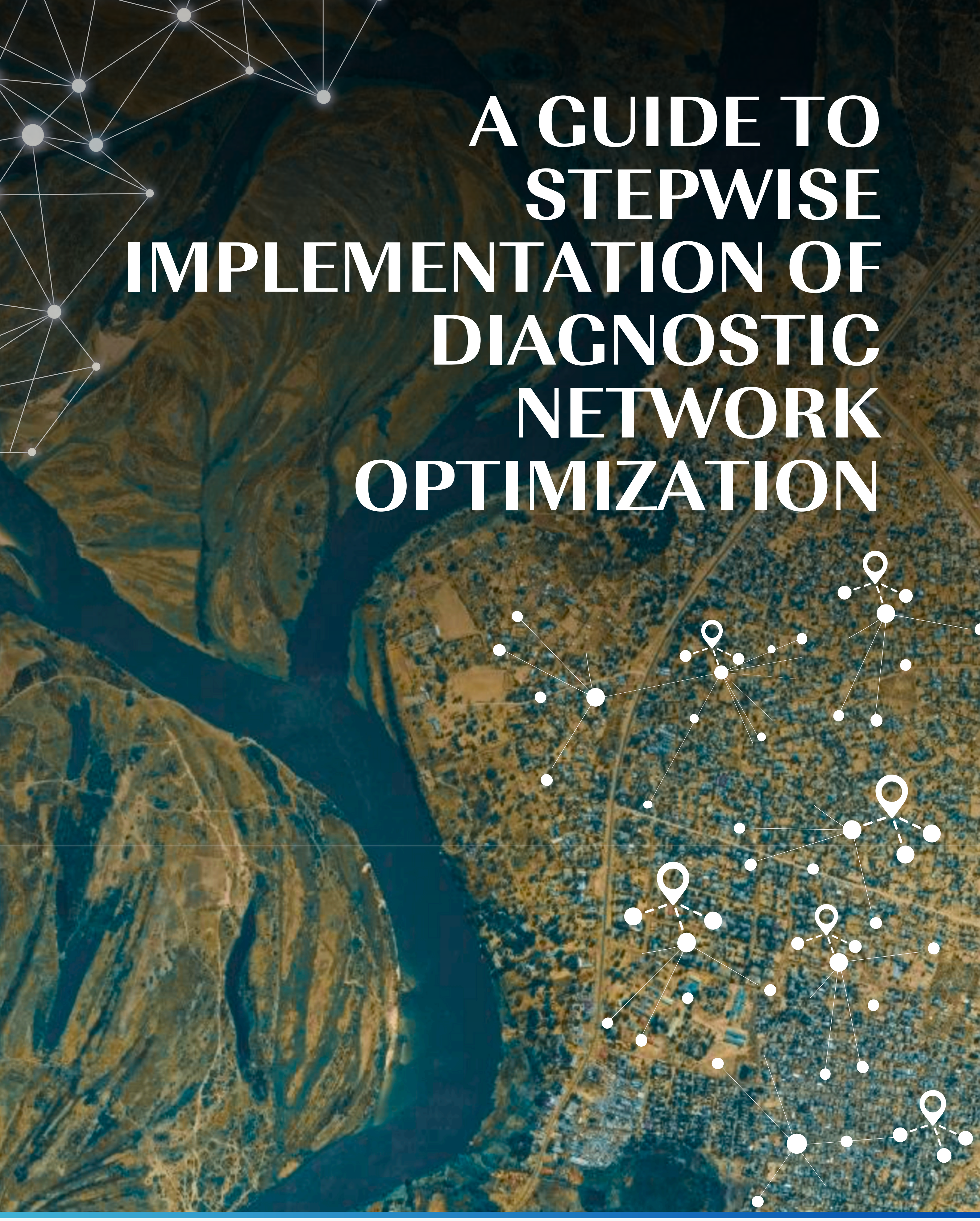
A GUIDE TO STEPWISE IMPLEMENTATION OF DIAGNOSTIC NETWORK OPTIMIZATION



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Lead authors of the manual included **Thomas Crompton, Heidi Albert, Marie Brunetti** (FIND, Geneva, Switzerland), **Juhi Gautam** (FIND, Delhi, India), and **Archana Beri** (FIND, Delhi, India). **Mayank Pandey**, **Mayur Dagale**, and **Amit Singh** (FIND, Delhi, India) contributed to country analyses, DNO software development, and the conceptual approaches described in the guide.

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Abbreviations

AMR	Antimicrobial Resistance
ASLM	African Society for Laboratory Medicine
BI	Business Intelligence
BNTP	Botswana National Tuberculosis Program
CDC	Centers for Disease Control and Prevention
CSV	Comma Separated Values
CXR	Chest X-Ray
DNO	Diagnostic Network Optimization
EID	Early Infant Diagnosis
FAQs	Frequently Asked Questions
GDF	Global Drug Facility
GIS	Geographic Information System
GLI	Global Laboratory Initiative
GPS	Global Positioning System
HeRAMS	Health Resources and Services Availability Monitoring System
HF	Health Facility
HIV	Human Immunodeficiency Virus
HPV	Human Papillomavirus
LMICs	Low- and Middle-Income Countries
MAD	Maximum Allowable Distance
MFL	Master Facility List
MOH	Ministry of Health
mWRDs	molecular WHO-recommended Rapid Diagnostics
NAAT	Nucleic Acid Amplification Tests
NGO	Non-Governmental Organization
NSP	National Strategic Plan
NTP	National Tuberculosis Program
PEPFAR	President's Emergency Plan for AIDS Relief
PNLCa	Programme National de Lutte contre le Cancer
PNLS	Programme National de Lutte contre le Sida
PNLT	Programme National de Lutte contre la Tuberculose
RFP	Request for Proposal
SARA	Service Availability and Readiness Assessment
SRS	Sample Referral System
TAT	Target Turnaround Time
TB	Tuberculosis
TGF	The Global Fund
USAID	United States Agency for International Development
VL	Viral Load
WHO	World Health Organization

Executive summary

Tuberculosis (TB) diagnostic networks face significant challenges in providing equitable and timely access to quality testing, particularly in rural and underserved areas. Despite advancements in diagnostic technologies, many patients still rely on microscopy and clinical evaluation, resulting in delays initiating treatment and misdiagnoses.

Scaling up World Health Organization (WHO) recommended tools and addressing network inefficiencies is critical to closing these gaps. Diagnostic Network Optimization (DNO) leverages geospatial analytics to enhance diagnostic networks by identifying gaps in population accessibility, optimizing device placement, and improving sample referral systems. To date, DNO has been conducted in over 30 low- and middle-income countries (LMICs), where it supported strategic planning and was used as evidence to inform funding decisions to strengthen the diagnostic network.

DNO analyses begin with stakeholder engagement, a situational assessment, and country planning to align efforts with national priorities and funding cycles. For example, DNO can identify opportunities to integrate TB diagnostics with other disease testing to enhance access and efficiency, but collaboration with all relevant disease programmes is essential to align priorities.

DNO analyses provide answers to four common national-level goals: increasing access to diagnostics, integrating test types, optimizing device placement, and improving sample referral systems. These goals are approached through four types of analysis.

- **Quantifying population accessibility** is the simplest type, requiring minimal data and focusing on measuring equitable access for populations across the country.
- **Visualize and analyse** incorporates data on device capacity and utilization that provides insights into the geographical distribution and utilization of diagnostic equipment.
- **Basic optimization** uses data on expected testing volumes from health facilities and tool(s) to suggest optimal device placement that would reduce sample referral distances.
- **Advanced optimization** integrates historical referral data, network costs, and advanced algorithms to provide solutions that optimize access, utilization, and minimize costs across the diagnostic network.

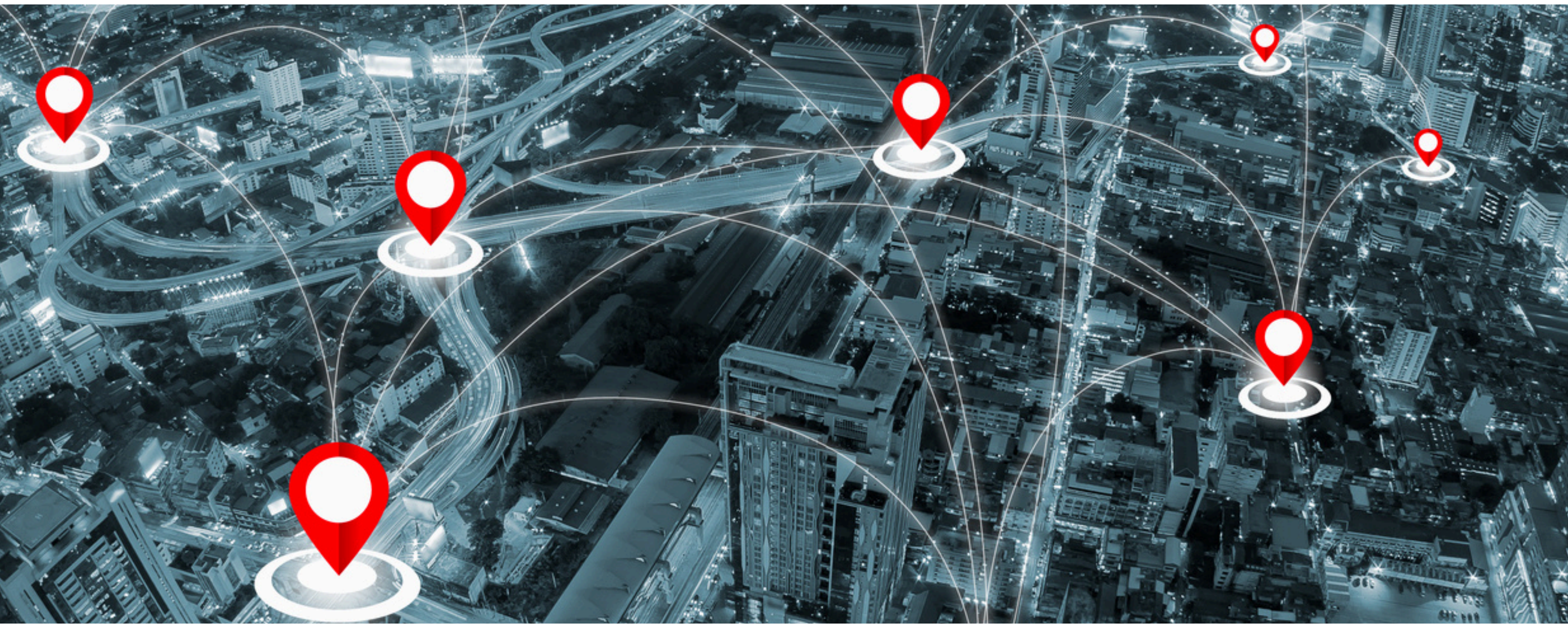
Advanced analyses provide more comprehensive recommendations but require more data, a longer timeline, and higher budget. Therefore, countries are encouraged to begin with preliminary analysis, even if the data availability is limited. Suggestions on which DNO tools are the best match for the analysis are based on the complexity of available data.

DNO findings translate into actionable insights, such as device procurement and relocation, referral network adjustments, and test integration, with phased implementation ensuring gradual scaling. Monitoring and evaluation frameworks should be used track implementation progress and network performance, ensuring that DNO-driven plans achieve their intended impact while aligning with strategic health objectives.

Purpose of the guide

This implementation guide provides countries with a simple and practical framework for conducting a DNO. It explains how to use a data-driven approach to enhance TB diagnostic networks, detailing each phase of the process. Countries will learn when and how to conduct a DNO, which stakeholders should be involved, and key considerations when starting.

The guide outlines various types of DNO analyses; the challenges they address; and the time, data, and tools required for each. It also provides frameworks for conducting DNO, implementing the results, and monitoring progress over time. A range of case studies is included to showcase real-world examples and outcomes of DNOs in several countries. By the end of the guide, countries will understand which type of DNO analysis best fits their unique context and have the materials available to carry it out effectively.



