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A Multi-Level Framework for Characterizing Prosthetic and Orthotic Systems and Translating Barrier Analysis into Strengthening Strategy: Development and Application in Post-Conflict Sierra Leone

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Method Article

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Abstract

What is already known on this topic

Only 1 in 10 people requiring prosthetic and orthotic (P&O) services globally can access them, with the greatest deficit in states with weak and destroyed health systems. The existing barrier literature catalogues constraints within categories but does not map them to health system levels or analyze how they interact across those levels. No replicable methodology exists for translating multi-level P&O barrier findings into an integrated strengthening strategy.

What this study adds

SABI (Systems Assessment for Barrier Interactions) provides a replicable methodology for characterizing how barriers interact across health system, service delivery, and individual/community levels. MAPS (Multi-level Architecture for P&O Strengthening) translates SABI findings into evidence-based domain selection for context-specific intervention design. Applied in Sierra Leone, this assess-then-design methodology produced SITE, a nationally formalized strengthening strategy, demonstrating proof of concept for comparable settings globally.

How this study might affect research, practice or policy

Standardized assessment and strategy design tools for P&O systems improve comprehensive understanding of barriers and guide interventions that improve care for persons with disabilities. Governments, NGOs, and international partners can apply SABI and MAPS as shared tools for moving from P&O systems characterization to strategy design. The methodology provides a foundation for multi-site validation toward a generalizable implementation guide for post-conflict and crisis-affected settings.

Introduction

Background and Methodological Gap

Of the estimated 35-40 million people globally who require P&O services, only 1 in 10 can access them [1], a treatment gap that constitutes both a service delivery failure and a fundamental health equity crisis. The gap is most severe in states with weak and destroyed health systems, where the same forces that elevate disability incidence (conflict, infectious disease, infrastructure destruction) simultaneously impede access to rehabilitation care [2,3]. Fewer than 3% of persons with disabilities in low-income countries access required rehabilitation services [4]. P&O care is particularly demanding to deliver: custom fabrication, trained clinicians, equipped workshops, reliable supply chains, and sustained multi-visit follow-up are all required, making it vulnerable to precisely the conditions that characterize these settings [1,5,6].

The existing P&O barrier literature, analyzed through the WHO Health System Building Blocks framework [7], documents constraints across service delivery, workforce, medical products, financing, and governance [8,9,10,11,6,12,13,14,15,2,16,17]. Health information systems remain conspicuously absent from this literature [18,19]. Critically, barriers are catalogued within categories rather than analyzed as an integrated system: the literature provides limited guidance on how interactions across levels produce outcomes that no single-level intervention can address [14,13,20]. This paper addresses that integration failure.

Solving it requires addressing two linked problems. The first is characterization: existing tools – the WHO P&O Standards [1], the WHO Assessment Package [31], and the barrier literature – do not together provide a methodology that simultaneously assesses barriers across all levels, models how they interact, and produces findings actionable enough to drive intervention design. The second is translation: even where rigorous assessments exist, no systematic process connects multi-level P&O barrier findings to an integrated strengthening plan. The record of P&O programs in states with weak and destroyed health systems reflects this gap: genuine needs have been addressed and important foundations laid, but without a shared methodology for designing toward the enabling conditions of continuity, these efforts have not consistently accumulated into lasting system capacity [4,16,2]. SABI (Systems Assessment for Barrier Interactions) addresses the first problem; MAPS (Multi-level Architecture for P&O Strengthening) addresses the second.

Sierra Leone as Proof of Concept

Sierra Leone experienced a decade-long civil war (1991-2002) and two subsequent health system shocks (Ebola 2014-2016; COVID-19), producing an estimated 60,000 persons needing P&O care, the largest disability group in the country [21,22]. At assessment, one clinician practiced nationally against a WHO benchmark of 5-10 per million, a deficit of 40-80 times the minimum standard. More than two decades of external interventions– device donation, technology introduction, short-term training – addressed genuine needs but were not designed with the enabling conditions for continuity as an explicit goal, and as a result, Sierra Leone's sector had not yet reached independent function [4,16,13,2]. The government's 2021-2025 Assistive Technology (AT) Policy and the MIT-MOHS partnership (Memorandum of Understanding January 2023-January 2027) provided both the institutional commitment and the sustained research access required to apply this methodology comprehensively [22,23]. Sierra Leone is where SABI and MAPS were developed and first applied; it is not the limit of their intended application.

Objective

This paper presents SABI and MAPS as complementary methodological contributions for P&O system strengthening in states with weak and destroyed health systems. Applied together in Sierra Leone, they demonstrate an assess-then-design methodology: SABI characterizes how barriers interact across

levels; MAPS translates those findings into evidence-based intervention design, producing SITE as Sierra Leone's context-specific strategy. Both frameworks are intended to be applicable across comparable settings globally.

