DIAGNOSTIC NETWORK OPTIMIZATION:

A network analytics approach to design patient-centred and cost-efficient diagnostic systems

CONTENTS

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ABBREVIATIONS

COVID-19	Coronavirus disease 2019
C/DST	Culture/drug susceptibility testing
DNO	Diagnostic network optimization
EID	Early infant diagnosis for HIV
LPA	Line probe assay
MAD	Maximum allowable distance
MGIT	Mycobacteria Growth Indicator Tube
PCR	Polymerase chain reaction
RO	Route optimization
SRS	Sample referral system
TAT	Turnaround time
TB	Tuberculosis
VL	Viral load

EXECUTIVE SUMMARY

Access to diagnostics is essential for ensuring health for all, but testing remains one of the weakest links across the patient care-seeking pathway. How a diagnostic network is designed is key to delivering patient-centred and equitable diagnostic services. Diagnostic network optimization (DNO) is a geospatial network analytics approach to plan diagnostic networks consistent with national health goals and strategies, including universal health coverage. It helps planners and managers analyse the current diagnostic network and recommend the optimal type, number and location of diagnostics and an associated sample referral network that together enable greatest access to services, while maximizing the overall efficiency of the system. DNO enables decisions on the best network design in a given setting through evaluation of testing demand, testing capacity and utilization, cost efficiency, access to services, and application of real-life constraints. As part of DNO, these factors are analysed to generate insights on the best network configuration and understand trade-offs between cost, access and device utilization. By doing so, DNO can help specify the investments that are needed to achieve disease goals and health equity, and can enable prioritization of interventions with the greatest impact, if resources are limited.

A DNO analysis can help avoid common issues with diagnostic network planning, which can include a lack of clear visibility into current network gaps and inefficiencies in how existing devices are used and accessed by patients. It can be particularly useful when a network assessment shows significant gaps and inequities in service delivery, when procurement of new diagnostic devices or integration of new tests on existing devices is being considered, or when improving access to services is a priority. Insights from DNO can contribute to evidence-based national strategic plans, funding requests, informing resource allocation, as well as procurement and operational planning. The value and impact of DNO ultimately depend on whether the suggested interventions are adopted and how well they are implemented and monitored.

DNO is a disease-agnostic and highly adaptable approach that can be applied to various country-specific needs. While the core implementation framework can be universally applied, the process of conducting a DNO is driven by factors unique to each setting, such as the overall purpose, objectives, scope, and timing of the analysis. A typical DNO exercise comprises five key steps. Initially, a multi-stakeholder project team defines the scope of the analysis, in terms of which diseases, tests, and geographies need to be considered and priority questions to be answered, as well as identifying both the system requirements to meet health strategic goals and budgetary or other constraints that need to be incorporated in the analysis. Next, available data are identified, collated, and cleaned for entry into the DNO tool. From this, a baseline model of the network can be developed, i.e. a digital representation of how the diagnostic system is currently organized, to identify gaps in the current network. Subsequently, this model is adjusted to investigate the effect of varying factors such as device locations, test menu, sample flows, and the requirements generated by applying various constraints such as maximum turnaround times or service distances. The resulting scenarios can be analysed and compared with health strategic goals to investigate options for the future network, and scenarios can be refined to identify the most feasible and impactful solution for the context. Robust investment cases can then be prepared, preferred scenarios can be implemented, and the effect of changes in the network can be monitored. DNO analyses can be subsequently updated to incorporate significant changes to the assumptions and inputs.

DNO works best when integrated closely across stakeholders and diseases, aligned with national disease programmes and targets, with periodic follow-up assessments. The availability and quality of data significantly affect resources needed and timelines for conducting DNO, as well as outcomes of the analysis. DNO and other forms of geospatial analysis have been applied to inform diagnostic strategy and planning across a number of countries, largely for tuberculosis and HIV, and to a limited extent for other diseases, including COVID-19. DNO enables enhanced laboratory systems planning, through greater network visibility and its ability to incorporate multiple factors simultaneously.