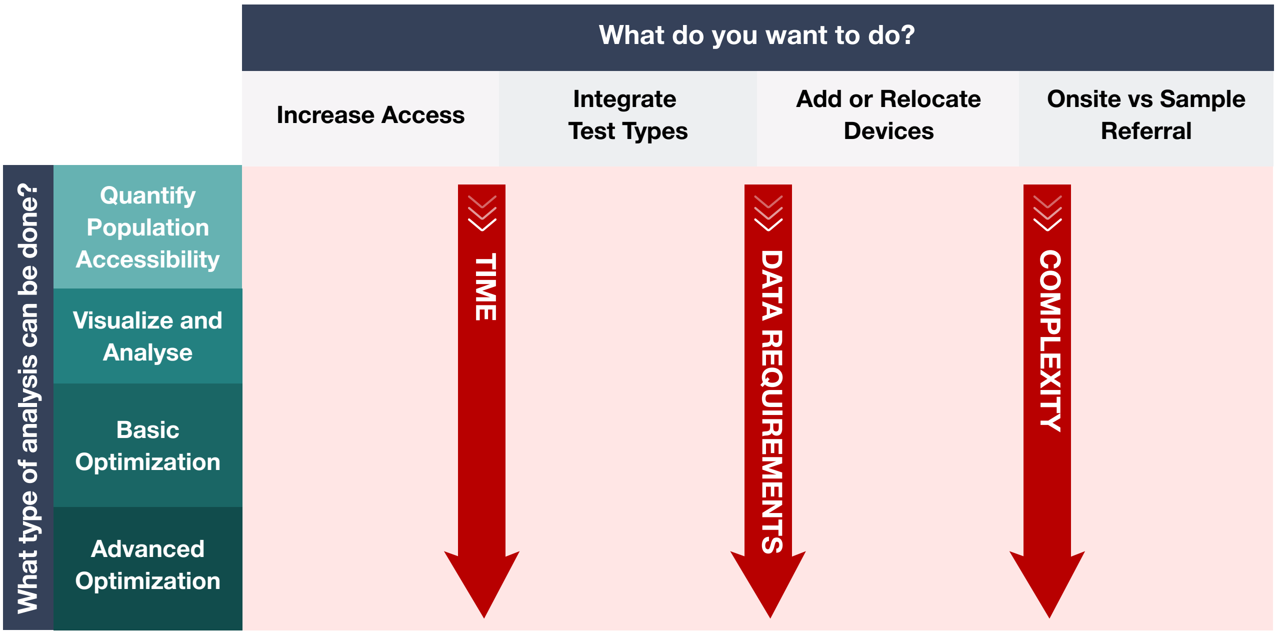
I. Objectives

This document is designed to guide countries, funders, and implementing partners on how to implement DNO for diagnostic networks. This hands-on guide will lead users through the process of conducting a DNO from stakeholder engagement, planning, and resourcing data collection to analysis and implementation. Key objectives include:

- Providing guidance on how to **use data for improving diagnostic networks**, including introducing new diagnostics and transforming diagnostics.
- Enabling users to **identify and understand each phase of conducting a DNO**, from initial planning and data gathering, to analysis, implementation, and ongoing monitoring – ensuring comprehensive coverage of the DNO lifecycle.
- Presenting **practical contexts that outline a step-by-step approach to tackling DNO challenges,** offering actionable insights that users can apply in real-world scenarios.
- Informing users about the most **suitable tool(s) for addressing common contexts** – enabling effective data analysis, interpretation, and decision-making for improved diagnostic networks.
- Guiding users on **identifying the types of data required for different DNO analyses**, locating reliable sources, and understanding how data sets contribute to answering key DNO contexts.
- Enhancing **the impact of DNO analyses** through alignment with National Strategic Plans (NSPs), funding cycles, and continued monitoring and evaluation.

The guide helps readers decide the type of analysis goal(s) they want to achieve, and links them to analysis type(s) associated with those goal(s).

Figure 1: Summary of possible DNO analysis goals and analysis types



II. Target audience

This report is designed to support a range of key stakeholders involved in strengthening TB (or other) diagnostic networks. in LMICs:

- Ministries of health (MoH), national TB programme managers, and other related programme managers (e.g., human immunodeficiency virus [HIV], malaria): At the national, provincial, and regional levels, health officials engaged in TB programmes, and departments that work with TB programmes, can use this guide to understand the processes and best practices for conducting and implementing DNO.
- Donors and health system funders: Organizations investing in health system strengthening, including those shaping strategic funding and resource allocation, will find insights into how DNO outputs inform impactful investment decisions.
- Implementing partners: Organizations collaborating with ministries of health to perform DNO or implement the findings to enhance TB diagnostic networks will gain structured guidance to better align with national health objectives.

III. Background

Overview of TB diagnostics, current status and gaps in LMICs, WHO policies, and TB diagnostics access standards

Diagnosis is the weakest link in the TB care cascade.[1] Despite the WHO policy recommending molecular testing as the initial diagnostic test for TB and rapid drug resistance testing, and substantial investments to scale up these tests over the past decade, only half the population has access to diagnostic services. The molecular WHO-recommended rapid diagnostic test (mWRD) was used as the initial test for TB diagnosis with varying proportions across WHO regions. The European region had the highest coverage (78%) and the South-East Asia region had the lowest (39%). In 2023, 68 countries reached at least 80% coverage, while 25 countries had coverage below 20%. In total, only 48% of persons with TB were tested using mWRD.[2] For the remaining patients, diagnosis relies largely on microscopy and clinical evaluation, which can result in misdiagnosis and delays in initiating appropriate treatment.

There is an expanding range of technologies recommended by the WHO, including low-, moderate-, and high-complexity nucleic acid amplification tests; digital chest X-ray with artificial intelligence-based software for interpretation; and next-generation sequencing for detection of drug resistance.[3]

Molecular platforms, including sequencing, offer the possibility to integrate testing for multiple diseases on a single device, bringing efficiencies and accessibility benefits. The COVID-19 pandemic demonstrated the value of integrated systems strengthening, and there are now opportunities to repurpose the diagnostic capacity introduced during the pandemic for other diseases, such as TB.

In most countries, health facility-based passive case finding predominates. To reach undiagnosed persons with TB, locally tailored, cost-effective active case finding strategies and expanded testing coverage are urgently needed. While digital chest X-ray capacity is currently limited at primary care level due to high capital costs, the arrival of affordable and portable systems in the market offers opportunities to significantly expand screening. Additionally, access to quality testing within countries remains inequitable, with people frequently travelling long distances and incurring significant out-of-pocket expenditure to access services, especially those living in rural and remote settings. Ensuring equitable access to quality TB diagnosis in LMICs is challenging: varying epidemiological, geographical, and health system contexts to be considered when designing the best way to reach the population with diagnostic services and ensure effective linkages to care for diagnosed patients.

Currently, diagnostic networks providing testing for TB and other priority diseases face several challenges, including under- and over-utilization of diagnostic devices, frequent instrument downtime and reagent stock-out, and fragmented and inefficient sample referral systems – leading to missed and delayed diagnosis. As countries continue to scale up access to existing WHO-recommended technologies and prepare for introduction of new diagnostics in the development pipeline, a good understanding of a country's diagnostic network configuration and performance is essential to identify gaps and provide data-driven recommendations on the optimal interventions to address the diagnostic gaps.

Overview of DNO

Diagnostic services are an essential element of healthcare systems. To tackle TB and other priority diseases, it is critical to deliver uninterrupted access to quality testing close to where people seek care and enable rapid linkage of diagnosed patients to appropriate care and treatment. The optimal diagnostic network configuration to achieve this goal needs to respond to national priorities; account for disease burden, geographic and demographic context, and health system infrastructure at a sub-national level; and enable the delivery of reliable results within an acceptable turnaround time (TAT) to inform clinical decisions.

Across countries, the expansion of TB diagnostic coverage has often been shaped by existing infrastructure and capacity, with limited coordination between the government, donors, and partners during planning. This has led to network inefficiencies, over- and under-utilization of testing capacity, and sub-optimal TAT of results hindering patient care, especially in remote or underserved areas.

Tailoring diagnostic network design requires a variety of data insights to balance trade-offs and ensure value-for-money investments that strengthen systems for maximum impact on equitable healthcare. This calls for better use of available diagnostic system data to identify gaps in equitable access to services and generate context-specific insights that can inform targeted interventions. Such an approach enables the most optimal, cost-effective use of the available diagnostic tools to improve testing coverage and ensure timely linkage to.

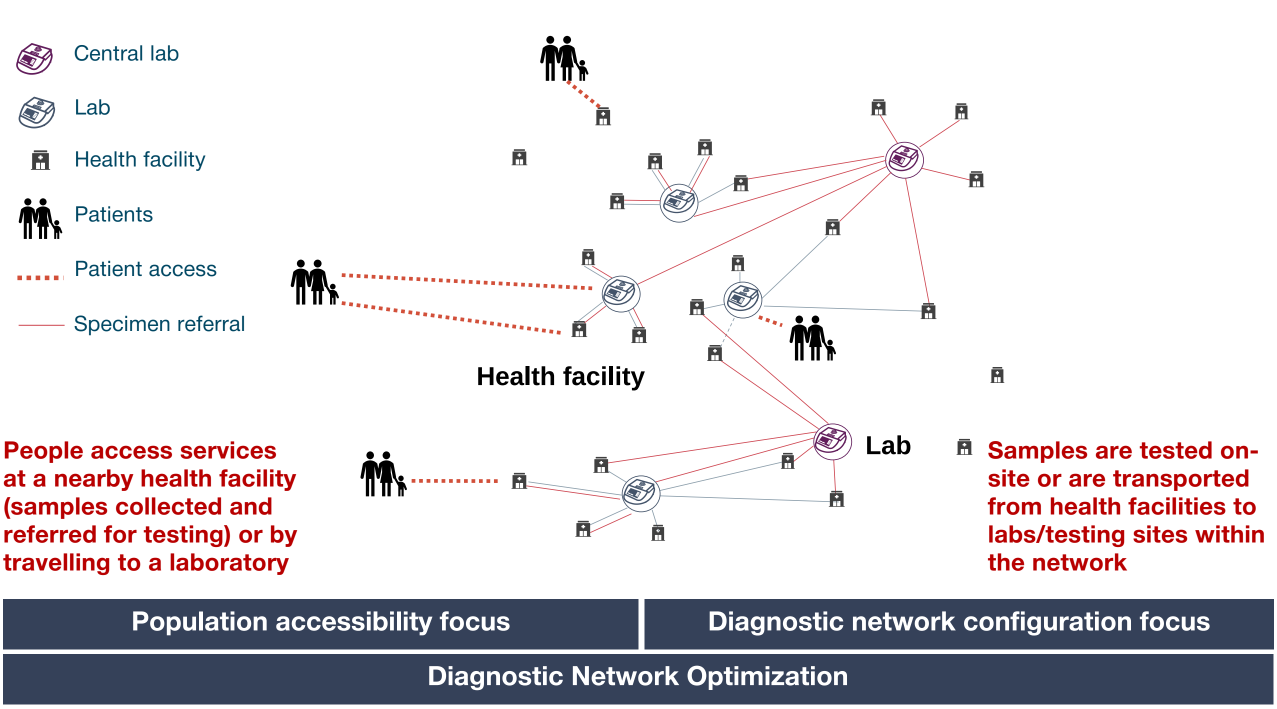
DNO consists of a range of geospatially powered visualization, analysis, and optimization approaches that are used to:

- **Analyse** a country's current diagnostic network to identify sub-national gaps and opportunities for systems strengthening.
- **Recommend or inform** changes to the type, capacity, and location of diagnostic devices and tests and associated sample referral systems aligned with national health goals and priorities and tailored to the local context.
- **Model introduction** of new diagnostic tools and approaches that can improve equitable access to quality diagnosis.
- **Define indicators** for the performance of the network and tools, and train personnel on capturing and monitoring these indicators as part of routine network management.[4]

In this guide, we use DNO as an umbrella term for any geospatially powered network analytics that seeks to analyse and optimize diagnostic networks with a view to identifying gaps in equitable provision of testing services and generate data insights that inform system strengthening interventions to close gaps through changes in device/test selection, testing capacity, location, testing integration and sample referral linkages. **Section 4** describes the various tools and analytical approaches that are available to address different questions.