Methods

Literature Review

A targeted review of peer-reviewed and gray literature was conducted to identify gaps in existing methodology and to provide a theoretical foundation for the multi-level systems assessment developed in this study. The review analyzed literature across three categories: (1) barrier documentation in P&O care; (2) comparable health systems assessment frameworks from adjacent fields; and (3) implementation science approaches relevant to barrier interaction analysis. Search and selection methodology, including databases, inclusion criteria, and retrieval approach, is detailed in Supplementary Table S1.

Document Review

Document review established policy context, baseline capacity metrics, and gaps between policy commitments and implementation realities. Documents analyzed included the Sierra Leone Assistive Technology Policy and Strategic Plan 2021–2025 [22], the CHAI Assistive Technology Country Capacity Assessment: Sierra Leone [21], WHO/USAID Standards for Prosthetics and Orthotics [1], MOHS strategic planning documents [24], and previous P&O program reports and evaluations, 2003–2015 (anonymized; multiple NGO sources).

Characterization of Sierra Leone's P&O Sector

Study Design

This study employed a longitudinal, mixed-methods pre-implementation systems characterization design conducted between 2021 and 2023 within the MIT-MOHS partnership. The research team served dual roles as researchers and practitioners, providing systems-level insights through sustained field engagement consistent with participatory action research methodologies [25,26]. Assessment visits were conducted by different team subsets across the three field trips, strengthening triangulation and reducing single-observer bias.

Assessment of P&O System via Multi-Level Interest-Holder Consultations

Field visits to “amputee camps” and “polio-persons camps” (communities built to house and support persons with disabilities and their families post-war) and communities across multiple districts documented environmental barriers, geographic access challenges, and social contexts affecting care-seeking. Interest-holder consultations (n = 90) were conducted with users or potential users of P&O Devices (n = 35), P&O providers and clinicians (n = 22), healthcare administrators and policymakers (n = 21), and NGO and donor representatives (n = 12), consistent with participatory action research methodologies [25,27,28]. Field notes documented aggregate themes without individual attribution; full methodology is in Supplementary Methods A. See Table 1 for the full consultation breakdown by stakeholder group, setting, and district.

Table 1
Interest-Holder Consultations (n = 90)

Stakeholder Group	Subgroup	Setting / District	Key Topics Explored
Users or Potential Users of P&O Devices *n = 35*	Lower limb amputees	Bo, Masiaka, Makeni, Masanga, Koidu, Kenema, Freetown	Barriers to access; device quality and durability; economic constraints; stigma; transportation; abandonment
	Upper limb amputees	NRC Freetown; amputee camps	Device fit; cultural appropriateness; community perception; livelihood impact
	Persons with polio-related disability	Polio-persons camps; Northern Province	Orthotic access; geographic barriers; stigma; healthcare utilisation; care-seeking
P&O Providers & Rehabilitation Professionals *n = 22*	P&O clinicians (Category I–III)	NRC, Bo, Makeni, Koidu clinics	Workforce shortage; infrastructure constraints (power, equipment); supply chain unreliability; training needs; quality assurance; lack of supervision
	P&O technicians	NRC, Bo clinics	Workshop equipment functionality; fabrication materials; daily workflow constraints; supply chain
	Physiotherapists & nurses	NRC, Bo, Makeni clinics	Referral pathways; patient follow-up; wait times; coordination gaps across services
Healthcare Administrators & Policymakers *n = 21*	MOHS leadership (Minister, Deputy Minister, CMO)	Freetown (MOHS HQ, Connaught Hospital, State House)	Policy implementation; budget and financing; health system integration; governance; strategic priorities; partnership scope
	Facility administrators & clinic leads	NRC, Bo, Makeni, Koidu clinics; Bo Government Hospital; Koidu Government Hospital	Operational constraints; supply chain; staffing; data systems; referral pathways
	District health officers	Bombali, Tonkolili, Port Loko, Bo, Western Area	District-level access; rehabilitation referral; coordination; resource constraints
NGO & Donor Representatives *n = 12*	International NGO program staff	Freetown; Bo; Koidu; Masanga	Prior program models; lessons learned; coordination; sustainability; international standards adaptation

Stakeholder Group	Subgroup	Setting / District	Key Topics Explored
	Bilateral & multilateral donor representatives	Freetown	Funding architecture; sector priorities; coordination gaps; donor dependency
Total n = 90		Geographic representation spans Freetown (NRC), Bo, Makeni, Koidu; amputee and polio-persons camps in rural and urban areas; community settings across Western, Northern, Southern, and Eastern Provinces	

Consultations conducted November 2021 – March 2023. Field notes documented aggregate themes without individual attribution; full methodology in Supplementary Methods A.

Clinical Infrastructure and Capacity Assessments

Systematic infrastructure assessment was conducted at all four MOHS-operated P&O facilities across three field visits: November-December 2021 (all four facilities; FRA, DD, AK), July 2022 (all four facilities; DD, NMB, LA, AK), and January-March 2023 (NRC and Bo Clinic only; FRA, DD, AK, PK) (Supplementary Methods A). Facility conditions were assessed across five domains — power supply, water access, workspace adequacy, equipment functionality, and safety and infection control — each scored 0–5 for a facility total of 0–25; the full rubric is in Supplementary Table S3. Equipment inventories, workforce data, service volume records, and supply chain conditions were documented at each visit.