OBJECTIVE OF THIS GUIDE

This guide provides an overview of diagnostic network optimization (DNO), a geospatial analytics approach to analyse and optimize diagnostic networks to enable the greatest access to services, while maximizing the overall efficiency of the system. It includes a description of the concepts of DNO, the process to conduct a DNO analysis, data requirements, software solutions for conducting DNO and how outputs from DNO analyses can be used to inform decision-making.

The guide emphasizes the importance for country leadership and engagement of stakeholders throughout the DNO process and presents case studies that demonstrate how DNO can be used to support strategic and operational planning and budgeting. It also provides examples of completed DNO exercises using several tools, which highlight a range of DNO objectives and outputs and illustrate how recommendations have been used to shape national strategic plans, considerations for funding and operational planning. These examples demonstrate how DNO can be tailored to ensure the outputs of DNO are relevant, grounded in the country reality, understood by decision-makers, implementable within budgetary considerations, and lead to sustainable improvements in diagnostic services in line with country health strategies.

This guide may appeal to a range of audiences, primarily decision-makers and leadership from:

- Ministries of Health (national, provincial, regional staff) with an emphasis on resource-limited settings;
- donors supporting health system strengthening, who are considering supporting DNO exercises to shape investment decisions; and
- implementing partners with capacity and interest in supporting Ministries of Health with conducting DNO analyses.

This guide is also relevant for project teams directly involved in conducting DNO analyses, in conjunction with other technical resources.

With this in mind, the guide is centred on the key requirements to plan and conduct DNO analyses and to ensure outputs can be used effectively to bring improvements to diagnostic services.

I BACKGROUND

Importance of diagnostics

Equitable access to quality and timely diagnosis linked to appropriate care is critical for ensuring health for all. However, access to testing is the weakest link across the patient care-seeking pathway. Basic diagnostic capacity exists in just 1% of primary care clinics and 14% of hospitals in low- and middle-income countries.[1] Close to half of the world's population has limited or no access to diagnostics.[2] Even where testing capacity is available, it is often unaffordable and inaccessible, with testing devices being underutilized, and delivery of test results may be inaccurate or too delayed to inform clinical decision-making.[3,4,5]