Designing optimal diagnostic networks requires an understanding of how a population accesses healthcare facilities where diagnostic services are provided as well as how the health system is configured to deliver diagnostic services where and when they are needed in a cost efficient and sustainable manner. DNO uses an analytical approach that incorporate both these dimensions. An example of a simplified diagnostic network is provided in **Figure 2**.

Figure 2: Graphic representation of population accessibility and diagnostic system configuration in DNO



DNO has been applied in more than 30 LMICs to shape strategic and operational plans for disease-specific and integrated laboratory networks, as well as inform investment decisions, including funding requests to key donors, such as The Global Fund (TGF) and President's Emergency Plan for AIDS Relief (PEPFAR). DNO analysis is a recommended approach to inform funding decisions[5] for TB, HIV, malaria testing, and integrated health system strengthening.

While there has been significant focus on the use of DNO for TB and HIV (given large investments in strengthening diagnostics for these diseases), it has also been increasingly applied to a range of other diseases (including Antimicrobial Resistance [AMR], yellow fever, and Lassa fever),[6] and shaped the implementation of packages of essential diagnostics for primary care.[7] DNO has commonly been used to shape decisions in:

- **Procurement** and optimal placement of molecular diagnostic devices, including mWRDs
- **Integration** of testing on multi-disease testing platforms,
- **Establishment** or strengthening of integrated sample referral systems (SRS), and,
- **Expansion** of decentralized testing coverage to hard-to-reach or underserved areas.

DNO recommendations typically include the selection of diagnostic devices, addition of new devices, addition of new tests on existing diagnostic devices, relocation of devices, and establishment or modification of sample referral linkages to improve accessibility and efficiency. To be effective, DNO should be conducted on a regular basis and timed to align with strategic planning and budgeting cycles. DNO is an analytics approach and, therefore, it is critical to monitor the uptake of recommendations and the impact they have on network performance by measuring key performance metrics such as population coverage, testing volumes, device utilization, TAT, notification rates, and patient outcomes.

IV. Implementing DNO analyses

This document provides a step-by-step guide for conducting DNO related to TB diagnostics – from an assessment of need and planning the right team to selecting appropriate analysis types and tools based on data and specific analysis goals. It then outlines how to conduct the analysis, establish monitoring and evaluation (M&E) processes, and ultimately implement recommendations across healthcare levels while ensuring impact measurement. **Figure 3** provides an overview of the steps involved; each step is discussed in detail in subsequent sections.

Figure 3: Outline of the process to follow DNO implementation

1. Stakeholder engagement

Who should be involved in the DNO analysis?
Ensure you have the correct team in place before beginning.

2. Situational assessment

Assessment of your network

- *What are the current gaps?*
- *What are the current interventions to address these gaps?*

3. Country planning

When is the best time to conduct a DNO?
Time the DNO so it aligns with funding applications.

SEQUENTIAL

4. Types of DNO

- **Broad categories and high-level analysis goals.**
- **Identify which one is most applicable.**

Select analysis goal(s) based on the scope of analysis.

5. Key questions

Detailed questions that can be answered at each category of DNO analysis.
Select the most appropriate type(s) for the analysis.

6. Data requirements

What data is needed to answer the questions?
If the required data is not available, go back to Step 4 to refine the analysis type(s).

7. DNO tool(s)

What tool(s) are best suited to address the analysis type(s)?
Once the analysis goal(s) and analysis type(s) have been confirmed, choose the most appropriate tool.

ITERATIVE FEEDBACK LOOP

8. Conducting DNO analysis

Using specified tools and data, conduct analysis to answer your chosen question(s).
Answer questions initially setup in Steps 3 & 4.

9. Implement reccomendations

Work with all levels of the healthcare system to implement the findings of the analysis.
Continue collecting data to respond to your original question(s).

10. Monitoring and evaluation

Measure the effects of your DNO.
Monitor the impact of your implementation.

SEQUENTIAL

When initiating a DNO exercise, the national team should conduct a comprehensive review of existing strategies, gaps, and previous analyses. This ensures a clear understanding of the problem areas and the practical needs the analysis should address.

Begin by reviewing national strategic documents (e.g. NSPs) and disease-specific plans (e.g. NTPs) to understand current national goals, targets, and whether a DNO analysis has already been previously recommended or completed. If one has been recently completed, assess whether the outputs align with the current NSP. If so, then use the outputs of that analysis to inform decisions. Alternatively, if there are gaps in the previous analysis, clearly define the problem that needs to be solved.

Assess past DNO reports for any unimplemented recommendations that remain relevant. Identify any current gaps in the diagnostic network, for example, through the TB Diagnostic Network Assessment[8] and/or other reports. Take note of these gaps, as they can be used to outline the problem statement for the analysis.

Finally, identify any interventions that are currently in place to address these gaps. These will be used to understand what is practical when implementing DNO findings. **Figure 4** provides an overview of this process.

Figure 4: Situational assessment: what has been the history of DNO, and what is the current state?

Establish a team at the national level.	Gather existing documentation.	Understand DNO history.	Establish the goal you want to achieve.
Suggested members: • NTP • Implementing partners • Other disease programmes (if applicable) • Sub-national representatives • MoH Data Unit	• Is there an NSP, NTP, or national plans from other disease programmes? • Is there a clear problem that needs to be solved using DNO?	• Has a DNO been done before? • Does it fully answer the current problem statement? • Have these recommendations been implemented? • Do they still align with the NSP?	• What gaps are you trying to solve? If you are unclear on what problem you need to solve, continue reading. • What interventions are currently in place to address these gaps?

1. Stakeholder engagement

1. Stakeholder engagement → 2. Situational assessment → 3. Country planning
4. Types of DNO → 5. Key questions → 6. Data requirements → 7. DNO tool(s)
8. Conducting DNO analyses → 9. Implement reccomendations → 10. Monitoring and evaluation

Overview
The key stakeholders required for a successful DNO analysis are outlined.

Key takeaway
Key stakeholders should be identified and mapped, and an appropriate coordinating mechanism should be established based on the country context.

DNO generates insights at a systems level and must be under the purview of the MoH, typically led by the national laboratory directorate, relevant disease programmes, and other directorates such as primary healthcare. The right entry point is critical to ensure senior-level MoH approval and appropriate convening of relevant stakeholders at national and sub-national level. The MoH Data Unit (or equivalent) should be engaged as they are most likely to have the requisite knowledge on the best place to access relevant data and will be custodians of the outputs of the analysis.

Since DNO can help bring planning and system efficiencies across siloes of disease programmes, agencies, departments, and both public and private sector, it is essential to engage all relevant stakeholders from the outset. This includes ensuring programmes, sectors, and partners contribute their inputs and participate in implementing the recommendations that emerge.

For example, DNO can help analyse where diagnostic network capacity for TB could be integrated with testing for other diseases to improve access and efficiency. However, any proposed changes to testing services for one disease should involve experts and representatives from all related disease programmes to ensure that the needs and priorities of each are adequately addressed.

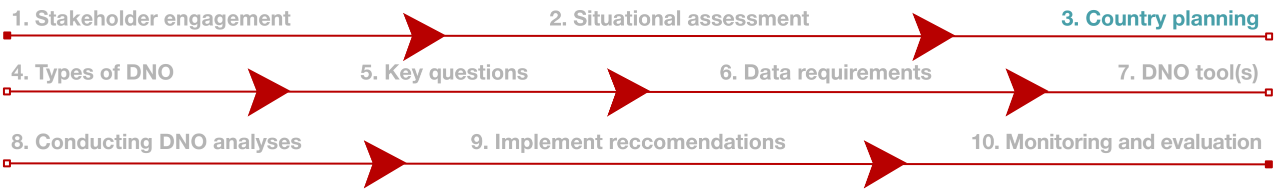
2. Situational assessment

1. Stakeholder engagement → **2. Situational assessment** → 3. Country planning
4. Types of DNO → 5. Key questions → 6. Data requirements → 7. DNO tool(s)
8. Conducting DNO analyses → 9. Implement reccomendations → 10. Monitoring and evaluation

Overview
Guidance provided on determining whether a DNO is needed and what gaps remain.

Key takeaway
Review of existing documentation and previous DNO analyses should be conducted, and existing national plans should be used to determine what questions need to be addressed.

3. Country planning



Overview
Factors that affect the planning, timing, and coordination of a DNO analysis are discussed.

Key takeaway
Where possible, the DNO should conducted so that outputs can be used as evidence for funding applications.

In planning for DNO, it is important to consider both immediate programmatic needs and longer-term strategic goals, along with associated budgetary requirements. DNO is most effective when the analysis design accounts for current constraints as well as aspirational targets, typically aligned with strategic planning cycles. The timing of DNO analysis is critical to ensuring that outputs are available at the right time to inform planning for funding applications. If the DNO analysis is conducted too late, there is a risk that outputs may be used to validate decisions that have already been made rather than informing those decisions. For example, an appropriately timed DNO can help determine if additional diagnostic devices are needed, and, if so, how many and where they should be placed. In contrast, a delayed analysis will simply demonstrate the potential impact of deploying a pre-determined number of diagnostics devices (some of which may not be needed to reach the desired goal of increasing access).

The timing of DNO analysis is critical to ensuring that outputs are available at the right time to inform planning for funding applications.

When planning the DNO analysis, it is critical to clearly define the key questions to be addressed and how they align with the national strategy and targets. This should be accompanied by early discussions on the policy and implementation framework, and the potential for implementing certain DNO recommendations, to set realistic expectations around the types of network changes that may be feasible. For example, if the analysis shows that cross-district sample referral can significantly improve cost efficiency and accessibility, is it operationally and politically feasible to implement this? Can existing diagnostic devices be relocated or replaced by alternative devices? Have procurement decisions already been made or can DNO findings shape those decisions on technology selection, device quantities, and optimal placement?

Another important consideration is the target TAT. Different tests require different TATs; for example, the TAT for TB and HIV Early Infant Diagnosis (EID) are usually faster compared to the TAT for HIV Viral Load (VL). This will affect the design of the specimen referral system. **Section 4.4** provides detailed guidance on the types of DNO analysis that can be undertaken.

4. Types of DNO analysis

1. Stakeholder engagement → 2. Situational assessment → 3. Country planning
4. Types of DNO → 5. Key questions → 6. Data requirements → 7. DNO tool(s)
8. Conducting DNO analyses → 9. Implement reccomendations → 10. Monitoring and evaluation

Overview
Examples of what the DNO analysis aims to achieve (analysis goal), and what analysis types are possible for each analysis goal are provided.

Key takeaway
Analysis goal(s) and analysis type(s) that align with the problem statement(s) should be understood and selected by countries.

To determine the appropriate type of analysis to perform, it is important to first understand the priorities identified by the stakeholders for the DNO. Typically, DNO focuses on improving the TAT of testing and/or reducing the distance people need to travel to access health facilities offering testing or sample collection. The implementation guide organizes this into four areas of analysis goal(s):

- **Increasing** access to testing,
- **Integrating** multiple test types on devices and/or within sample referral networks,
- **Adding or relocating** devices, and
- **Deciding** between onsite testing and an enhanced sample referral system.

For each goal a country may want to achieve, multiple types of analyses may be appropriate, depending on factors such as timeline, budget, and data availability. Broadly, these can be categorized into one of four types:

- **Quantify Population Accessibility:** This is the simplest type of analysis and requires the least amount of time and data. It provides information on changes in population accessibility. For example, DxGeoMap (an online Geographic Information System [GIS] application for mapping population accessibility to diagnostics) has built-in population and geographic data that is readily available for the user and reduces the time to value of an accessibility analysis.

- **Visualize & Analyse:** This requires data at a device level and incorporates the capacity and utilization of devices to provide a geographical representation of laboratories and devices. This type of analysis is good for getting a quick visual overview of the diagnostic network.

- **Basic Optimization:** This requires data on the expected number of tests from each health facility and uses advanced algorithms and software to make recommendations on the optimal location of devices for reducing sample referral distances.

- **Advanced Optimization:** This requires historical data on the way samples have been referred from facility (via hub) to a testing site, and the costs across the network. This type of analysis can optimize the diagnostic network across access, utilization, and cost, whereas other types of analyses model the diagnostic network without cost considerations.