Framework Design and Four-Step Translation Process

SABI and MAPS were developed iteratively from the characterization data described above, through two linked and sequenced components: barrier interaction analysis and a four-step translation process.

Barrier Interaction Analysis

Relationships between barriers across the three assessment levels were mapped to identify compounding effects, feedback loops, and cross-level dynamics, adapting barrier mapping techniques from systems thinking approaches and multi-level barrier interaction frameworks [14,29]. The analysis proceeded through four steps: (1) barrier linkage identification, tracing connections between barriers at different levels; (2) feedback loop modeling, mapping vicious cycles in which barriers at one level create downstream constraints that reinforce the original barrier; (3) compound effect analysis, examining whether co-occurring barriers produce multiplicative rather than additive access constraints; (4) cascade analysis, distinguishing downward cascades (system-level failures propagating to create apparently local barriers) from upward masking (individual-level barriers that appear demand-side but reflect unaddressed supply-side failures above); and (5) cross-source validation, cross-referencing proposed barrier interactions across literature, field observations, and interest-holder accounts before inclusion in the framework.

Four-Step Translation Process and MAPS

Barrier interaction findings were translated into a generalizable domain architecture through four steps: (1) barrier-domain mapping, linking each barrier cluster to the intervention domain it most directly constrains; (2) prior support model analysis, examining which approaches had been attempted in Sierra Leone and what the consequences of systematic absences had been; (3) international framework alignment against WHO P&O Standards benchmarks [1] and WHO Health System Building Blocks; and (4) participatory co-design with MOHS leadership, Sierra Leonean clinicians, and program partners. This process produced SITE — the context-specific strategy selected from MAPS based on Sierra Leone's barrier profile — formalized in the MIT-MOHS Memorandum of Understanding (January 2023-January 2027).

Ethical Considerations

Pre-implementation systems assessment and interest-holder consultations were conducted within the MIT-MOHS partnership as part of needs assessment and partnership development activities. Infrastructure and capacity assessments are standard components of health system evaluations and do not require IRB approval when focused on organizational rather than individual human subjects data [30]. All facility visits and consultations were conducted with explicit permission from facility administrators, organizational leaders, and the MOHS, with participant understanding that input would inform program development. Consultation records were maintained as aggregated thematic summaries with no individual attribution, direct quotation, or personally identifying information recorded, consistent with participatory action research principles [27,28,25]. The dual researcher-practitioner role of the research team is explicitly acknowledged as a potential source of bias; triangulation across multiple independent data sources, co-authorship with Sierra Leonean practitioners, and external validation through committee review were employed to mitigate this. This study is a systems-level characterization; sex and gender disaggregated data were not collected as part of the assessment methodology and are not reported.

Patient and Public Involvement

Persons with disabilities who use P&O devices were involved in this research both as interest-holder consultation participants and as students in the educational curriculum developed through the MIT-MOHS partnership. Ministry of Health and Sanitation leadership and Sierra Leonean P&O providers and professionals have been engaged as active partners throughout the design and implementation of the strengthening strategy described in this study, including through co-authorship of this paper. Findings will be disseminated to MOHS partners and participating communities through the ongoing partnership.

Results

SABI and MAPS: Framework Overview

SABI (Systems Assessment for Barrier Interactions; *sabi* means 'know/understand' in Krio, the lingua franca of Sierra Leone) comprises three components: multi-level barrier identification across the health

system and policy, service delivery and clinic, and individual and community levels; systematic mixed-methods data collection tailored to each level; and barrier interaction analysis that maps how limitations at one level create, amplify, or sustain barriers at others. MAPS, developed through the four-step translation process described in Methods, organizes 14 intervention domains across these three levels. **Figure 1** presents the assess-then-design methodology as a whole, showing how SABI barrier findings drive domain selection from MAPS to produce a context-specific strengthening strategy; **Figures 2 and 3** present each framework in full detail. The sections below document their application in Sierra Leone.

Multi-Level Barrier Findings

Level 3 — Health System and Policy

At the health system and policy level, SABI assessment identified a pattern of policy commitment without implementation capacity. The 2021-2025 AT Policy [22] represented genuine government commitment, but no dedicated P&O budget line existed at assessment. The CHAI Country Capacity Assessment (2019) — which itself represents a meaningful contribution to understanding the sector — confirmed that until 2019 no financial resources had been allocated to the AT sector nationally, with the first-ever government allocation of 2 billion Sierra Leonean leones for rehabilitation services announced in FY2019-20 — described by CHAI as politically significant but programmatically insufficient [21]. Coordination across MOHS, NGOs, and donors was fragmented with no designated P&O sector lead below the Minister level. Clinical records were paper-based and non-standardized across facilities; no national P&O registry existed.

Level 2 — Service Delivery and Clinic

Assessment of all four MOHS-operated P&O facilities revealed severe and consistent infrastructure constraints across all five scored domains (Table 2).