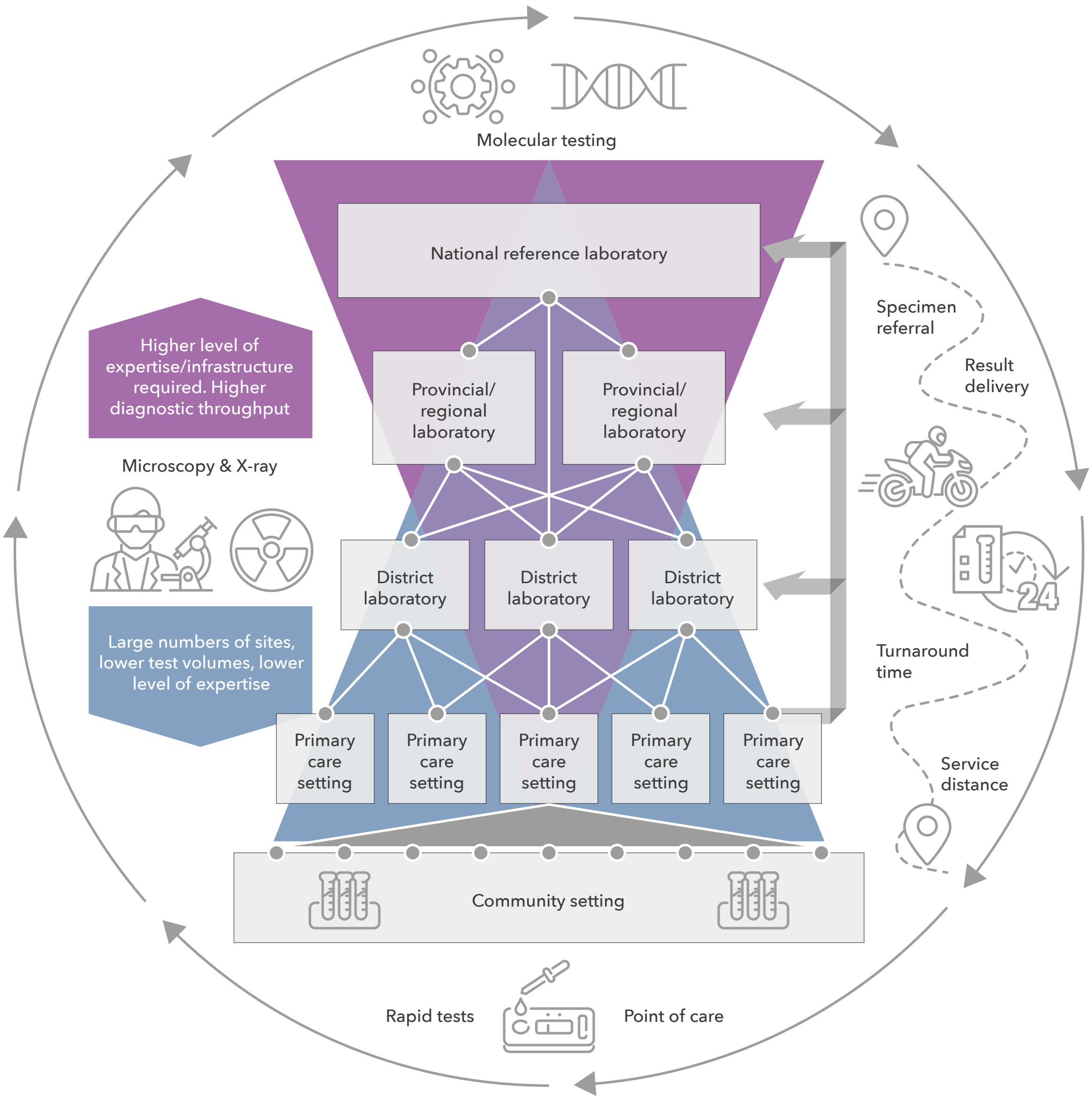
Delivering patient-centred and equitable diagnostic testing services is complex. Despite significant investments over the past decade to strengthen diagnostic systems, particularly for HIV and tuberculosis (TB), critical gaps and weaknesses remain. Furthermore, diagnostic services for different diseases often function in a siloed and fragmented manner. Given that significant investments in diagnostic network capacity are clearly needed to meet disease-specific goals and for universal health coverage, the empirical case for such investments needs to be as robust and compelling as possible.

Diagnostic networks

A diagnostic network is an interconnected system comprising human resources, infrastructure, referral systems and diagnostic testing devices, to detect, manage and monitor diseases in a clinical or public health setting. It includes both physical elements, such as sites, devices and tests, and rules or policies that govern operations, such as sample referral linkages.

The goal of a diagnostic network is to deliver the right amount of testing, in the right place, at the right time, for the right people and at an affordable and sustainable cost, ensuring that accurate test results are delivered in a timely manner to inform patient care and public health decision-making, on a scale consistent with national goals and strategies.[6] To achieve this, most countries provide diagnostic services through a national laboratory network aligned with the multi-tiered health system, comprising both public and private healthcare providers. Different tiers typically have a specified test menu based on population testing needs, infrastructure requirements, and resource constraints.[7]

Figure 1: Illustrative example of a diagnostic network



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Whether diagnostic services are delivered using a more centralized or decentralized model can also vary by country and disease. During the COVID-19 pandemic, many existing laboratory systems for TB and HIV have been utilized for COVID-19 testing, both on centralized polymerase chain reaction (PCR) platforms and decentralized molecular devices, and through integration of sample transport in some cases.[9,10] The importance of testing during the COVID-19 pandemic has further highlighted the value of investing in diagnostic systems and the benefits of an integrated diagnostic network.