A DNO analysis does not need to focus on a single goal; however, it is generally recommended to begin with one analysis type. Starting with a quicker analysis using readily available data can yield valuable initial insights that lay the groundwork for more in-depth assessments as more data becomes available. This approach also helps build a clearer understanding of the network configuration, identifies opportunities for future analysis, and promotes coordinated decision-making among stakeholders.

Time and resource planning for DNO

The type of DNO analysis to be undertaken will determine the time and resources required, with stakeholder engagement, scoping, and data collation typically being the most time-intensive components.

Historically, DNO has often been led by external technical assistance partners, working as business consultants consulting with the MoH as the client. While the MoH provides strategic direction, stakeholder coordination, and leads the implementation of recommendations, the planning and execution of the analysis is often partner- and donor-driven. This is most commonly the case when advanced DNO software is utilized, requiring specialized analytics skills that are only needed occasionally. In contrast, when simpler DNO tools are used, it becomes possible to build analytics proficiency at country level and within the MoH. This enables true ownership of all aspects of the analysis and implementation, leading to the sustainable use and institutionalization of DNO for decision-making.

Similarly, the financial resources required to conduct a DNO analysis will also depend on the chosen approach and the scope of analysis – whether it is at the national or sub-national level, the range of diseases and tests to be considered, the complexity of the network, and the range of scenarios to be explored. Different DNO approaches and tools require varying levels of data, and data collection and validation are often among the most resource-intensive aspects of any DNO exercise. Large-scale complex analyses typically demand more time and thus incur more costs in terms of staffing and logistics. Finally, the decision to engage external technical assistance partners, work with local partners, or conduct DNO analysis in-house will also affect the budget required. **Table 1** provides guidance on the possible goal(s) and type(s) of DNO analyses.

Table 1: Potential goal(s) and type(s) for DNO analyses

What type of analysis can be done?	What do you want to do?				
	Increase Access	**Integrate Test Types**	**Add or Relocate Devices**	**Onsite vs Sample Referral**	**Estimated Timeline**
Quantify Population Accessibility	Measure change in population accessibility	Quantify increased population that can access devices after integration	Add: quantify increase in population coverage; compare between different scenarios Relocate: compare reduction in access in one area to increase in access in another area	What % of population has access to onsite vs. via referral. Does the referral network cover all the population?	0-2 months
Visualize and Analyse	Analyse capacity and utilization across the network to identify gaps in testing	Understand impact on capacity & utilization. Where is it possible to integrate?	Understand increase in testing & impact on utilization. Which devices are over/under utilized?	Quantify onsite utilization versus referral utilization	2-3 months
Basic Optimization	Understand impact on utilization from increased sample collection sites	Optimize referrals for all test types	Understand impact on capacity & utilization across the network	Make recommendations on optimal locations based on distances between labs and facilities.	3-6 months
Advanced Optimization	Identify areas with long TAT and referral pathways	Identify optimal mix of devices and sample referral across disease programme	Identify optimal mix of devices and sample referral across disease programmes	Identify optimal mix of devices and sample referral across disease programmes	3-12 months

5. Key questions that DNO can answer

1. Stakeholder engagement → 2. Situational assessment → 3. Country planning
4. Types of DNO → **5. Key questions** → 6. Data requirements → 7. DNO tool(s)
8. Conducting DNO analyses → 9. Implement reccomendations → 10. Monitoring and evaluation

Overview

Detailed questions that each type of DNO analysis can and cannot address are provided based on the analysis goal(s) and type(s) selected in **Section 4.4.**

Key takeaway

The analysis goal(s) and type(s) should be refined by selecting specific combinations that align with the original problem statement. If alignment is not achieved, other goal-analysis combinations should be reviewed to identify the most appropriate option for the country context.

Using **Table 2,** countries can identify the key question(s) to be answered and select the analysis types that best suit the specific context. It expands on the framework laid out in **Table 1**, providing for each main analysis goal along with the corresponding analysis type. It also offers guidance on what analysis *cannot* be done without further data and resources, and how these limitations may influence decision-making. For instance, if a country wants to integrate test types, it is possible to start with just a *Quantify Population Accessibility* analysis. This approach can assess how access improves when new tests are added at facilities that previously offered only a single test. It is especially useful for assessing equitable access across a country. For example, by comparing population accessibility across provinces, this analysis would highlight that provinces that do not currently have access to testing services and can thus be prioritized for new device placement.

However, *Quantify Population Accessibility* will not provide any insights into the capacity and utilization of the network to accommodate demand from multiple disease programmes, which can inform. *Quantify Population Accessibility* analyses are very useful to get a quick understanding of equitable access across a country, for example comparing population accessibility across provinces. This analysis would highlight which provinces do not currently have access to testing services and may be prioritized for new device placement. While these initial insights can be valuable, insights on diagnostic capacity and utilization of available capacity are important for decision-making to ensure an efficient network configuration. To gain this deeper insight, further data collation and analysis – typically under the *Visualize & Analyse* category – may be necessary to support evidence-based decision-making.

While planning for improvement to access to services for its population, countries often face the challenge of deciding between selecting and procuring new diagnostic devices and strengthening sample referral systems. To directly inform this decision-making requires, a *Basic Optimization* approach can be used, which provides outputs on the optimal utilization of available diagnostic capacity across multiple test types, potential shifts in the proportion of tests done on-site, and reductions in average referral distances if test integration is pursued. Since cost is a critical decision driver, wherever data and resources are available, countries may choose to undertake *Advanced Optimization* analysis to assess the cost implications of test integration.

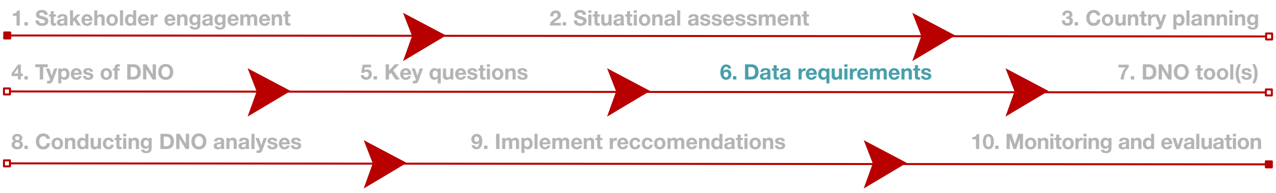
Selecting the appropriate type of DNO analysis depends on factors such as the priorities and targets for all decision-makers, data availability, and the timeline and budget for the project. When more advanced optimization is not feasible, countries are encouraged to begin with a simpler analysis and build on it over time as additional data and resources become available.

Where data and resources do allow for advanced optimization, and multiple analysis goals exist, it is possible to conduct multiple analysis types – either in parallel or sequentially. For example, after completing an *Advanced Optimization* analysis, a country may want to *Quantify Population Accessibility* to assess the impact of the modelled network.

Table 2: Details and examples of questions that can be answered within each analysis goal and analysis type

What type of analysis can be done?		What do you want to do? Increase Access	Integrate Test Types	Add or Relocate Devices	Onsite vs Sample Referral
Quantify Population Accessibility	Possible analysis	A country wants to determine which provinces/districts currently have the lowest population accessibility to TB testing.	A country wants to integrate TB and HIV testing on all GeneXperts across the country and understand the increase in population accessibility.	**Add devices:** Measure the change in population accessibility when adding 5 new devices across the country at specified labs. **Relocate devices:** Move an mWRD from a central lab with multiple devices to a rural lab with no devices and measure the increase in population accessibility.	How accessible are current mWRDs to the population (travel time/distance)? Via onsite testing and/or sample referral.
	Not included	Understanding the diagnostic capacity & utilization across the network to measure and estimate capacity for integration.		Add devices: Which types of devices could be selected based on device capacity and test demand (volumes).	Understand the length of sample referrals (direct to lab or via hub), and the costs of the system.
Visualize and Analyse	Possible analysis	To what extent is capacity utilized across different districts? Which districts have the lowest/highest utilization in the country?	Are any devices under-utilized that could be good candidates for testing integration, e.g., TB, HIV, HPV, among others?	**Add:** Which mWRDs are over utilized and may need an additional module or different type/size of device? **Relocate:** For laboratories with low utilization, is there sufficient capacity to relocate a device to another laboratory with high utilization?	Is there enough diagnostic capacity for devices to start receiving samples from the surrounding health facilities?
	Not included	Understand the length of sample referrals, and the costs of the system which is useful for reducing turnaround times at a lower cost.		It is not possible to determine the optimal location for adding or removing devices, however the outputs would provide directional guidance.	Understand the length of sample referrals (direct to lab or via hub), and the costs of the system.
Basic Optimization	Possible analysis	What is the required number & locations of mWRDs to ensure good access for all health facilities, especially in remote areas?	What is the reduction in average referral distance if devices integrate test types?	If testing was to be increased by 50% next year to meet NSP targets for patient notification, given the current diagnostic footprint, what are the optimal locations to add 5 new devices to enable the greatest improvement in population accessibility to services?	Where should new devices be placed so that the average referral distance is reduced?
	Not included	Compare the cost of the diagnostic network between scenarios and mapping the existing sample referral system versus an optimized one. To analyse costs, this must be done separately and requires additional data.			
Advance Optimization	Possible analysis	In the current referral system, which facilities are sending samples further than a given threshold? How can we change the network to reduce sample referral distances?	What is the estimated cost savings if testing and sample referral was integrated across disease programmes?	Should more devices be purchased to add to the network, or should more spending on sample transportation be considered? What combination gives the best access with the lowest cost based on sub-national contexts?	What is the estimated cost of a sample referral system for the optimized network? How does that compare to the current costs?
	Not included	Dynamic and live tracking of all diagnostic devices, tests, referrals, and TATs. Possible to link to a live sample tracking system.			

6. Data requirements and data sources



Overview
Guidance provided on determining data required to complete the DNO analysis using the analysis goal(s) and type(s) identified in the previous steps.

Key takeaway
Data availability required for the analysis should align with the question(s) to be answered.

Countries starting out with an initial DNO analysis may not have comprehensive data available. In such cases, it is advisable to focus on basic analyses using available data – beginning with mapping the location of the laboratories and the diagnostic devices at each site. This information is sufficient to conduct *Quantify Population Accessibility* analyses.

As the next step, countries may start collecting information on the broader set of health facilities (without diagnostic services on site) and their location. Most of this data can be found in the Master Facility List (MFL). Additional sources include the WHO Service Availability and Readiness Assessment (SARA),[9] WHO Health Resources and Services Availability Monitoring System (HeRAMS),[10] or Africa Society for Laboratory Medicine (ASLM) LabMap.[11]

To progress to *Visualize & Analyse* analyses, countries may collect additional information on the devices at each laboratory, the number and type of each one, the number of shifts worked for each device, and the maximum number of tests that can be performed per shift using each device. With this information, the capacity of a device can be calculated, which can be aggregated up to district, provincial, and national levels.

Device Capacity (tests):

$$\frac{\text{max.\# of shifts per day* available hours per shift *\# working days per year}}{\text{Average time to complete the test}}$$

Note: For instruments like GeneXperts with modules, multiply this result by the number of modules the device has, to calculate the total capacity for the device.

Device capacity example:

A GeneXpert IV device performing Xpert MTB/RIF Ultra is placed in a laboratory. The average time required to perform the Xpert MTB/RIF Ultra test is 2 hours. The laboratory works one, eight-hour shift per day, and performs testing 250 days per year. The device capacity per year:

Device capacity (tests):

$$= \frac{\text{max.\# of shifts per day* available hours per shift *\# working days per year}}{\text{Average time to complete the test}}$$

$$\text{Device capacity (tests):} = \frac{\text{1 shift * 8 hours * 250 days * 4 modules}}{\text{2 hours}}$$

$$= \frac{8{,}000}{2}$$

$$= \text{4,000 tests per year}$$

The next step is to collect data on the historical testing volumes conducted on each device, e.g., the GeneXpert in Lab A conducted 100 tests last year. The historical utilization can then be calculated by comparing actual testing volumes to device testing, as outlined in Benchmark 6 of the WHO standard: universal access to rapid tuberculosis diagnostics.[12] To do *Basic Optimization* analyses, it is also necessary to estimate the actual demand for testing from each health facility. For guidance on how to calculate this, refer to the Forecasting diagnostic testing demand for geospatial analysis guide.[13] With this, utilization levels can be estimated for each device, assuming a simple referral network that links health facilities to the nearest laboratory with testing capacity (using straight line distance). For *Advanced Optimization* analyses, it is necessary to collect data on historical referrals and associated costs, which are used for determining the optimal network across access, utilization, and cost.