Table 2: Infrastructure Assessment Summary — All Four National P&O Facilities

Facility	Power (0-5)	Water (0-5)	Workspace (0-5)	Equipment (0-5)	Safety (0-5)	Total (0-25)
NRC Freetown	2	2	3	1	2	**10**
Bo Clinic	2	3	3	1	2	**11**
Makeni Clinic	3	3	4	2	2	**14**
Koidu Clinic	2	3	1	1	1	**8**
Mean	**2.25**	**2.75**	**2.75**	**1.25**	**1.75**	**10.75**

All scores on 0-5 scale. Total score classification: 20-25 = fully operational; 15-19 = operational with limitations; 10-14 = severely constrained; 5-9 = minimally functional. Full scoring rubric in Supplementary Table S3.

Equipment functionality was the most severe constraint nationally, with a mean score of 1.25/5. Across facilities, fewer than 25% of workshop machines and tools were operational at the time of assessment, with the remainder non-functional, awaiting unavailable parts, or beyond repair. The consequences of equipment failure were compounding: when lamination and vacuum forming capabilities failed, clinicians adapted by fabricating sockets from thermoplastics rather than the gold-standard carbon fiber and resin construction. Thermoplastic sockets are not designed for the load-bearing demands of permanent prosthetic use and fail prematurely under sustained weight-bearing activity. When the ovens required to mold thermoplastics subsequently failed, fabrication quality degraded further still, producing a progressive downward spiral in which clinicians trained to higher standards were constrained to produce devices of declining quality through no fault of their own. Power unreliability was the second most severe constraint (mean 2.25/5), directly limiting fabrication capacity: at the NRC, grid power was available for an estimated 4-6 hours per day, with generator use constrained by fuel costs. Workspace adequacy was relatively stronger (mean 2.75/5) but insufficient to compensate for equipment and power deficits.

Nationally, one Category I clinician was practicing independently, against a WHO benchmark of 5-10 qualified P&O clinicians per million population [1]. With Sierra Leone's population of approximately 8.4 million, this represents a deficit of 40-80 times the minimum recommended standard. National device production averaged 56 new devices per year (range 39-73, 2019-2022), with a declining trend over the period.

Level 1 — Individual and Community

At the individual and community level, SABI assessment identified barriers across four domains: stigma and social inclusion, community demand and awareness, geographic and physical access, and cultural

appropriateness. Each domain produced distinct but interacting constraints on both care-seeking and sustained device use, as described below.

Stigma and social inclusion. Stigma manifested across urban and rural settings in family separation, concealment of disability, and the perception among some community members that physical disability was accompanied by cognitive incapacity. Amputee and polio-persons camps established after the war functioned simultaneously as sites of solidarity and structural isolation: placement off paved roads limited residents' access to urban centers for work and healthcare, and individuals without family or peer support faced compounded geographic, economic, and logistical barriers to clinic attendance.

Community demand and awareness. Community demand for P&O services at MOHS facilities was constrained less by absence of awareness than by rational disengagement from an unreliable system. Consultations documented that service availability and quality at government clinics were inconsistent: care was sometimes free when external organizations were sponsoring and at other cost when they were not, while device quality varied with equipment and supply conditions. For rural service users facing substantial travel costs, this unpredictability made care-seeking a high-risk calculation. Over time, communities adapted by directing demand toward episodic external provision — NGOs and visiting organizations — rather than the formal MOHS system, consistent with documented responses to chronic service unreliability in fragile health systems [4,16].

Geographic and physical access. Economic and geographic barriers were pervasive and compounded each other. Across surveyed amputee camps in the consulted Northern and Western Provinces (n=130 respondents, Bombali, Tonkolili, and Port Loko districts), 70% of respondents lived more than one hour from the nearest P&O clinic, with 55% reporting travel times of 3-5 hours and 5% requiring 1-2 days of travel. Cost was the most frequently cited accessibility barrier, followed by lack of transportation and distance. The true cost of access was insurmountable for many rural service users, including transportation, missed labor, and accommodation for multi-visit care pathways.

Cultural appropriateness. Field observations documented a recurring pattern in which devices and materials supplied through external channels were misaligned with the social and environmental demands of users' daily lives. Donated components from external sources were repeatedly observed to be incompatible with locally available parts, rendering devices irreparable after first failure. Some prosthetic hands supplied by visiting groups were designed around concealment of disability, with colorings and forms misaligned with users' own appearance and preferences, imposing external assumptions rather than responding to expressed needs. A 3D-printed prosthetic project observed during a field visit used materials that degrade with water exposure — a critical shortcoming given the terrain and seasonal conditions users navigate daily, where device removal is neither practically nor socially feasible. Across these observations, the common failure was the absence of meaningful user input in design and supply decisions made by external actors.

Barrier Interaction Analysis

The barrier findings above, considered in isolation, would suggest that addressing any single constraint, whether infrastructure, workforce, or financing, could substantially improve P&O access. The interaction analysis (Supplementary Table S2) reveals why this has not been the case despite decades of international engagement, and why it will not be the case without integrated, sequenced intervention.