Current status of diagnostic network planning and challenges

Various strategy, planning and operational guidelines are available to countries to support planning and decision-making for diagnostic networks, mainly aimed at national TB and HIV programmes.[11-17] However, countries have to adapt such guidance to their own settings, and consider a number of context-dependent factors when planning a diagnostic system, such as disease epidemiology, the structure of health systems, types of tests available and geographical factors that may affect access to diagnostic services e.g. available transport networks. Designing an effective system is therefore complex and highly context-dependent, requiring a multitude of inputs and assumptions.

Currently, the decision on how many diagnostic devices are needed and where they should be placed is often based on geographic or administrative considerations rather than need for services, which can lead to network inefficiencies, avoidable costs, and issues with access, with some devices being over-burdened while others remain significantly underutilized. For most countries, planning is done using spreadsheets, which limits the extent to which changing multiple data inputs can be examined and limits the ability to extract insights from the data.

DNO is one particularly valuable approach to help countries design efficient and cost-effective diagnostic networks adapted to their own settings and priorities. The analytical processes of network design and optimization aim to improve the implementation of diagnostic networks with enhanced effectiveness, efficiency, and adaptability.

II
DIAGNOSTIC NETWORK OPTIMIZATION

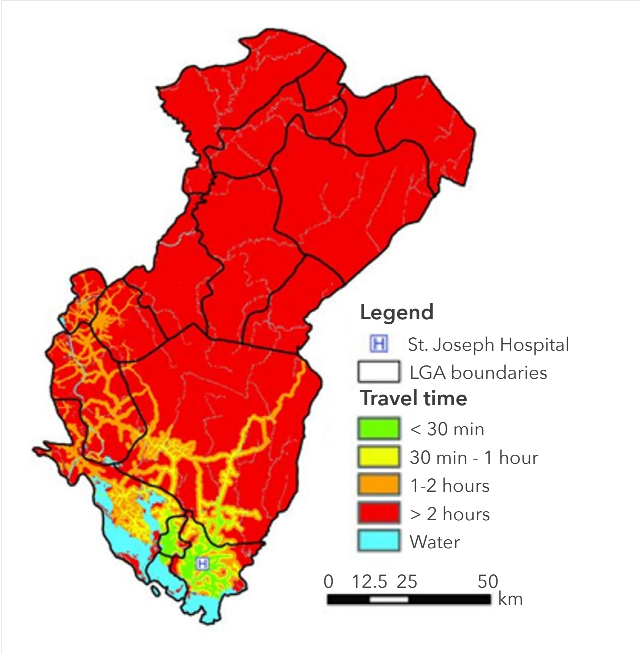
DNO is a specific form of geospatial analysis that looks at optimizing diagnostic network design. This section introduces geospatial analysis, DNO, and route optimization (RO). DNO builds upon geospatial analysis of a network to visualize potential network designs and compare trade-offs.

Geospatial analysis

Geospatial analysis is the compilation, display and analysis of data that have a geographic component, most commonly location information such as geographic information system (GIS) coordinates. Geospatial analysis has several key benefits for health systems planning, including better geo-targeting of health investments that can maximize the impact and equity of health interventions.

Methods used for geospatial analysis vary, from manual methods through to use of specialized mapping software solutions, often used in conjunction with statistical software.[18] Examples of the use of geospatial analysis related to diagnostic systems and healthcare include its application to improve access to point-of-care testing and cardiac care in Thailand, to assess the feasibility of mobile health interventions for tackling malaria in Uganda, to identify TB hotspots in Malaysia (data not shown), and to propose standardized geographical indicators of physical access to emergency obstetric and newborn care in low- and middle-income countries (Figure 2).[19]

Figure 2: Travel time from one basic emergency obstetric and newborn care facility (St Joseph Hospital) to the nearest comprehensive emergency obstetric and newborn care facility across local government area (LGA) boundaries in Nigeria.