In some cases, it may be useful to conduct *Quantify Population Accessibility* analysis along with a *Basic* or *Advanced Optimization* analysis, since the former provides insights on the ability to reach services and the latter generates information on the diagnostic network capacity and efficiency. For example, *Quantify Population Accessibility* analysis may be conducted to calculate the expected change in population access to services, following optimization of the network.

Table 3 describes the different data required for each analysis type. For further suggestions on where to find these datasets, consult the DNO Data Guidance Tool.[14] To see a more detailed description of the data elements for different tools, refer to **Annexure B: Data Templates for Tools**.

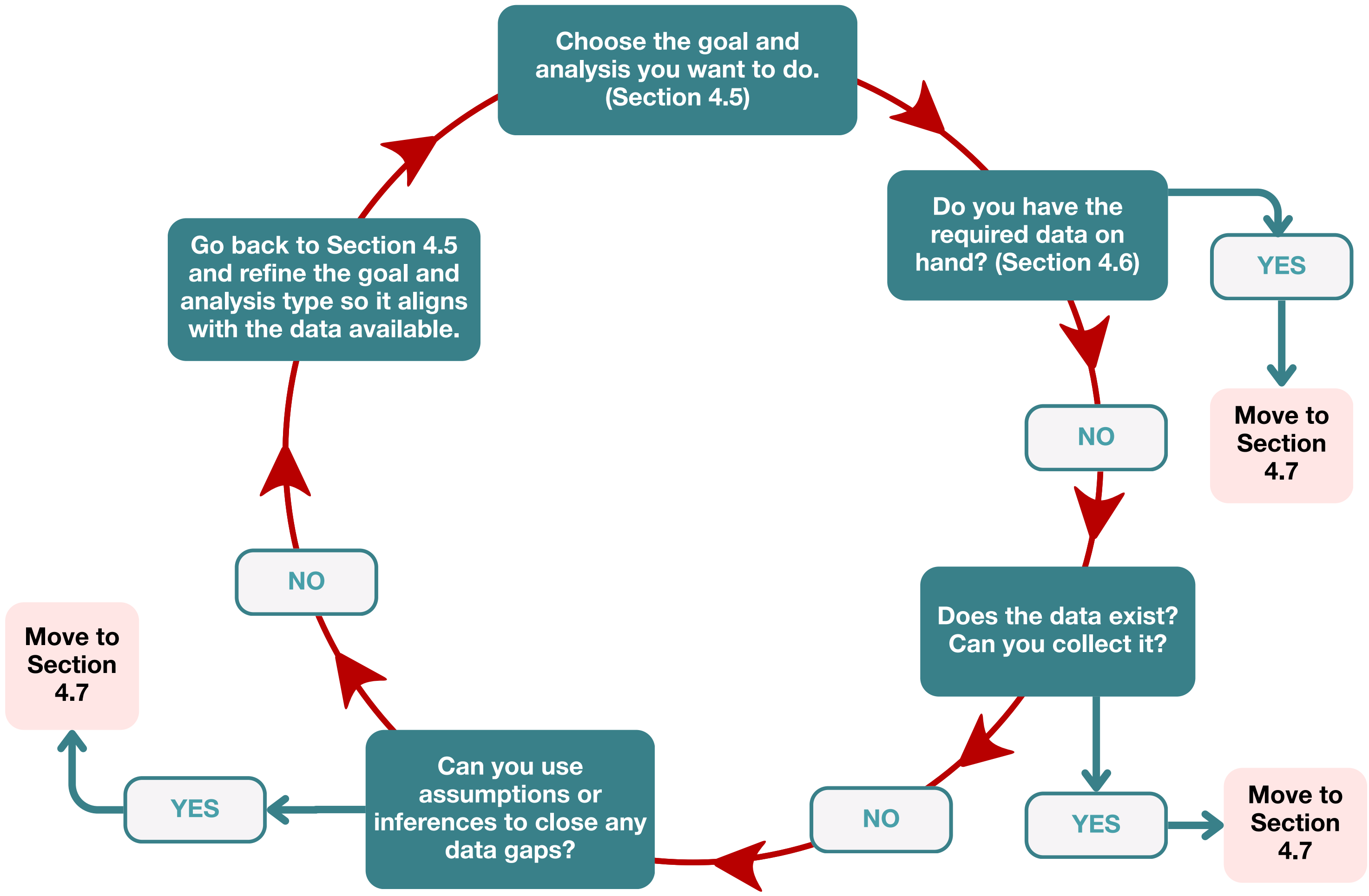
Table 3: Types of data required for DNO Analysis

Type	Data type	Detail
Quantify Population Accessibility	Lab data	Labs: Global Positioning System (GPS) coordinates of each laboratory that has a device.
	MFL	Health Facilities: all health facilities in the country, including GPS coordinates.
Visualize & Analyse	Lab device information	Device information: • Type & quantity of each device at each laboratory • Number of shifts worked per device • Number of hours in a shift • Maximum number of tests per shift
	Testing data	Per device: Total number of tests performed for each test type
Basic Optimization	Health facility demand	Per health facility: Total number of samples collected for testing for each test type
Advanced Optimization	Historical referrals	For each sample collection to testing site pair: • Sample collection site and number of samples collected by test type • Type: direct to lab or via a hub location (if applicable) • Testing site
	Costs	Staff, overhead, startup and transport costs
Dynamic DNO	Live data	Live tracking data of devices, health facility sample collection sites and vehicle tracking of samples.

Note: Data are cumulative, moving down the table requires all previous data.

Figure 5 provides an overview of the iterative process used to determine whether a country has the specific data required for the DNO analysis. **Section 4.5** provided examples for specific analysis goals and types. The next step involves comparing the chosen analysis type to the level of available data. It should be verified whether the necessary data is already accessible or can be collected within the required timeframe and resource constraints. If data gaps are identified, consideration should be given to whether this data exists, can be collected, or if assumptions can reasonably fill the gaps. If these options are not feasible, the analysis type may need to be refined to align with the available data.

Figure 5: How to determine whether a country has the necessary data required for the context



7. Selecting appropriate DNO tool(s)

1. Stakeholder engagement → 2. Situational assessment → 3. Country planning
4. Types of DNO → 5. Key questions → 6. Data requirements → **7. DNO tool(s)**
8. Conducting DNO analyses → 9. Implement reccomendations → 10. Monitoring and evaluation

Overview
Guidance provided on selecting the tool(s) best suited for the context based on available data and requirements of each tool.

Key takeaway
The tool(s) most appropriate for the context, based on the analysis type, should be selected.

Table 4 provides guidance on selecting the most appropriate tool(s) for analysis based on data availability identified in **Section 4.6**. Each tool requires specific types of data and generates various outputs. Generally, greater data availability allows for more accurate and granular analyses that better reflect the on-ground realities, albeit with implications for extended timelines and increased budgets. For instance, limited data (e.g., lab coordinates) and a short timeline may favour a

Quantify Population Accessibility analysis using tools like DxGeoMap or LabMap. Conversely, if comprehensive data on device capacity, utilization, referrals, and costs is available, an *Advanced Optimization* using OptiDx may be conducted, enabling detailed cost comparisons and recommendations for the most cost-efficient sample referral network to improve access.

Annexure C: Table of Tools provides additional details to support tool selection, while online tool-specific resources offer guidance on conducting the chosen analysis; the Landscape Review of Diagnostic Network and Route Optimization Tools[15] provides further details on different tools available and their capabilities.

Table 4: Types of data required for DNO Analysis

Data Elements	DxGeo Map*	LabMap*	PlanWise *	BI (PowerBI, Tableau)	R / Python	Access Mod*	ArcGIS / QGIS	OptiDx*	Commercial Supply Chain Optimization Tools++
Lab Data	X	X	X	X	X	X	X	X	X
Master Facility List	X	X	X	X	X	X	X	X	X
Lab Device Info			X	X	X	X	X	X	X
Testing Data		X	X	X	X	X	X	X	X
HF Demand			X		X	X	X	X	X
Land Cover						X			
Barriers						X			
Roads						X			
Historical Referrals		X			X			X	X
Costs			X					X	X
Analysis Type	Quantify Population Accessibility		Visualize & Analyse			Basic Optimization		Advanced Optimization	

**** Tools are specifically designed for DNO***

+ Business Intelligence

++ Examples of Commercial supply chain optimization tools: Coupa, OptiLogic, AIMMS

CHECK BEFORE PROCEEDING

Before proceeding, use the materials in **Sections 4.1-4.7** to decide on the following key elements:

- List the stakeholders that will be involved, e.g., NTP, district health managers, implementing partner, DNO partner(s).
- Choose the type(s) of DNO analyses the country will be aiming to complete. There can be more than one, e.g., increase access and integrate test types.
- Define the objective(s) of the analyses to be completed, e.g., assessing the impact of integrating TB and HIV testing on device utilization and population accessibility.
- Identify the type of data required for this analysis, such as lab location, MFL, device information, and testing data).
- Check whether the selected DNO tool (e.g., Plan Wise) supports the required analysis and whether the necessary data is available for input.
- Finally, confirm that the estimated timeline on the project is in line with expectations, e.g., 2-3 months).

As outlined in Table 5, a single DNO analysis may incorporate multiple elements across different analysis goals.

Table 5: Checklist for analysis plan

Stakeholders									
Type(s) of DNO	**Increase access**		**Integrate test types**		**Add/relocate devices**			**Onsite vs sample referral**	
Objective(s)									
Analysis Type(s)	**Quantify Population Accessibility**		**Visualize & Analyse**			**Basic Optimization**		**Advanced Optimization**	
Data available	Labs	MFL	Device info	Testing data		HF demand		Referrals	Costs
Tool(s)	DxGeo Map	LabMap	PlanWise	BI (PowerBI, Tableau)	R / Python	Access Mod	ArcGIS QGIS	OptiDx	Supply Chain
Timeline	0-2 months	1-4 months	2–5 months			3–6 months		3-12 months	

8. Conducting DNO analyses

1. Stakeholder engagement → 2. Situational assessment → 3. Country planning
4. Types of DNO → 5. Key questions → 6. Data requirements → 7. DNO tool(s)
8. Conducting DNO analyses → 9. Implement reccomendations → 10. Monitoring and evaluation

Overview
When conducting a DNO, there is a standardized process that should be followed to ensure a successful project.

Key takeaway
An analysis framework should be used to guide the DNO analysis project. A common framework is to develop a baseline, create various scenarios, interpret the outputs and compare the costs.

DNO analyses are highly customizable and vary in their objectives, scope, and methodology depending on the context. The total duration of a DNO analysis can also differ significantly, based on the type of analysis, its goals, and data availability. Basic mapping and visualization of a network can take 2-4 weeks, while more advanced DNO analyses requiring complex modelling may take several months. Longer time periods may be required where data cannot be readily compiled or if significant primary data collection and cleaning is required.

Sections 4.1 to 4.7 describe when to conduct a DNO and what data and tools to prepare. When beginning the DNO analysis, it is recommended to follow the approach outlined below.

Develop a baseline

A relevant software tool, selected in **Section 4.7**, should be used to create a digital representation of how the diagnostic system is currently organized. This baseline model should be validated with relevant stakeholders. Baseline analyses help assess existing testing capacity, the current distribution of diagnostic devices, and utilization across geographies – disaggregated by test/device types. These insights reveal gaps in equitable allocation of devices, the accessibility of services in various regions of a country, areas of under or over-utilization of capacity, and data-driven approaches to plan interventions to improve the diagnostic network.

In more advanced analyses, the baseline model can serve as a reference point against which to compare the outcomes of various optimization scenarios. The specific type of DNO analysis selected will influence how the baseline model is defined and constructed.

