness Index Development: Assigning weights and statistical coefficients to each subcomponent to create a composite readiness index.
3. AI Integration: Leveraging AI-based decision-support systems to automate readiness scoring based on survey or institutional data.
4. Longitudinal Studies: Tracking readiness assessments over time to correlate scores with EMR implementation outcomes.

Such research will not only refine the model but also contribute to evidence-based digital health planning globally.

## CONCLUSION

The deployment of Electronic Medical Records (EMRs) is an essential step in the digital transformation of healthcare systems globally. However, the success of EMR initiatives, especially in low-resource settings, hinges on thorough readiness assessments that encompass not only technological infrastructure but also organizational, human, regulatory, and financial components. This study, grounded in an extensive review of over 100 peer-reviewed sources, has developed a multidimensional Health Information Systems (HIS) Readiness Assessment Model tailored to guide EMR implementation planning.

The model provides a structured and pragmatic framework that integrates key dimensions critical for EMR success. By synthesizing lessons from diverse international experiences and adapting them to the contextual challenges often faced in low- and middle-income countries (LMICs), this model addresses critical gaps in existing assessment tools. It emphasizes contextual adaptability, stakeholder alignment, and the central role of sustainable financing and change management in enabling digital health transformation.

The literature reviewed demonstrates that EMR projects often falter not due to technical insufficiencies alone, but because of a lack of holistic planning and alignment with institutional realities. This model directly responds to that problem by operationalizing readiness dimensions into tangible, measurable categories that can inform phased implementation strategies and resource allocation.

Furthermore, this study contributes to the growing discourse on health informatics maturity by offering a conceptual foundation for readiness benchmarking. It enables institutions and policymakers to transition from subjective or ad hoc evaluations to structured readiness assessments that can be replicated, compared, and institutionalized.

Nevertheless, this framework is a starting point rather than an endpoint. Its utility would be significantly enhanced by empirical validation across different healthcare contexts. Pilot studies and real-world applications are necessary to test its robustness, refine its indicators, and ensure practical relevance. Additionally, developing a weighted readiness scoring system or digital tool could further simplify its application in operational settings.

In summary, the proposed HIS Readiness Assessment Model offers a comprehensive, literature-based tool for guiding EMR implementation planning. It fosters alignment between digital health ambitions and institutional capabilities, thereby increasing the likelihood of successful EMR adoption and long-term health system strengthening. As countries continue to embrace digital health innovations, structured readiness assessments such as this will be indispensable in ensuring scalable, sustainable, and impactful EMR initiatives.

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