Diagnostic network optimization

What is diagnostic network optimization?

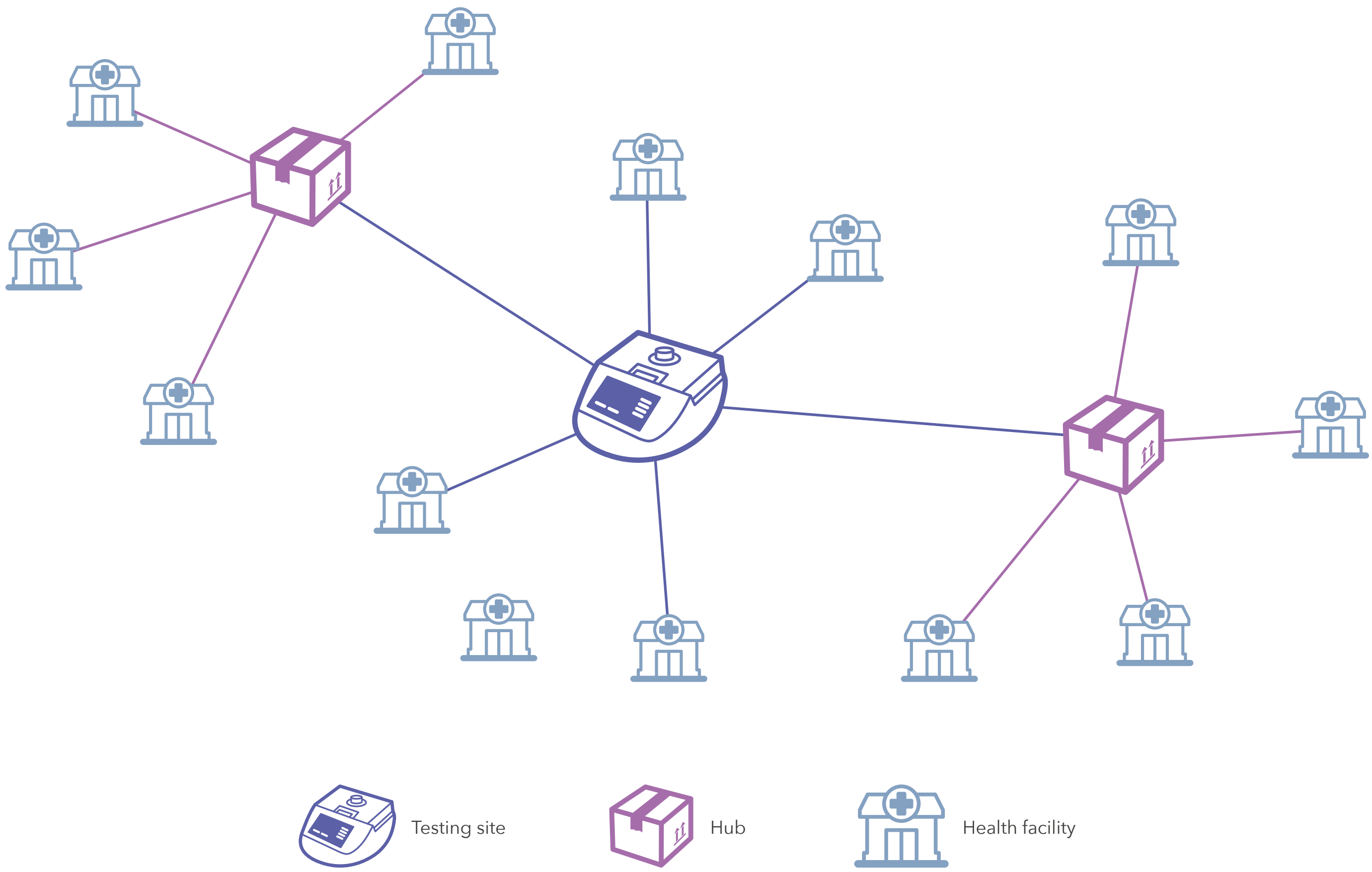
DNO is a **geospatial analytics approach** to analyse the current diagnostic network and recommend the optimal type, number and location of diagnostics and an associated sample referral network that enable achievement of national health goals, especially **greatest access** to services, while **maximizing the overall efficiency** of the system within applied constraints.