Scenario comparison

DNO analysis often involves building and evaluating multiple future-state scenarios, i.e., possible changes to the diagnostic network aimed at achieving specific objectives, such as improved access to services or enhanced network efficiency. Scenarios are developed by adjusting data inputs, such as the number and location of testing sites, or adding other test types to the model. In *Advanced Optimization* analyses, further constraints can be applied to the baseline model, such as:

- TAT requirements for specific tests
- Maximum allowable distance (MAD), i.e., the maximum distance that a sample can be referred from the health facility to the laboratory, while meeting the required sample transport conditions
- Service delivery constraints, such as rules on specimen referral or cross-border transport
- Budget considerations, e.g., limited funding for procuring new devices or expanding services

The impact of changing various inputs and constraints across different scenarios is assessed in terms of diagnostic utilization, cost, and access. Comparing outputs from these alternative scenarios against the baseline and against each other enables decision-makers to evaluate and identify the most effective solution from a range of possible approaches, to meet specific priorities.

It also helps to engage stakeholders early on to agree on which scenarios will be modelled and what specific inputs or constraints will be applied. Once the first round of scenarios is created, these are often refined further in collaboration with country teams, based on a review of preliminary outputs.

Interpreting DNO outputs

Outputs from DNO analyses need careful review and interpretation, in close consultation with all relevant stakeholders. The nature of the outputs will vary depending upon the scope and type of analysis and the software used. For example:

- Maps/list of regions with low population coverage and accessibility
- Sites with high or low levels of utilization
- Service delivery constraints, such as rules on specimen referral or cross-border transport
- Changes in distance or time to the nearest facility by relocating or adding devices
- Impact of integrating testing for multiple diseases on access, device utilization, costs, etc.

Selected outputs should be carefully reviewed to determine the approach that balances key elements – typically the geographic distribution and utilization of available testing capacity – along with improvements in access to testing. Advanced DNO software can model additional elements such as integration of testing across multiple diseases, sample referral linkages, and cost implications – features that may not be available in simpler visualization or analysis tools. The relative importance of these various factors – such as access, utilization, cost, and integration – will vary depending on country-specific priorities and constraints, such as the available budget, feasibility to implement in different settings, and long-term sustainability considerations.

Recommendations based on the selected scenarios must then be implemented and the resulting impact on diagnostic network performance should be monitored over time.

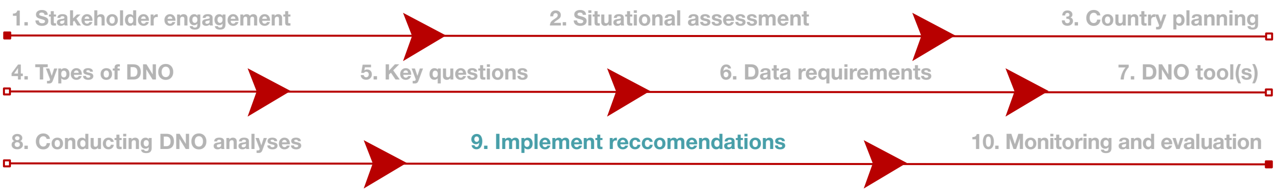
Interpreting DNO outputs

Advanced Optimization analyses (see **Case Study 5:** What is the optimal diagnostic network?) may include a component of costing. In such cases, the main purpose is to assess and compare the cost of implementing a potential strategy against the baseline or an alternative strategy. For example, the cost of operating a centralized HIV EID testing system (baseline) can be compared to that of a fully integrated and decentralized TB-HIV testing approach or a partially integrated approach where a mix of centralized and decentralized testing is adopted. This allows decision-makers to evaluate the relative cost-effectiveness of each potential strategy and intervention in terms of improved testing coverage, access to testing, or other efficiencies achieved by integrating testing on multi-disease platforms. Ultimately, this supports policy and programmatic decisions that maximise impact while improving the value for money of investments in health.

While assessing *costs vs impact*, it is essential to consider both immediate and longer-term requirements, to identify the best fit approach that helps achieve overall national analysis goal. For example, to improve testing access and coverage, establishing an integrated multi-disease sample referral system may require higher initial investment but offer lower operational costs and greater efficiencies over time – compared to expanding device footprint for siloed programmes to achieve the same results.

Cost inputs may typically include components such as cost per test, equipment cost, staff cost per device, quality assurance costs for existing testing sites, and start-up costs to set up additional lab if needed. Inputs on this need to be collated from multiple sources across different disease programmes, such as lab information systems, procurement records, sample transport systems, and device manufacturers. For further guidance, consult the Global Drug Facility (GDF) report on Diagnostics, Medical Devices & Other Health Products Catalog[16] and the GLI Planning and budgeting tool for TB and drug resistant TB testing: calculation tool for further resources.[17]

9. Implementing DNO recommendations



Overview
Guidance is provided on how to ensure the successful implementation of the project.

Key takeaway
A plan should be established to monitor the implementation of the project.

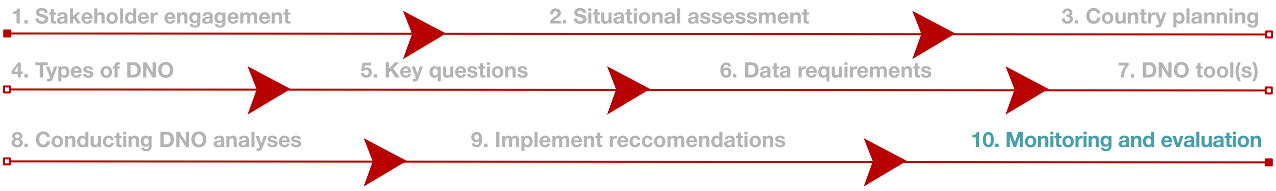
DNO recommendations provide actionable insights into diagnostic system improvements, directly influencing national health policies, such as procuring new devices, changing procurement plans, relocation of existing devices to new health facilities, the establishment or modification of sample referral linkages to improve accessibility and efficiency, and the integration of testing at existing or new laboratories. DNO findings can also help inform strategic and operational planning, including the development of national disease/laboratory strategic plans, the development of detailed work plans for resource allocation, and the procurement of essential testing equipment.

The implementation of the recommendations often occurs in phases, allowing gradual integration and evaluation before national scaling. In Kenya, for example, DNO outputs shaped both national and county-level policies for TB and sample referrals. Findings from the DNO have been used to inform Kenya's TB National Strategic Plan 2019–2023[18] and 2023-2028,[19] and revise Kenya's National Integrated sample referral system guidelines. These recommendations were operationalized at the county level, improving sample referral systems in 15 counties, with further scale-up planned nationwide.

DNO outputs are also useful for guiding funding applications by demonstrating specific healthcare and laboratory system strengthening needs, allowing health ministries to secure donor support for critical resources. For example, the Philippines, India, and Kenya have used DNO findings to inform their GeneXpert procurement plans and device placement to best meet their national TB programme goals.[20]

Finally, DNO can support diagnostic networks integration across multiple diseases. In Zambia and Côte d'Ivoire,[21] DNO demonstrated how existing testing capacity could be leveraged and optimally used to improve access and turnaround time to HIV viral load testing in priority populations, i.e., pregnant and breastfeeding women and children, and early infant diagnosis. Findings suggested that GeneXpert devices with available capacity could be leveraged for priority HIV testing, without negatively impacting TB testing, helping achieve both access and cost benefits.

10. Monitoring and evaluation and continuous improvement



Overview
Guidance is provided on how to ensure the M&E component is an integral part of measuring the success of the project.

Key takeaway
An M&E framework should be established to evaluate the impact of the project. Common metrics include test volumes, device utilization, testing coverage, turnaround times, and costs.

Monitoring and evaluation (M&E) frameworks are essential for tracking the implementation of DNO recommendations and assessing their impact on the diagnostic network. This ensures that DNO-driven plans achieve their intended outcomes. Each DNO should be accompanied by an operational plan outlining how recommendations will be implemented and how performance of the diagnostic network will be monitored and evaluated, typically through the use of key performance indicators (KPIs).

The successful adoption of the DNO recommendations will depend on their feasibility and acceptability among decision-makers, laboratory personnel, and healthcare workers. Multiple factors affect the uptake of DNO outputs, making it important to identify key enablers and barriers to diagnostic system strengthening decision making and implementation. Common enablers include early and continuous engagement with stakeholders at all levels of the system, including policymakers, programme implementers and laboratory staff; effective communication and capacity-building for end users. Possible barriers include shortage of human resources at health facilities, supply chain issues, and delays in approval processes.

The Implementation of DNO recommendations Is expected to improve access to diagnostic services, yield of testing, and effective linkage to care in the most cost-efficient manner. The impact of DNO on laboratory systems strengthening can be evaluated at both national and laboratory/device level using KPIs (where data is available), such as test volumes, device utilization, testing coverage, TAT, and costs. For further guidance, refer to **Annexure D: M&E Framework**.

Ideally, countries should track these metrics in real time using existing routine data collection systems, as continuous monitoring is essential for demonstrating the impact of DNO on both network performance and patient outcomes.

V. Case studies

Case Study 1: Increasing accessibility to diagnostic testing

Identifying gaps in population accessibility to TB services to inform the placement of TB diagnostics in Botswana									
Stakeholders	Botswana National Tuberculosis Program (BNTP); FIND								
Type(s) of DNO	**Increase access**		Integrate test types		Add/relocate devices			Onsite vs sample referral	
Objective(s)	Assess accessibility to TB services at a national and sub-national level.								
Analysis Type(s)	**Quantify Population Accessibility**		**Visualize & Analyse**			**Basic Optimization**		**Advanced Optimization**	
Data available	**Labs**	MFL	Device info	Testing data		HF demand		Referrals	Costs
Tool(s)	**DxGeo Map**	LabMap	PlanWise	BI (PowerBI, Tableau)	R Python	Access Mod	ArcGIS QGIS	OptiDx	Supply Chain
Timeline	**2 weeks**		2–5 months			3–6 months		11 months	

Problem Statement

BNTP needed to rapidly understand population accessibility to TB services (Chest X-Ray [CXR] or TB testing sites) across all the districts and sub districts in the country. The results of this analysis would help inform the placement of several new GeneXpert devices in areas with low access to TB services.

Note: This case study is included to highlight the kind of geospatial DNO analysis that can be achieved in a very short period, with very limited data. It can be used as a baseline for more advanced future DNO analysis.

Aim

Quantify the level of population accessibility to TB services countrywide and identify the districts and sub-districts with low population accessibility for placement of new GeneXpert instruments.

Data

The input data used in DxGeoMap analysis for this context were:

- MFL provided by BNTP
- Freely available population data from www.worldpop.org (2020 census)[22]

Analysis

To identify the gaps in access to TB services, sites with either CXR or GeneXpert, for a total of 41 locations spread across 10 districts. The population accessibility was defined as the number and percentage of the population within a 15-, 30-, and 60-minute walking and driving distance.

Results

The analysis using the DxGeoMap tool assisted the BNTP to identify sub-districts with current gaps in population access to TB services and where the new GeneXpert devices should be prioritized for placement to improve equitable population coverage to TB services. This evidence was used to support the countries' TGF funding request.

Additional examples:

- Accessibility to chest X-ray and TB testing in Kenya[23]
- Potential gains in population accessibility to TB testing services in Pakistan[24]

Case Study 2: Expanding equitable access to TB, HIV, and other priority diseases

<table>
<tr><th colspan="10">Mapping laboratory access and test integration in Mozambique</th></tr>
<tr><td>Stakeholders</td><td colspan="9">República De Moçambique Ministério Da Saúde - Direcção Nacional de Assistência Médica; ASLM; Africa Centre for Disease Control (CDC)</td></tr>
<tr><td>Type(s) of DNO</td><td colspan="2">Increase access</td><td colspan="2">Integrate test types</td><td colspan="3">Add/relocate devices</td><td colspan="2">Onsite vs sample referral</td></tr>
<tr><td>Objective(s)</td><td colspan="9">Analyse access, capacity, and implications of test integration.</td></tr>
<tr><td>Analysis Type(s)</td><td colspan="2">Quantify Population Accessibility</td><td colspan="3">Visualize & Analyse</td><td colspan="2">Basic Optimization</td><td colspan="2">Advanced Optimization</td></tr>
<tr><td>Data available</td><td>Labs</td><td>MFL</td><td>Device info</td><td colspan="2">Testing data</td><td colspan="2">HF demand</td><td>Referrals</td><td>Costs</td></tr>
<tr><td>Tool(s)</td><td>DxGeo Map</td><td>LabMap</td><td>PlanWise</td><td>BI (PowerBI, Tableau)</td><td>R Python</td><td>Access Mod</td><td>ArcGIS QGIS</td><td>OptiDx</td><td>Supply Chain</td></tr>
<tr><td>Timeline</td><td>0-2 months</td><td>1-4 months</td><td colspan="3">2–5 months</td><td colspan="2">3–6 months</td><td colspan="2">3-12 months</td></tr>
</table>

Problem Statement

Mozambique faced challenges in providing equitable access to diagnostic services across its 162 districts and 1,858 health facilities. With a network of 503 laboratories spanning four levels, the country sought to improve access to testing and identify the number of GeneXperts required so it could be added to a TGF funding request.