Vicious cycles

The most consequential vicious cycle identified links infrastructure deficit, device quality, community perception, and government prioritization in a self-reinforcing loop. Infrastructure deficits constrain fabrication time and material quality, producing devices that fit poorly and fail prematurely. Poor device quality leads to abandonment, documented in interest-holder consultations as a pattern in which service users receive devices, find them inadequate, and do not return for follow-up care (Author, fieldwork 2021-2023). Through peer networks within amputee communities, experiences of device failure circulated as shared knowledge, reinforcing community-level perceptions that locally produced P&O devices were unreliable. This perception was not unfounded given the fabrication constraints described above, but it created a feedback loop in which reduced demand further depressed the visible case for government investment in the facilities producing those devices. Low community confidence reduces demand and patient volume, reducing the visible case for government infrastructure investment and leaving the underlying deficit unaddressed. [4,16].

Multiplicative effects

For rural service users, who represent the majority of Sierra Leone's population with disabilities, barriers to P&O care do not add; they multiply. Among surveyed amputee camp residents, 55% reported travel times of 3-5 hours to the nearest clinic, with a further 5% traveling 1-2 days. Field observations documented cases in which the physical demands of travel itself constituted a safety barrier: one upper limb amputee sustained injuries falling from a motorcycle on an unpaved road en route to the clinic and did not return for follow-up care (Author, fieldwork 2021-2022). A P&O care pathway requires multiple visits, encompassing assessment, fitting, adjustment, and follow-up, each requiring transportation to an urban clinic, time away from economic activity, and often accommodation. Combined with the unpredictability of service availability driven by power outages and supply stockouts, rural service users face effective access costs substantially greater than the nominal zero charge for devices. This multiplicative dynamic explains why demand-side interventions have limited impact without prior stabilization of supply-side conditions.

Upward Masking

A fourth interaction pattern, upward masking, was identified in the barrier analysis. Individual and community barriers that appear to reflect low demand often mask unaddressed supply-side failures at

the service delivery or system level above. In Sierra Leone, low rates of care-seeking and device abandonment were initially interpretable as demand-side failures attributable to stigma or awareness gaps. Barrier interaction analysis revealed, however, that the primary driver was service-side: infrastructure collapse, device quality failures, and workforce absence meant that supply was inadequate to sustain demand even where demand existed. Communities with prior negative experiences of P&O care communicated those experiences through peer networks, suppressing apparent demand for services that had in practice failed them. This dynamic has a direct methodological implication: demand-side interventions implemented without prior supply-side stabilization are unlikely to produce lasting change, because the conditions generating low demand remain in place. Upward masking is therefore diagnostically important for sequencing decisions: where it is identified, supply-side conditions should be addressed before or alongside demand-side programming.

Downward cascades

The absence of a dedicated P&O budget line meant that workforce expansion could not proceed through government channels alone. With a single Category I clinician nationally, caseload exceeded sustainable capacity, limiting time per patient and quality of follow-up. Wait times of 4-12 weeks from assessment to device delivery were reported across facilities (Supplementary Methods B). Long waits functioned as a Level 1 barrier: service users who had traveled long distances returned home without devices and did not return. This cascade illustrates why training additional clinicians in isolation is insufficient: without a financing mechanism to employ them, trained clinicians emigrate or leave the profession, a pattern documented consistently in the prior engagement literature [4,16].

From Characterization to Strategy: Applying MAPS to Sierra Leone

The SABI barrier findings and interaction analysis described above directly informed domain selection from MAPS. The full MAPS comprises 14 domains across three levels (Figure 3). The four-step translation process applied to Sierra Leone's barrier profile produced SITE (Supplementary Figure S1), encompassing Supply chain, Infrastructure, Technology, and Education, as the four priority intervention domains, all drawn from Level 2.

The selection logic proceeded as follows. Level 3 enabling conditions — governance commitment and policy framework — were partially in place through the AT Policy and MIT-MOHS partnership, sufficient to support Level 2 intervention without requiring prior Level 3 strengthening as a prerequisite. Level 1 demand barriers were assessed as substantially driven by Level 2 failures; improving service reliability was expected to activate latent demand without requiring parallel demand-side investment. Level 2 therefore represented the highest-leverage entry point.

Within Level 2, Supply Chain, Infrastructure, Technology, and Education were selected because the barrier interaction analysis confirmed them as an interdependent set. Addressing any subset without the others would reproduce the vicious cycles and cross-level cascades documented above: supply chain without infrastructure leaves fabrication constrained; infrastructure without workforce leaves facilities underutilized; workforce without technology produces clinicians without appropriate devices to fit. The SITE strategy was formalized in the MIT-MOHS Memorandum of Understanding (January 2023-January 2027) and constitutes the subject of evaluation in a companion paper in preparation. MAPS remains applicable across settings: other contexts applying SABI will produce different barrier profiles and therefore different domain selections from the same architecture. In the words of Sierra Leone Minister of Health, at the time of the partnership formalization: *"This collaboration will foster access, innovation, and capacity-building in the Orthotic and Prosthetic division. The ministry is pleased to work with and learn from MIT over the next four years in building resilient health systems, especially for vulnerable groups."*

Discussion

The central methodological gap this paper addresses is the absence of a replicable process connecting multi-level P&O systems characterization to evidence-based intervention design (Fig. 1). Existing tools — the WHO P&O Standards and Assessment Package [1] — do not together provide a diagnostic methodology for characterizing barrier interactions or translating findings into a strengthening strategy. The barrier literature has remained largely descriptive, cataloguing barriers within categories rather than analyzing relationships across them [31,14,13,20]. SABI and MAPS together address this gap; multi-site validation is underway.

