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Bridging the Humanitarian-Development Nexus in Prosthetics and Orthotics: Operational Frameworks and Scaling Challenges in Protracted Emergencies

Mahmoud Zazaa

pt.mahmoud.zazaa@gmail.com

Liverpool John Moores University

Research Article

Keywords: Implementation Science, Prosthetics and Orthotics, Surrogate Governance, DHIS2, Unique Patient ID, Humanitarian-Development Nexus, Protracted Crises, Syria

Posted Date: November 6th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11595306/v1

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Additional Declarations: No competing interests reported.

Abstract

Modern armed conflicts generate staggering numbers of life-altering injuries, yet humanitarian responses frequently default to short-term "biological survivalism," neglecting long-term physical rehabilitation and assistive technology (Balsari et al., 2020). This study evaluates the operational, digital, and surrogate governance framework deployed in northwest Syria (2022–2024) to coordinate prosthetics and orthotics (P&O) services amidst protracted displacement, institutional collapse, and NGO fragmentation (Goyaux et al., 2021). Drawing from cross-border coordination reports, technical working group documentation, and multi-agency field assessments (OCHA, 2024), we analyze the transition from uncoordinated NGO silos to a unified digital ecosystem powered by DHIS2. Key interventions included establishing a unique patient identifier system, consensus-driven minimum quality standards (WHO, 2017), data quality audits (DQAs), predictive supply chain forecasting based on device lifespans, and proactive lifecycle planning. Applying Proctor's Implementation Outcomes Framework, we demonstrate how this surrogate governance model successfully eliminated multi-center duplicate registrations, optimized resource allocation, and improved spatial equity across isolated facilities. We address critical implementation hurdles, including NGO data sovereignty resistance, fragile digital infrastructure, high staff turnover, and political fragmentation, while offering strategic recommendations for institutionalizing P&O governance across global conflict settings.

1. Introduction and Epidemiological Burden

Modern armed conflicts and protracted humanitarian crises generate staggering numbers of life-altering injuries, leaving vast populations in urgent need of specialized physical rehabilitation (Blanchet et al., 2017). Globally, humanitarian responses frequently default to a model of "biological survivalism"—prioritizing immediate trauma surgery and life-saving interventions while failing to secure long-term physical rehabilitation, assistive technology, and societal reintegration (Spiegel et al., 2010; WHO, 2017). This conceptual and structural deficit leaves a massive population of persons with disabilities and amputees without continuum of care, exacerbating long-term disability outcomes and driving socioeconomic marginalization (Kett & van Ommeren, 2009; Kruk et al., 2018). A prosthetic device is not merely a technical orthopedic apparatus; it represents a fundamental lifeline for restoring mobility, securing livelihoods, and supporting household economics in environments lacking formal social safety nets (Sphere Association, 2018).

Empirical and epidemiological evidence generated from frontline P&O facilities and multi-agency assessments in northwest Syria (2022–2024) underscores an acute rehabilitation crisis: **89.3%** of lower- and upper-limb amputations stem directly from explosive violence, landmines, and shelling (OCHA, 2024). These injuries disproportionately impact males (**86.6%**), alongside a deeply concerning proportion of minors under the age of 18 (**25.4%**). Across the broader Syrian conflict context, close to 3 million injuries have occurred, leaving approximately half with permanent disabilities, including an estimated **86,000 amputation cases**.

The fallout of conflict-related amputations extends far beyond physical loss. Baseline assessments in northwest Syria reveal that overall unemployment among persons with severe disabilities and amputations reaches **82%** (compared to 40% for non-disabled peers). Furthermore, between 15% and 41% of amputees suffer from post-traumatic stress disorder (PTSD), and 20% to 55% experience severe clinical depression. Standard mechanical lower-limb prosthetics range in cost from $300 to $1,500 (and up to $1,000 for upper limbs), while advanced bionic devices command between $7,000 and $50,000. In crisis zones where over 90% of the population lives below the poverty line, basic assistive devices remain inaccessible to over **60%** of those in need without sustained humanitarian aid (WHO, 2021). For pediatric amputees, rapid skeletal and muscular growth requires socket adjustments and component replacements every **6 to 12 months** (compared to 3 to 4 years for adults). Failing to provide continuous replacements leads to severe secondary structural deformities, chronic pain, and permanent physical impairment (ISPO, 2017).