To do this, DNO provides insights around **testing demand, testing capacity and utilization, cost efficiency, and access to services**.

The benefit of DNO is that you can compare all these aspects at the same time, apply real life constraints to gain greater understanding of the key network drivers, **consider trade-offs** and use this information to make decisions on the best network design to achieve national targets.

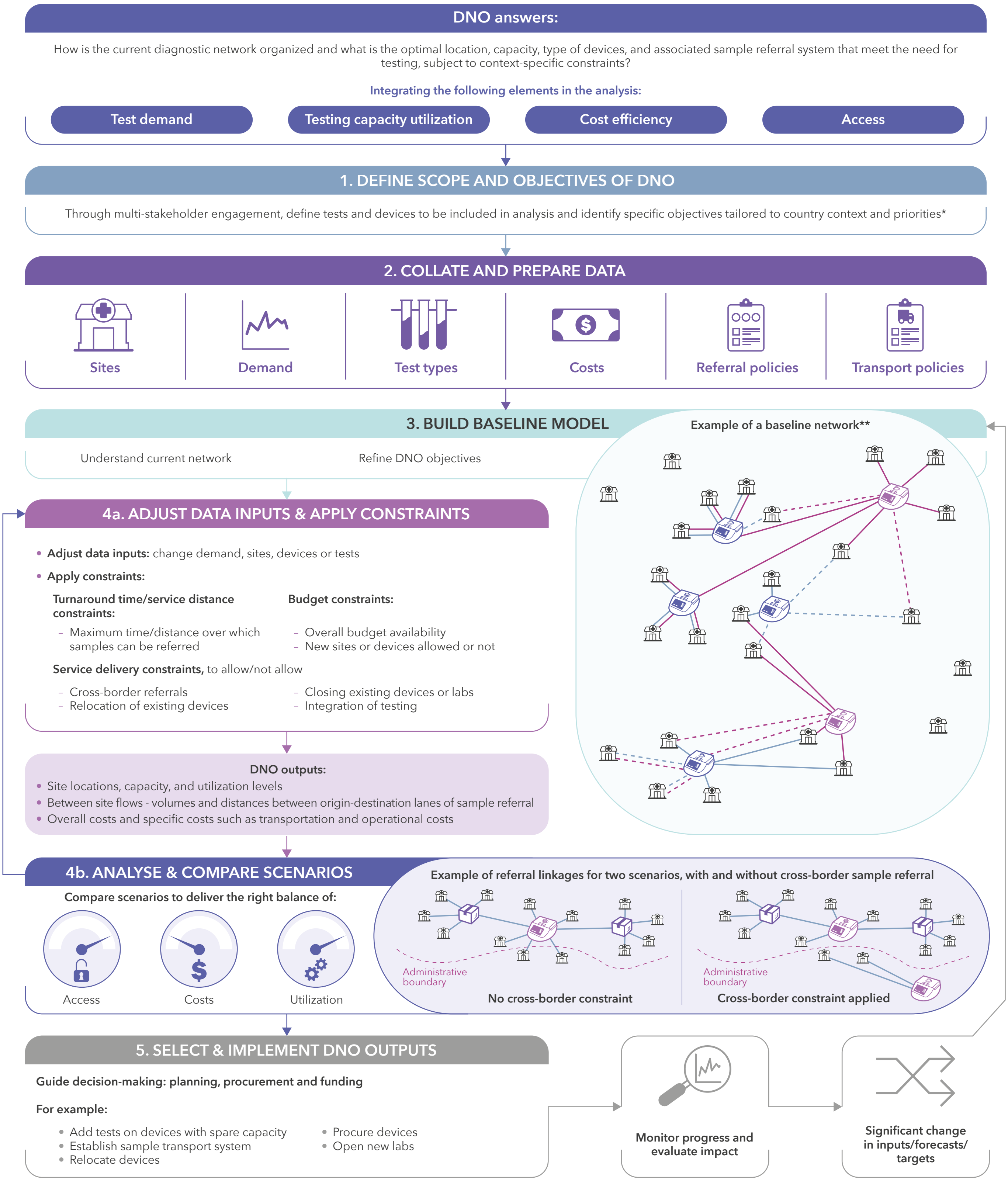
DNO comes from the practice of supply chain network analytics, which is commonly used across the commercial sector.[20,21]