The barrier interaction analysis has a specific implication for intervention evaluation. Where barriers sustain each other across levels, single-level outcome measures may misattribute the causes of failure: an infrastructure improvement that does not produce lasting quality gains may reflect not implementation failure but the reconstitution of fabrication constraints through supply chain and workforce pathways left unaddressed. Outcome frameworks for P&O system strengthening should therefore be designed to capture cross-level dynamics, not only domain-specific outputs.

Several limitations warrant acknowledgment. Data were collected during active partnership development, with the team serving dual roles as researchers and practitioners; cross-referencing across multiple independent sources was used to mitigate positionality risks, though replication by independent teams would strengthen confidence. This is a single-country application; the barrier profile and domain selection documented here are specific to Sierra Leone and should not be assumed to generalize directly to other settings. The barrier interaction analysis is empirically grounded but does not include formal quantitative modeling of interaction effects, which remains a methodological frontier.

SABI and MAPS are offered as shared methodological resources for all actors engaged in P&O system strengthening, including governments, NGOs, international partners, clinical programs, and training institutions. The goal of sustainable, quality P&O care that continues to function as partnerships and

funding change is one that external and internal actors share; a common methodology for assessing systems and designing strategy collaboratively is one practical means of working toward it.

Conclusion

This study demonstrates that integrated, multi-level P&O systems characterization reveals barrier dynamics that single-level approaches cannot detect and that single-level interventions cannot address. SABI and MAPS together provide a replicable methodology for moving from characterization to evidence-based strategy in states with weak and destroyed health systems. Applied in Sierra Leone, this methodology produced SITE — a nationally formalized, interdependent strengthening strategy grounded in local barrier evidence. Multi-site validation is the explicit next step toward establishing generalizability across comparable settings.

Declarations

Competing Interests

All authors declare no financial competing interests. Riccio-Ackerman, Dotz, Clarissimeaux, Humure, Kaili, Kamara, and Herr declare that this research was funded in part through the K. Lisa Yang Center for Bionics, with which several authors are affiliated (see author affiliations). Kaili additionally receives salary support from the Ministry of Health and Sanitation, Sierra Leone. Muñoz Buderus, Alhallaak, and Planells are employed by Human Study, an organization contracted by the K. Lisa Yang Center for Bionics to develop and deliver the P&O educational curriculum described in this study. These institutional relationships are fully disclosed in the Funding statement and do not constitute personal financial competing interests in the findings. No author holds any commercial interest in the frameworks described.