In protracted conflicts where central state authorities collapse, healthcare delivery suffers from extreme **institutional fragmentation and governance vacuums** (Rubenstein, 2011). In the absence of a central Ministry of Health to enforce quality standards and regulate service mapping, non-governmental organizations (NGOs) operate in isolated operational silos (Howe, 2019; Goyaux et al., 2021). Overcoming these structural barriers requires establishing **surrogate governance frameworks** capable of bridging the gap between emergency relief and sustainable development—the Humanitarian-Development Nexus (Martineau et al., 2015). This study provides a critical analysis of the P&O response in northwest Syria (2022–2024), examining the deployment of a surrogate governance model led by the WHO Health Cluster, the Trauma & Disability Technical Working Group (T&D TWG), and the P&O Sub-Group, backed by an open-source **DHIS2** platform and a **Unique Patient Identifier** system (Zazaa et al., 2025).

2. Structural Gaps and the Political Economy of NGO Operations

The failure of P&O service delivery in protracted crisis settings extends beyond raw resource scarcity; it is rooted in deep-seated **institutional voids and governance vacuums** (Woodward et al., 2016). When national health authorities are absent, humanitarian responses fragment into uncoordinated NGO interventions (Alhaffar & Janos, 2021; Goyaux et al., 2021). We identify ten interconnected structural gaps:

1. **Governance Vacuum as a Master Driver**: Absence of regulatory authorities to enforce unified Standard Operating Procedures (SOPs), quality benchmarks, and national injury registries, leading to conflicting NGO operational paradigms (Savedoff, 2011).

2. **NGO Data Sovereignty and Political Economy**: Data hoarding among NGOs is driven by humanitarian political economy. Agencies treat patient registries as proprietary assets to maintain competitive advantages in donor bidding, fearing that transparency might expose operational inefficiencies or reduce grant allocations (Goyaux et al., 2021).

3. **Breakdown of Referral Pathways**: Complete disconnection between acute trauma surgical centers and P&O facilities, as well as an absence of inter-facility referral networks to balance patient loads (Epping-Jourdain et al., 2018).

4. **Data Sensitivity Void**: Reluctance to share clinical registries due to legitimate security concerns, coupled with a lack of standardized data protection protocols in active conflict zones (Ford et al., 2009).

5. **Patient Duplication and "Patient Shopping"**: Rational beneficiary behavior driven by perceived risk of aid disruption, leading patients to register across 3 to 4 different centers to secure backup devices, thereby artificially inflating waiting lists (Pallas et al., 2015).

6. **Socioeconomic Lifeline Deficit**: Failure of emergency programs to recognize prosthetics as economic enabling tools necessary for livelihood restoration (Sethi et al., 2019).

7. **Spatial Inequity**: Concentration of P&O centers in urban hubs driven by donor accessibility and security preferences (*Service Hotspots*), leaving rural areas as *Service Deserts* spanning 70 to 100 kilometers without coverage (Mullins et al., 2020).

8. **Data Vacuum and Flawed Proposal Engineering**: Complete lack of epidemiological baselines, forcing NGOs to engineer funding proposals based on speculative estimates rather than verified clinical demand (Haar & Rubenstein, 2012).

9. **Financing Precarity and Maintenance Deficits**: Annual, short-term grant cycles (6–12 months) that fund initial device fitting (*Output*) while completely ignoring long-term repair, component maintenance, and spare parts supply chains (World Bank, 2021).

10. **Pediatric Growth Replacement Vacuum**: Structural omission of pediatric growth cycles, leaving child amputees with ill-fitting sockets that cause bone overgrowth and skin breakdown (ISPO, 2017).

3. The Operational and Surrogate Governance Architecture

To dismantle these structural gaps, the humanitarian response engineered a **surrogate decentralized governance framework** combining institutional hierarchy with open-source digital infrastructure (AHO, 2020; WHO, 2023):

3.1 Institutional Hierarchy

The response was structured under a clear governance hierarchy:

- **WHO / Health Cluster**: Strategic leadership and neutral convening power.

- **Trauma & Disability Technical Working Group (T&D TWG)**: Inter-agency technical oversight body.

- **Prosthetics & Orthotics (P&O) Sub-Group**: Specialized operational arm responsible for clinical standards, workflow design, and facility coordination (WHO & ICRC, 2021).