Aim

The objective was to evaluate the national laboratory network to identify gaps, optimize diagnostic services, and develop a strategic plan to expand equitable access, particularly for TB, HIV, and other priority diseases.

Data

The analysis used historical data from 2021 and projected data for 2023–25, covering:

- Lab data – GPS coordinates
- Device information: location, capacity, and utilization

Analysis

A comprehensive mapping exercise was conducted to assess the laboratory network. The analysis utilized the LabMap tool and PlanWise software to assess diagnostic accessibility for TB and project future demands. Recommendations were aligned with national strategic goals, including optimizing the diagnostic network, updating laboratory infrastructure guidelines, and increasing the number of accredited and well-equipped laboratories.

Results

The analysis revealed that only 36.5% of the population had access to TB diagnostic services within the recommended 10 km radius, with 175 laboratories serving 230,581 people. To address this, Mozambique plans to increase GeneXpert devices to 203 by 2026, by adding 112 modules. Around 65% of the capacity will be used for TB testing, while the remaining 35% of capacity will be used for other tests, including COVID-19 and HIV viral load, and hepatitis. The findings informed the development of the TB Diagnostic Network Optimization Plan 2026 and the Strategic Plan for Clinical Laboratories for 2025–35, and were also used to inform the funding application to TGF.

Case Study 3: Assessing capacity within the network to integrate multiple test types on the same platform

<table>
<tr><th colspan="10">Using DNO to inform the design of integrated diagnostic testing services and sample referral networks for greater access to TB, HIV, and HPV services in Côte d'Ivoire</th></tr>
<tr><td>Stakeholders</td><td colspan="9">Programme National de Lutte contre le Cancer (PNLCa); Programme National de Lutte contre le Sida (PNLS); Programme National de Lutte contre la Tuberculose (PNLT); I-TECH; CDC; UNIGE; FIND</td></tr>
<tr><td>Type(s) of DNO</td><td colspan="2">Increase access</td><td colspan="2">Integrate test types</td><td colspan="3">Add/relocate devices</td><td colspan="2">Onsite vs sample referral</td></tr>
<tr><td>Objective(s)</td><td colspan="9">Integrate testing services to improve accessibility.</td></tr>
<tr><td>Analysis Type(s)</td><td colspan="2">Quantify Population Accessibility</td><td colspan="3">Visualize & Analyse</td><td colspan="2">Basic Optimization</td><td colspan="2">Advanced Optimization</td></tr>
<tr><td>Data available</td><td>Labs</td><td>MFL</td><td>Device info</td><td colspan="2">Testing data</td><td colspan="2">HF demand</td><td>Referrals</td><td>Costs</td></tr>
<tr><td>Tool(s)</td><td>DxGeo Map</td><td>LabMap</td><td>PlanWise</td><td>BI (PowerBI, Tableau)</td><td>R Python</td><td>Access Mod</td><td>ArcGIS QGIS</td><td>OptiDx</td><td>Supply Chain</td></tr>
<tr><td>Timeline</td><td>0-2 months</td><td>1-4 months</td><td colspan="3">2–5 months</td><td colspan="2">3–6 months</td><td colspan="2">11 months</td></tr>
</table>

Problem Statement

In Côte d'Ivoire, several diagnostic platforms are used for HIV viral load, EID, TB, and HPV, including both centralized and decentralized devices. To improve the network performance, specific interventions have been implemented. However, challenges remained, including suboptimal device utilization, inefficient sample referral systems, and restricted access to diagnostic services for priority populations such as children, pregnant women, and people living with HIV and TB. Further efficiency gains are therefore necessary to optimize the national diagnostic network and meet global goals to end the TB and HIV epidemics by 2030.

Aim

Optimize a multi-disease diagnostic network in Côte d'Ivoire to enhance access and efficiency in HIV, TB, and HPV testing. Key objectives are enhancing access to testing for priority HIV populations while maintaining or improving TB and HPV services and establishing an integrated and cost-effective sample referral system.

Data

The analysis used historical data from 2021 and projected data for 2023–25, covering:

- Labs, MFL, and hubs
- Testing volumes for HIV, TB, and HPV;
- Device information: location, capacity, and utilization
- Historical sample referrals; costs

Analysis

The DNO analysis used OptiDx to analyse the current diagnostic network (2021); model multiple optimization scenarios (2023–25), including the application of different network constraints (maximum service distance, testing integration); evaluate and compare scenarios based on access to diagnostic services (distance), device utilization, and cost to determine which one has the greatest impact in the most cost-efficient and sustainable manner

Results

Results indicated that the current testing capacity is sufficient to meet current and future country's needs for HIV, TB, and HPV testing, but that overcapacity issues would appear in 2023 for some m-PIMA and GeneXpert devices. The optimization of specimen referral linkages would reduce average distances to diagnostic services (from 52 km to 44 km), lower network costs by 47% compared with the 2023 planned network, and address the overuse of device capacity. Access to diagnostic services would be improved from 44 km to 30 km and costs would be reduced by 5% if viral load and EID testing were integrated into existing GeneXpert devices and if a maximum sample transport distance of 30 km for priority viral load and EID was implemented. Even after testing integration, the level and the access to TB testing would remain the same.

Implementation

Recommendations from the DNO analysis informed national policies and strategic plans, including the country's National Laboratory Strategic Plan for 2023–25, PEPFAR country operational planning, as well as a change in sample referral linkages. In 2024, a pilot implementation of an integrated sample transportation system across HIV, TB, and HPV was initiated in two regions in Côte d'Ivoire. A phased integration of HIV and TB testing on GeneXpert platforms is also planned. Outputs of the analysis was used in the TGF and PEPFAR funding applications, and by UNICEF for implementation funding.

Case Study 4: Determining the best locations to place new devices

<table>
<tr><th colspan="12">Increasing access andcoverage of molecular diagnostics in Kenya</th></tr>
<tr><td>Stakeholders</td><td colspan="11">Ministry of Health Kenya - National Tuberculosis, HIV, and HPV programmes; FIND</td></tr>
<tr><td>Type(s) of DNO</td><td colspan="2">Increase access</td><td colspan="3">Integrate test types</td><td colspan="3">Add/relocate devices</td><td colspan="3">Onsite vs sample referral</td></tr>
<tr><td>Objective(s)</td><td colspan="11">Integrate testing services to improve accessibility.</td></tr>
<tr><td>Analysis Type(s)</td><td colspan="2">Quantify Population Accessibility</td><td colspan="4">Visualize & Analyse</td><td colspan="3">Basic Optimization</td><td colspan="2">Advanced Optimization</td></tr>
<tr><td>Data available</td><td>Labs</td><td>MFL</td><td colspan="2">Device info</td><td colspan="2">Testing data</td><td colspan="3">HF demand</td><td>Referrals</td><td>Costs</td></tr>
<tr><td>Tool(s)</td><td>DxGeo Map</td><td>LabMap</td><td>PlanWise</td><td colspan="2">BI (PowerBI, Tableau)</td><td>R Python</td><td>Access Mod</td><td colspan="2">ArcGIS QGIS</td><td>OptiDx</td><td>Supply Chain</td></tr>
<tr><td>Timeline</td><td>0-2 months</td><td>1-4 months</td><td colspan="4">2-5 months</td><td colspan="3">3-6 months</td><td colspan="2">3-12 months</td></tr>
</table>

Problem Statement

In Kenya, equitable access to diagnostic testing for TB, HIV, and HPV was a challenge, particularly in remote areas, despite the use of molecular WHO-recommended diagnostics (mWRDs). Increasing the integration of testing across these disease programmes was needed to address equitable access and coverage in line with forecasted demand growth driven by planned future policies and diagnostic algorithms. Kenya wanted to expand the diagnostic network, while also ensuring that individuals in remote areas have equitable access to timely and reliable diagnostic testing.

Aim

Assess the required number and locations of molecular diagnostics to ensure high-demand coverage, especially in remote areas.

Data

- Labs & MFL
- Device information
- Historical testing data for TB, HIV and HPV
- Modelled future demand for TB, HIV and HPV

Analysis

An integrated DNO exercise was conducted for all three disease programmes to optimize the geographic coverage of modelled future demand. Various scenarios were run to identify the optimal number and location of new devices to ensure equitable demand.

Results

The final model expanded the diagnostic network by 40 new locations, increasing coverage in remote areas from approximately 77% to over 96% (within a 40 km radius). The selection balanced expected impact with available funding, future funding opportunities, and the practical capabilities of the disease programmes.

Case Study 5: Assessing the optimal diagnostic network

<table>
<tr><th colspan="10">Optimal location for Truenat devices and modelling the most cost-efficient sample transport system in Uttarakhand, India</th></tr>
<tr><td>Stakeholders</td><td colspan="9">State TB Cell, Directorate of Health and Family Welfare, Uttarakhand, India; FIND</td></tr>
<tr><td>Type(s) of DNO</td><td colspan="2">Increase access</td><td colspan="3">Integrate test types</td><td colspan="2">Add/relocate devices</td><td colspan="2">Onsite vs sample referral</td></tr>
<tr><td>Objective(s)</td><td colspan="9">Improve access to TB testing by improving sample referrals while reducing cost.</td></tr>
<tr><td>Analysis Type(s)</td><td colspan="2">Quantify Population Accessibility</td><td colspan="3">Visualize & Analyse</td><td colspan="2">Basic Optimization</td><td colspan="2">Advanced Optimization</td></tr>
<tr><td>Data available</td><td>Labs</td><td>MFL</td><td>Device info</td><td colspan="2">Testing data</td><td colspan="2">HF demand</td><td>Referrals</td><td>Costs</td></tr>
<tr><td>Tool(s)</td><td>DxGeo Map</td><td>LabMap</td><td>PlanWise</td><td>BI (PowerBI, Tableau)</td><td>R Python</td><td>Access Mod</td><td>ArcGIS QGIS</td><td>OptiDx</td><td>Supply Chain</td></tr>
<tr><td>Timeline</td><td>0-2 months</td><td>1-4 months</td><td colspan="3">2–5 months</td><td colspan="2">3–6 months</td><td colspan="2">3-12 months</td></tr>
</table>

Problem Statement

Uttarakhand faced significant challenges in its diagnostic network due to the state's unique geographic landscape. Hard-to-reach areas, exacerbated by landslides during the rainy season and heavy snow in winter, resulted in lengthy sample transit times. Devices remained underutilized and large amounts were being spent on centralized testing. At baseline, the state had a mix of GeneXpert and TrueNat devices.

Aim

Increase the number of TB testing sites by adding more TrueNat devices to improve access and reduce costs, improve sample referrals for patient care, and provide recommendations on the optimal routes and the number of personnel required for these routes.

Data

The analysis used historical data from 2021 and projected data for 2023–25, covering:

- Geocoordinates of health facilities, hubs, and laboratories
- Testing volumes for TB
- Device location, capacity, and utilization
- Sample referral linkages
- Costs

Analysis

The analysis was conducted using OptiDx to model the baseline and several different scenarios. OptiDx was used to model the sample transport system with optimized referral linkages. The introduction of six new TrueNat testing sites to reduce sample transport distance and costs was modelled. The analysis produced information that was included in the Request for Proposal (RFP) for sample transportation in the state (information on kms, total cost and resources required).