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Figures

FIGURE 1

Assess-then-design: the SABI–MAPS methodology for P&O system strengthening

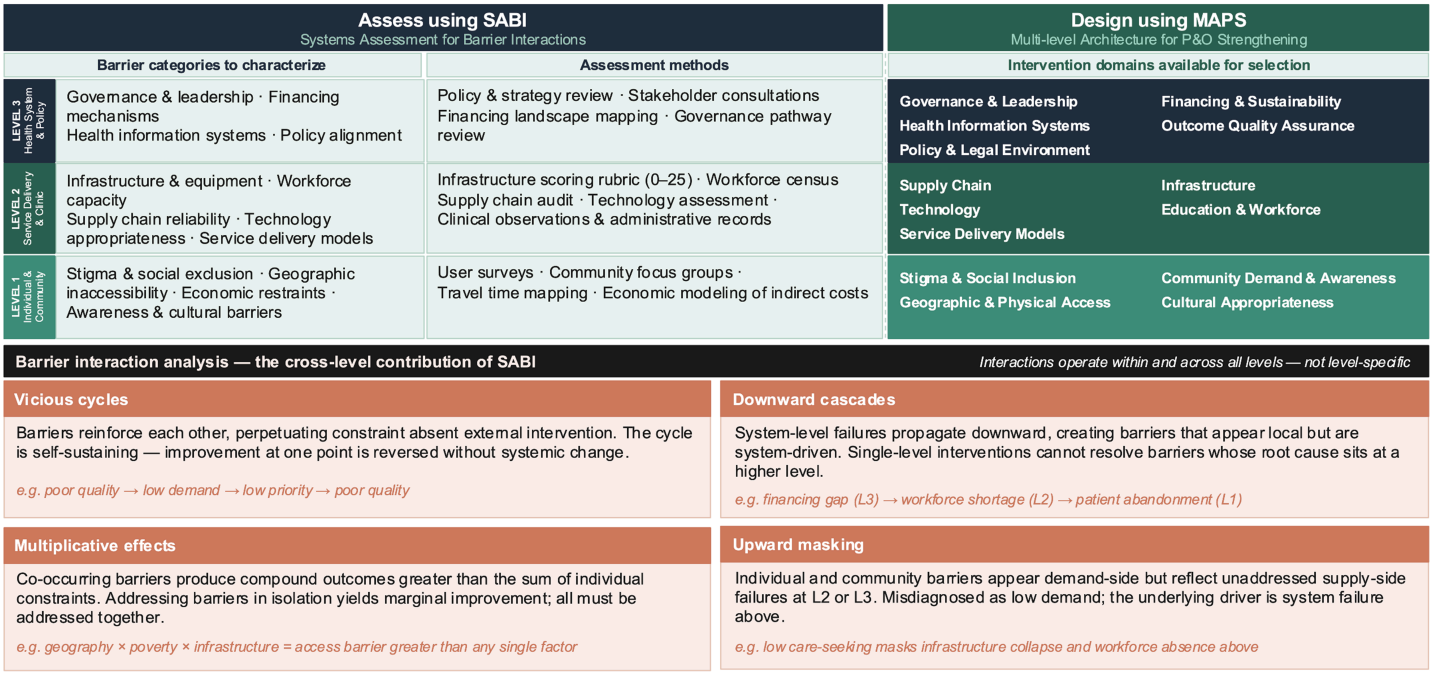


Figure 1

Assess-then-design: the SABI–MAPS methodology for P&O system strengthening. The assess-then-design methodology comprises two complementary frameworks. The upper panel presents SABI (Systems Assessment for Barrier Interactions) organized across three levels: Level 3 (Health System & Policy), Level 2 (Service Delivery & Clinic), and Level 1 (Individual & Community). For each level, the framework specifies example metrics, key barrier categories to identify, and relevant data sources. The barrier interactions panel illustrates four cross-level dynamics — vicious cycles, multiplicative effects, downward cascades, and upward masking — that SABI is designed to reveal. This framework is intended to be applied in any national or subnational P&O system; metrics, barrier categories, and data sources should be adapted to local context and data availability.

FIGURE 2

SABI — Systems Assessment for Barrier Interactions

A replicable methodology for multi-level P&O systems characterization. Apply at any national or subnational P&O system to identify barriers, assess their severity, and analyze how they interact.