3.2 Digital Architecture (DHIS2 & Unique Patient ID)

A centralized, open-source health information ecosystem was customized on **DHIS2** (Dehnavieh et al., 2019). Each patient is assigned an encrypted **Unique Patient Identifier** generated upon first entry. This system tracks the complete clinical journey across all 15 P&O facilities in northwest Syria while enforcing strict data privacy and encryption protocols (Dehnavieh et al., 2019; IASC, 2019; Zazaa et al., 2025).

3.3 Technical Standards and Supply Chain Forecasting

The P&O Sub-Group established consensus-driven minimum technical standards, mandating component interchangeability and universal raw material compatibility (ISPO, 2017). By leveraging verified DHIS2 device fitting timestamps and standard device lifespans (e.g., 5-year adult cycle, 6-month pediatric cycle), the platform enables predictive supply chain forecasting for thermoplastic materials and prosthetic joints years in advance.

4. Implementation Methodology and Operational Roadmap

The operational transformation was executed through a structured, multi-phase roadmap led by the Health Cluster, T&D TWG, P&O Sub-Group, and the Health Information System (HIS) Unit (Damschroder et al., 2009; Peters et al., 2013):

1. **Service Mapping & Gap Analysis**: Comprehensive mapping of all ~ 15 P&O facilities operated by > 10 NGOs, assessing spatial coverage, technical capacity, and staffing (OCHA, 2024).

2. **Standardized Patient Dossier & Data Protocols**: Development of a unified **Standardized Patient Clinical Dossier** capturing demographic, clinical, amputation type, and technical fitting data, alongside multi-agency data protection agreements (WHO, 2020).

3. **DHIS2 Customization & Pilot Phase**: Technical configuration of DHIS2 by the HIS Unit, followed by a rigorous pilot deployment at a specialized facility (PAC / Step for Hope) to validate data entry flows and offline functionality (Braa & Sahay, 2012).

4. **WHO Regional Workshop & Capacity Building**: A comprehensive regional workshop sponsored by WHO and the Health Cluster, training field personnel, facility managers, and data clerks across all partner organizations (WHO, 2023).

5. **Bi-Monthly Governance & Data Auditing Routines**: Institutionalizing bi-monthly review meetings between the HIS Unit and facility leads to monitor real-time data quality, resolve synchronization errors, and audit waiting lists.

Operational Framework Table

Phase	Milestone	Lead / Governance Entity	Key Output
Phase 1	Service Mapping & Needs Assessment	Health Cluster / T&D TWG	Spatial facility mapping and capacity baseline
Phase 2	Standardized Clinical Dossier & Unique ID	HIS Unit / P&O Sub-Group	Unified dossier & encrypted unique patient ID module
Phase 3	Data Protection & Governance Agreements	Health Cluster / Legal & Technical Leads	Multi-agency data sharing & privacy protocol
Phase 4	Pilot Implementation	Pilot Center (PAC) / HIS Unit	Field validation of DHIS2 workflows & offline sync
Phase 5	Workflow Refinement & Review	HIS Unit / P&O Sub-Group	Technical bug fixes & clinical form optimization
Phase 6	WHO Workshop & Regional Scale-Up	WHO / Health Cluster / Partners	Regional rollout across all 15 facilities & staff training
Phase 7	Bi-Monthly Governance & Data Quality Audits	HIS Unit / P&O Partners	Real-time list deduplication, spatial referrals, & forecasting

5. Enablers and Operational Constraints

5.1 Enablers

- **Neutral Convening Power**: The institutional backing of WHO and the Health Cluster provided neutral authority to break NGO data hoarding and enforce compliance (WHO, 2023).

- **Local Ownership**: Active engagement with local health directorates and administrative councils fostered trust and long-term community follow-up.

- **Adaptable Open-Source Technology**: DHIS2 offered a cost-effective, highly customizable platform tailored for low-resource crisis settings (Dehnavieh et al., 2019).

5.2 Constraints

- **Fragile Infrastructure**: Frequent power outages and intermittent internet connectivity disrupted real-time cloud synchronization, necessitating offline-first data entry modules.

- **High Staff Turnover**: Rapid transience among humanitarian workforce required continuous retraining programs on DHIS2 data entry and clinical protocols.

- **Cross-Border Supply Chain Bottlenecks**: Border delays and complex customs approvals periodically delayed imports of specialized thermoplastic materials and prosthetic joints.