Results

Optimization of the diagnostic network resulted in a 39% reduction in average service distance (distance from collection to testing site) – improving transit times and enabling faster diagnosis, which significantly reduced test turnaround times. Annual transportation costs were cut by 58% due to an increase in diagnostic sites. The RFP process facilitated a rise in the number of samples transported and tested. For Nucleic Acid Amplification Tests (NAAT) (GeneXpert or TrueNat), the turnaround time improved from two days to the same day.

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VII. Annexures

Annexure A: Frequently asked questions (FAQs)

1. **Do all countries need DNO? What factors should countries consider when planning or considering a DNO exercise?**
   If a DNO exercise has never been conducted before, it is recommended to do so in order to get an overview of the network. Countries should consider what questions they would like to answer, who should be involved, what is the timeline and budget, and what data they have available.

2. **DNO analyses seem to require a lot of data. What should countries do where data is limited?**
   Historically, advanced DNO required substantial data. However, current tools allow countries to get started with analysing their network within a few weeks using minimal data. It is recommended to start a DNO analysis that matches the data available within the country.

3. **Is there standard guidance on selecting the best fit DNO tool? Can multiple software tools be combined?**
   Yes, this implementation guide provides guidance on which tool is the most appropriate choice for different types of analyses. It is possible, and sometimes required, to use multiple software tools to answer different types of questions.

4. **Most examples of DNO analyses seem to focus on TB and HIV. Can DNO be leveraged for strengthening testing for other diseases?**
   Yes, DNO can be used across many different disease types. Integrating testing across multiple disease types is a common application and an example is provided in Case Study 2 of this guide.

5. **Should DNO analyses focus on individual disease testing or include all testing across diseases?**
   This depends on the country's context and the objective of the analysis. A comprehensive analysis across all priority tests, especially multiple tests performed on same devices, can provide a more comprehensive assessment of the current situation and support more robust planning for future. However, it may require more time, resources, and data than analysing individual programmes. It is recommended to include all relevant stakeholders for a DNO analysis and explore the best solution using a data-driven approach.

6 **What are the common challenges in implementing DNO findings on ground and how can these challenges be overcome?**
   Challenges might occur when all necessary stakeholders are not included from the beginning of the project and their input is not factored into the analysis. These may include incomplete or incorrect data inputs, misalignment between outputs from the data analysis and real-world context, or lack of resources and commitment to implement DNO findings. Additionally, a DNO project is more likely to achieve its goals with a robust implementation plan and monitoring and evaluation framework in place.

7. **How has DNO helped improve lab systems in countries? What have been some of the most valuable gains?**
Different types of DNO exercises have been used across countries, yielding positive results in different contexts. These include identifying cost benefits of test integration at the device level, highlighting the cost savings from an efficient sample referral system, and justifying the number of devices required for funding requests. For more examples, refer to the "Case Studies" section in this guide, the ASLM LabCop DNO Echo[25] sessions, and the ASLM Resource Centre[26] examples.

Annexure B: Data templates for tools

Table 6: DxGeoMap Data Template

Column name	Column value/options
Name*	Facility name
Latitude*	Value from -90 to 90
Longitude*	Value from -180 to 180
Level*	From 0 to 6
Sector*	Private, Public, Religious or NGO
Custom attribute 1-5	Optional values that can be specific to a dataset. Header name can be changed.

Notes:

- File should be in comma separated value (csv) format
- Fields marked by an asterisk are mandatory.
- Admin Levels 1 and 2 are optional but will be overwritten by the system if provided. When exporting a dataset in Comma Separated Values (CSV) format, the values for Admin Level 1 and Admin Level 2 calculated by the system will be included.

Links to further data templates or tools:

- PLANWISE[27]
- AccessMod[28]
- OptiDx[29]

Annexure C: Table of tools

Table 7: Overview of tools available for DNO

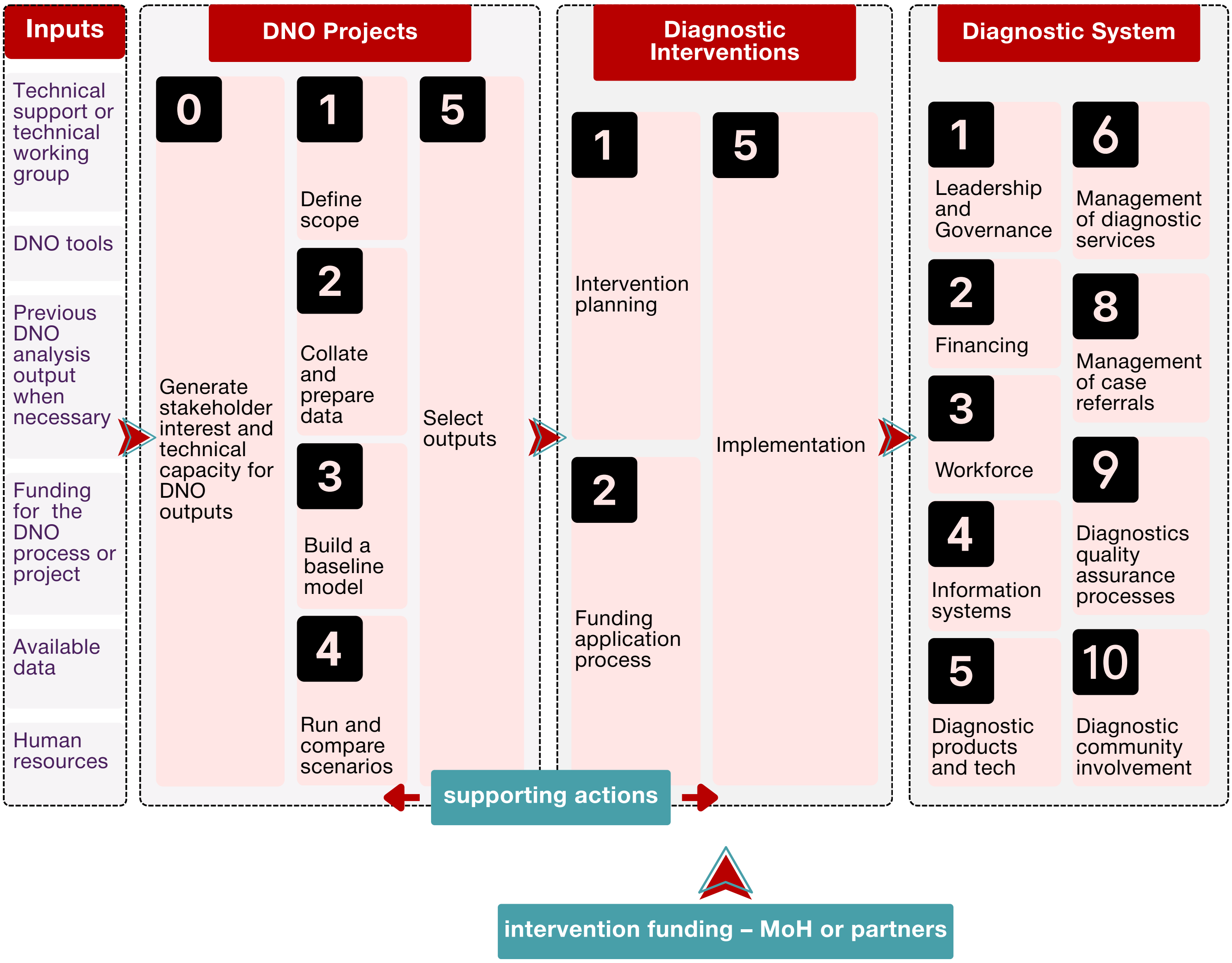
Characteristic	Excel	DxGeoMap	LabMap	Planwise	AccessMod	OptiDx	ArcGIS or QGIS	BI (PowerBI, Tableau)	R/Python	Commercial Supply Chain
Software License Fee	License	Open Access	Open Access	Open Access	Open Source	Open Access	ArcGIS: License QGIS: Free	License	Open Source	License
Skillset required	Programme Manager	Programme Manager	Programme Manager + Data Analyst	Programme Manager + Data Analyst	GIS Analyst	Supply Chain Analyst	GIS Analyst	Data Analyst	Data Analyst	Supply Chain Analyst
Timeline*	1-3 weeks	1-4 weeks	1-2 months	2-3 months	2-3 months	3-6 months	Depends on analysis	Depends on analysis	Depends on analysis	3-6 months
DNO History	No	No	No	Encouraged	Encouraged	Required	Depends on analysis	Depends on analysis	Depends on analysis	Required
Further Resources	Excel (30)	DxGeoMap (31)	LabMap (11)	PlanWise (27)	AccessMod (28)	OptiDx (29)	ArcGIS (32) QGIS (33)	PowerBI(34) Tableau (35)	R (36) Python (37)	Coupa (38) OptiLogic (39)

Annexure D: M&E framework

The 'Theory of Change' model suggested in this guide maps out the relationship between DNO projects, the recommendations that project generates, subsequent interventions, and changes in the diagnostic system (see **Figure 6**). The diagnostic system is expressed based on its function and performance components. The implemented DNO interventions impact the function of the system, which in turn affects its performance.

The model is based on the assumption that interventions will likely be informed by the recommendations that emerge from the DNO project, but these recommendations may be modified, or only partially implemented, and other interventions may be added. Thus, interventions may impact all nine components of the diagnostic system, while the DNO recommendations will only target components 5–7, i.e., diagnostic products and tech, management of diagnostic services, and management of case referrals.

Figure 6: DNO theory of change – linking inputs, DNO projects, diagnostic interventions, and the diagnostic system



Annexure E: Metrics used to measure DNO outputs

Table 8: Suggested metrics for summarizing and comparing DNO outputs

Metric	Analysis Type (at which metric is possible)
Health Facility and Diagnostic Testing Coverage by Administrative Areas	
Total Admin 1 area (e.g., province)	Quantify Population Accessibility
Total Admin 2 (e.g., district) areas	Quantify Population Accessibility
Number of health facilities	Quantify Population Accessibility
Number of testing sites (mWRD)	Quantify Population Accessibility
Number of testing sites (smear)	Quantify Population Accessibility
Number of health facilities with on-site mWRD diagnostic testing	Quantify Population Accessibility
Number of health facilities with access to mWRD diagnostic testing only, either on-site or through sample referral	Quantify Population Accessibility
Number of Admin 1 areas (e.g., province) with at least one on-site mWRD for diagnostic testing	Quantify Population Accessibility
Number of Admin 2 (e.g., district) areas with at least one on-site mWRD for diagnostic testing	Quantify Population Accessibility
Geographic Coverage of Health Facilities and Diagnostic Testing	
% of health facilities with on-site mWRD diagnostic testing	Quantify Population Accessibility
% of health facilities with sample referral for mWRD diagnostic testing only (i.e., smear not included)	Quantify Population Accessibility
% of health facilities with access to mWRD diagnostic testing only, either on-site or through sample referral	Quantify Population Accessibility
% of Admin 1 areas (e.g., province) with at least one on-site mWRD for diagnostic testing	Quantify Population Accessibility
% of Admin 2 (e.g., district) areas with at least one on-site mWRD for diagnostic testing	Quantify Population Accessibility
Access to Diagnostic Testing: Travel Time and Distance	
Average distance from health facility to mWRD testing site (in km) [split by admin 1 and admin 2 if available]	Basic Optimization
Number of health facilities within 1-14 min travel time of a mWRD testing site (i.e., not including on-site facilities)	Quantify Population Accessibility
Number of health facilities within 15-29 min travel time of a mWRD testing site	Quantify Population Accessibility
Number of health facilities within 30-60 min travel time of a mWRD testing site	Quantify Population Accessibility
Percentage of population within 1 hour travel time for health facilities offering access to on- site diagnostic testing	Quantify Population Accessibility
Percentage of population within 1 hour travel time from health facilities offering access to diagnostic testing through sample collection and referral site	Quantify Population Accessibility
Testing Capacity	
Total number of mWRD tests conducted	Visualize-Analyse
Percentage of population within 1 hour travel time from health facilities offering access to diagnostic testing through sample collection and referral site	Visualize-Analyse
Tests per 100,000 population by Admin 1 area (e.g., province)	Visualize-Analyse
Referral Distance	
Distance within which 80% of samples referred for testing are transported (excluding on-site testing)	Basic Optimization