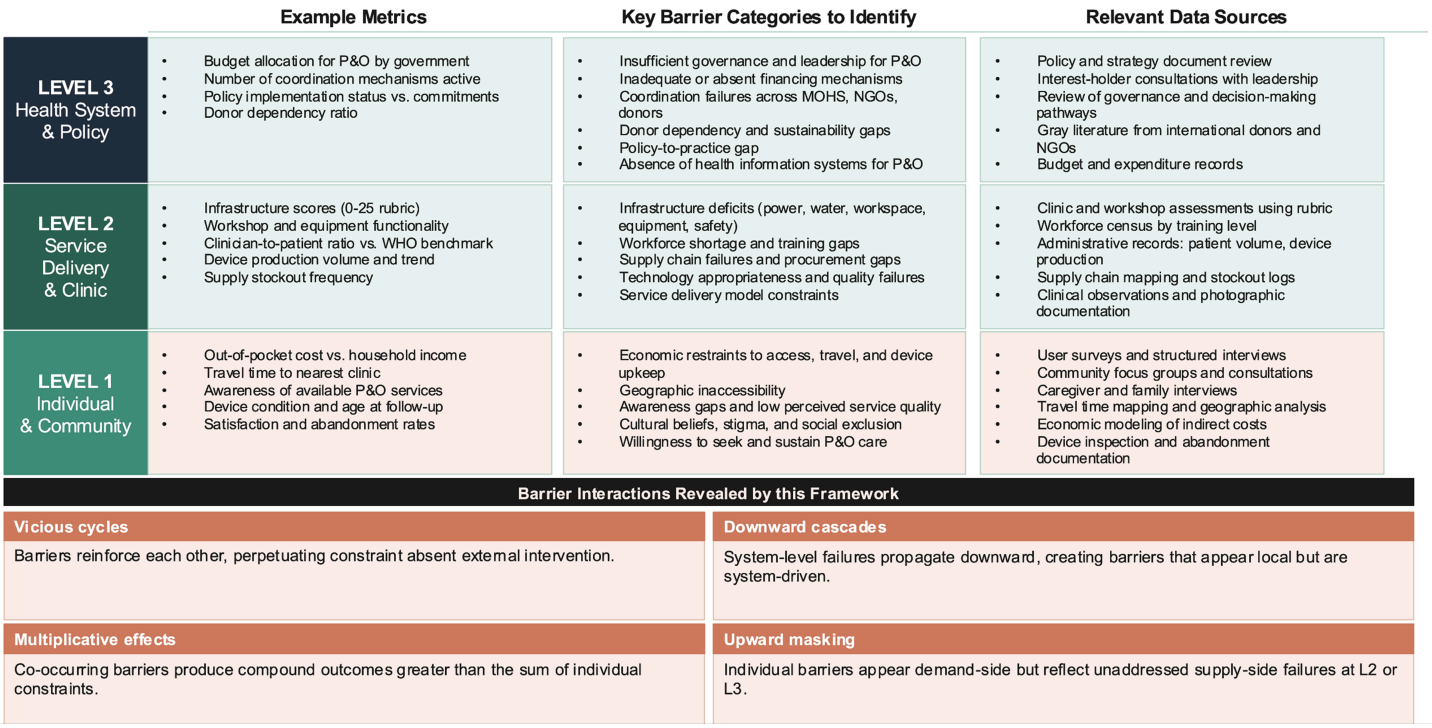


Figure 2

SABI (Systems Assessment for Barrier Interactions). A replicable methodology for multi-level P&O systems characterization. The framework organizes assessment across three levels: Level 3 (Health System & Policy), Level 2 (Service Delivery & Clinic), and Level 1 (Individual & Community). For each level, the framework specifies example metrics, key barrier categories to identify, and relevant data sources. The barrier interactions panel illustrates four cross-level dynamics — vicious cycles, multiplicative effects, downward cascades, and upward masking — that SABI is designed to reveal. This framework is intended to be applied in any national or subnational P&O system; metrics, barrier categories, and data sources should be adapted to local context and data availability.

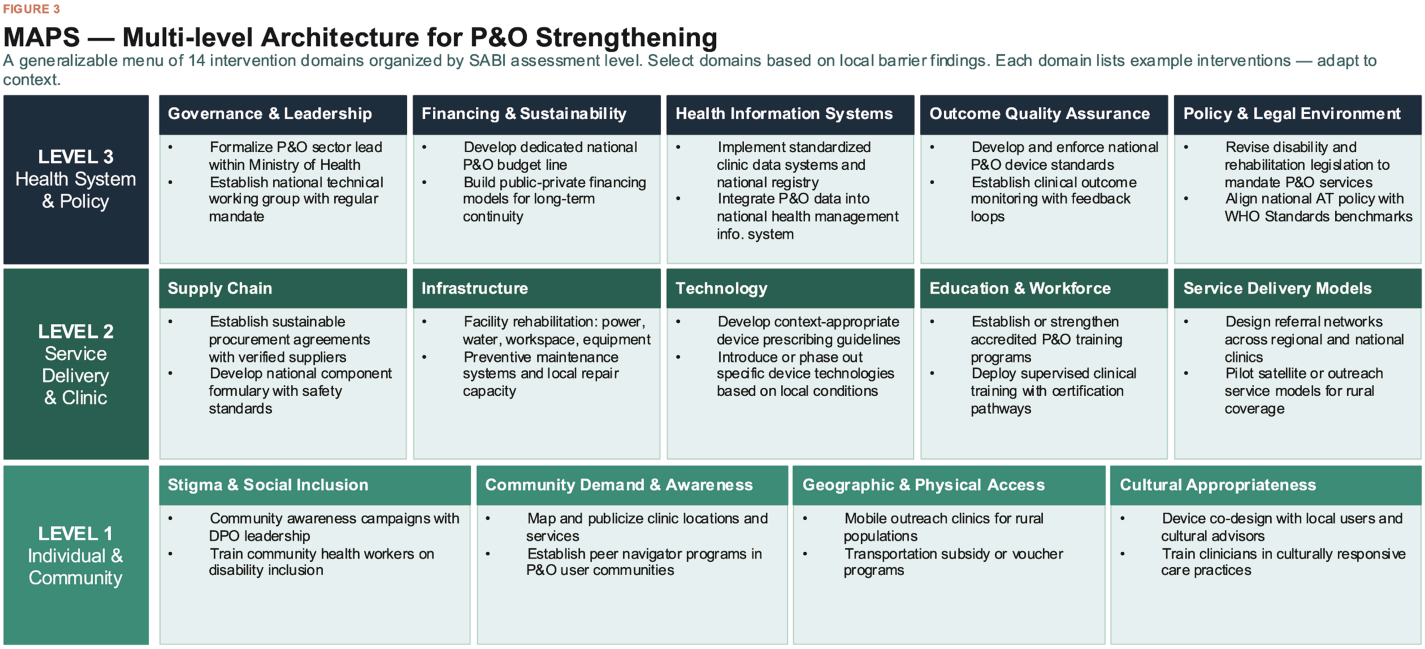


Figure 3

MAPS (Multi-level Architecture for P&O Strengthening). A generalizable menu of 14 intervention domains organized by SABI assessment level. A generalizable menu of 14 intervention domains organized by SABI assessment level, presented from Level 3 (Health System & Policy) through Level 2 (Service Delivery & Clinic) to Level 1 (Individual & Community). Domain selection for any given setting is driven by SABI barrier findings (Figure 2). Each domain lists example interventions to be adapted to local context. See Supplementary Figure S1 for the Sierra Leone domain selection.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- 06.17unblindedSupplemental.docx
- SuppFig1SABIMAPS.pdf