6. Results and Implementation Outcomes

Applying Proctor's Implementation Outcomes Framework (Proctor et al., 2011; Peters et al., 2013), the impact of this collective ecosystem—driven by the Health Cluster, T&D TWG, HIS Unit, NGO leadership, and frontline clinical staff—is evaluated across key dimensions:

6.1 Acceptability and Adoption

- **Eradication of Duplicate Registrations**: The Unique Patient ID system successfully eliminated multi-center cross-registrations, establishing a verified baseline of amputees across northwest Syria (Zazaa et al., 2025).

- **Data Quality Assurance**: Rigorous **Data Quality Audits (DQAs)** conducted bi-monthly by the HIS Unit minimized human entry errors and ensured high registry fidelity across all 15 centers.

6.2 Paradigm Shift: From Reactive Aid to Predictive Lifecycle Planning

- **Accurate Demand Forecasting**: Analyzing aggregate DHIS2 data enabled health leaders to calculate real device lifespans and schedule routine maintenance proactively.

- **Predictive Procurement**: The sector successfully transitioned from a **reactive emergency mode** (waiting for device failures) to a **proactive, predictive planning model**, forecasting raw material supply chains and pediatric growth replacements 12 to 24 months in advance.

6.3 Resource Optimization and Spatial Equity

- **Elimination of Resource Waste**: Centralized visibility over stock levels and waiting lists prevented localized material hoarding while other facilities faced acute shortages.

- **Addressing Spatial Inequity**: Real-time spatial tracking allowed the network to redirect patients from congested urban centers (*Hotspots*) to underutilized regional facilities and deploy mobile rehabilitation units to rural *Service Deserts* (Mullins et al., 2020).

6.4 Pediatric Continuity and Donor Confidence

- **Sustained Pediatric Replacement**: Automated DHIS2 tracking ensured children received scheduled socket replacements every 6–12 months, preventing severe secondary deformities (ISPO, 2017; WHO, 2021).

- **Multi-Year Funding Integration**: Transparent, verifiable DHIS2 data significantly enhanced donor confidence, driving a shift toward multi-year funding grants focused on lifecycle maintenance (Humanitarian Health Cluster, 2022).

7. Limitations and Contextual Adaptation

7.1 Study Limitations

While this evaluation demonstrates substantial operational gains, it relies primarily on aggregate programmatic and health system data. The study did not systematically incorporate Patient-Reported Outcome Measures (PROMs), such as long-term psychological quality of life or community reintegration scores, presenting a key avenue for future empirical research.

7.2 Contextual Adaptation and Scalability

Replicating this surrogate governance model in other crisis settings (e.g., Gaza, Ukraine, Sudan, Yemen) requires flexible **contextual adaptation** (Balsari et al., 2020; WHO, 2023). While northwest Syria operated under a cross-border, decentralized NGO hub model, applying this framework in contexts with centralized state authorities or restrictive security apparatuses demands balancing national regulatory mandates with civil society operational autonomy to avoid administrative bottlenecks.

8. Conclusions and Policy Recommendations

The experience in northwest Syria demonstrates that transitioning from fragmented emergency responses to structured, digital public health governance in prosthetics and assistive technology is both feasible and essential in protracted crises (Martineau et al., 2015; WHO, 2023; Zazaa et al., 2025). To sustain and replicate these gains globally, we offer four strategic policy recommendations:

1. **Early Institutionalization of Surrogate Governance**: Health clusters in emerging crises should deploy pre-configured DHIS2 P&O governance packages within the first 90 days of emergency response (IASC, 2019).

2. **Mandatory Unique Patient Identifiers**: Donors should condition physical rehabilitation funding on participation in centralized, privacy-protected health information systems utilizing unique patient IDs (WHO, 2021).

3. **Transition to Multi-Year Lifecycle Funding**: International donors must abandon short-term annual grant cycles in favor of multi-year funding frameworks that account for permanent device maintenance and pediatric growth cycles (World Bank, 2021).

4. **Decentralized Hub-and-Spoke Expansion**: Integrate mobile rehabilitation units linked via cloud-based DHIS2 nodes with acute trauma surgical centers to secure early referral pathways and bridge rural coverage gaps (Epping-Jourdain et al., 2018).

Declarations

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contribution

M.Z. conceived, designed, drafted, and finalized the entire manuscript independently, and approved the final version for publication.

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