Figure 3: Graphical representation of DNO-recommended network design, including optimal location of testing sites and linkage direct from referring health facilities or via hubs for pooling of samples during transport, where indicated, to improve efficiency.



The key components of a DNO are outlined in Figure 4 and further explained in Table 1, which shows the key steps and associated timings for a DNO analysis. Examples of specific questions that can be answered with DNO are also shown in Table 2.

Figure 4: Key components of DNO



* Generic scope statement to be customized based on country needs, e.g. inadequate capacity for scaling up both TB and COVID-19 testing, devices overburdened in urban areas and underutilized in rural areas, delays in sample referral from facilities in remote areas.

** This network has different devices and partly integrated sample referral. Referral linkage routes vary from fully functional, ad hoc or unreliable. Some health facilities are not currently linked to testing sites.

How can diagnostic network optimization be used?

DNO is an approach that helps you understand the diagnostic networks needed to achieve national health goals and targets. It helps you to identify areas for improvement in your diagnostic network design, examine alternative solutions to address the gaps, and consider trade-offs to enable selection of the preferred solution to implement. Application of DNO in the public health sector is growing, with examples of its use to inform diagnostic instrument placement,[22,23] sample transportation and referral mechanisms,[24,25] geographical prioritization[26] and integration of testing to meet the priority needs of a disease programme.[27]

DNO enables decision-makers to utilize data and build evidence to identify the most impactful interventions for:

- **better network visualization** facilitating enhanced coordination among programmes and partners and enabling better decision-making;
- **improving access** to diagnosis leading to reduced diagnostic delay and loss, resulting in more people diagnosed and treated; and
- **increasing network efficiency** resulting in reduced procurement and operating costs, enabling better prioritization of available resources.

DNO is a particularly valuable approach to support decision-making when 1) a network assessment shows significant gaps in service delivery, 2) procurement or placement of new devices or procurement of assays is being considered, 3) improving access to services is a priority, including through provision of point-of-care testing and/or establishment or enhancement of sample transport systems, 4) integration of a new test on existing devices is being considered, and 5) leveraging private sector capacity for scaling up access to testing.

In the absence of a DNO analysis, the following issues are often observed with diagnostic network planning:

1. Failure to establish diagnostic networks consistent with disease programme goals and aspirations for universal health coverage.
2. Lack of clear visibility into the gaps and opportunities of the current network.
3. Devices being over or underutilized leading to system inefficiencies.
4. Weak empirical basis for planning the needed investments in additional capacity.
5. Avoidable costs in procurement where new equipment might not be needed or due to expired overstocked test reagents or kits. Sub-optimal sample transport routes over long distances can also lead to higher recurring operational costs and network management complexity.

As part of DNO, trade-offs between access, utilization and costs, as well as broader programme strategy, have to be considered while comparing scenarios and selecting outputs for implementation. Figure 5 illustrates how trade-offs can be evaluated during the DNO process to identify the preferred solution for a given setting.

Figure 5: Example of trade-offs during DNO

TRADE-OFFS

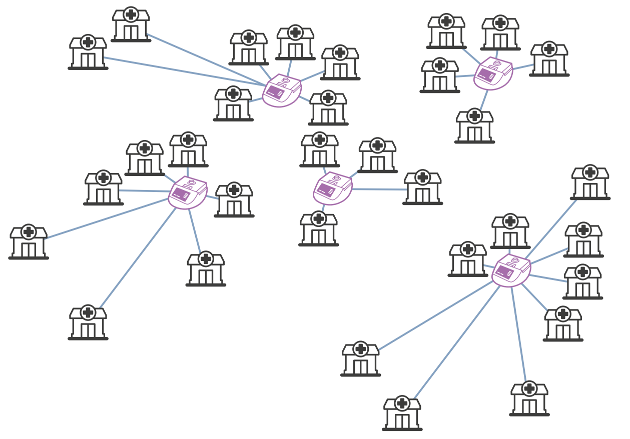
Case study: improving access to testing within a defined turnaround time while maximizing cost efficiency. Existing capacity in the network is underutilized and there is limited budget to invest in strengthening the system

What approaches can be considered to scale up access to testing within the diagnostic network?

DNO considers two different scenarios:

SCENARIO 1

Enhance use of available capacity within the network through sample referral. Do not allow model to consider new labs or devices.



DNO output

No new devices added, optimal allocation of sample referral flows to existing devices

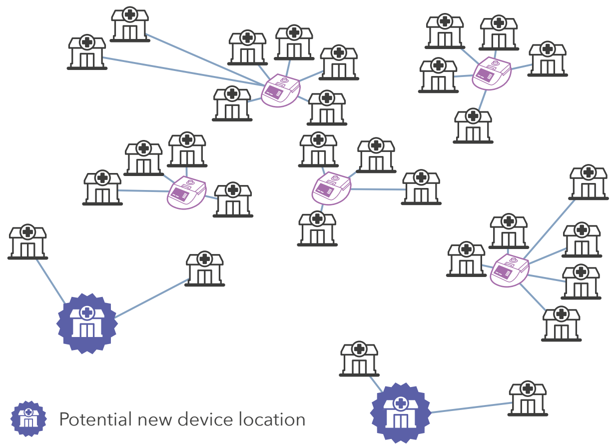
Pros	Cons
• Testing demand can be met with existing device footprint • Usually lower overall cost • Higher device utilization	• Some long transport legs, which may delay turnaround time and negatively impact access to care

SETTING-SPECIFIC FACTORS TO CONSIDER:

- Transport referral may be costly and difficult to sustain in challenging environments
- Turnaround time requirements for priority tests may not be achieved with a more centralized testing network in some settings

SCENARIO 2

Allow model to consider addition of new labs or devices if needed AND improve sample referral linkages.



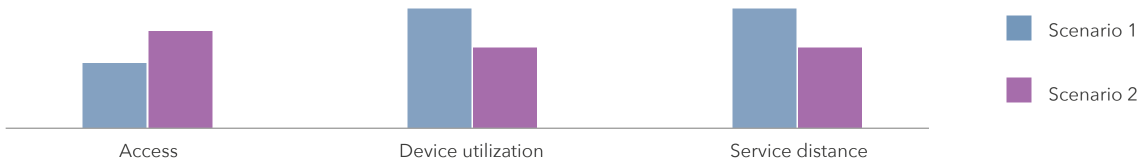
DNO output

Addition of two new devices at existing health facilities, plus optimal allocation of sample referral flows

Pros	Cons
• Reduced distance to testing sites, eliminating long transport legs	• May have higher overall cost in some settings • Lower device utilization

SETTING-SPECIFIC FACTORS TO CONSIDER:

- Additional budget and trained personnel required
- Additional devices may be preferred to enable on-site testing in remote settings
- Utilizing devices for multi-disease testing can lead to better use of available capacity



Decision-makers weigh up pros and cons for each scenario in their setting to decide on preferred scenario for implementation

Route optimization

What is route optimization?

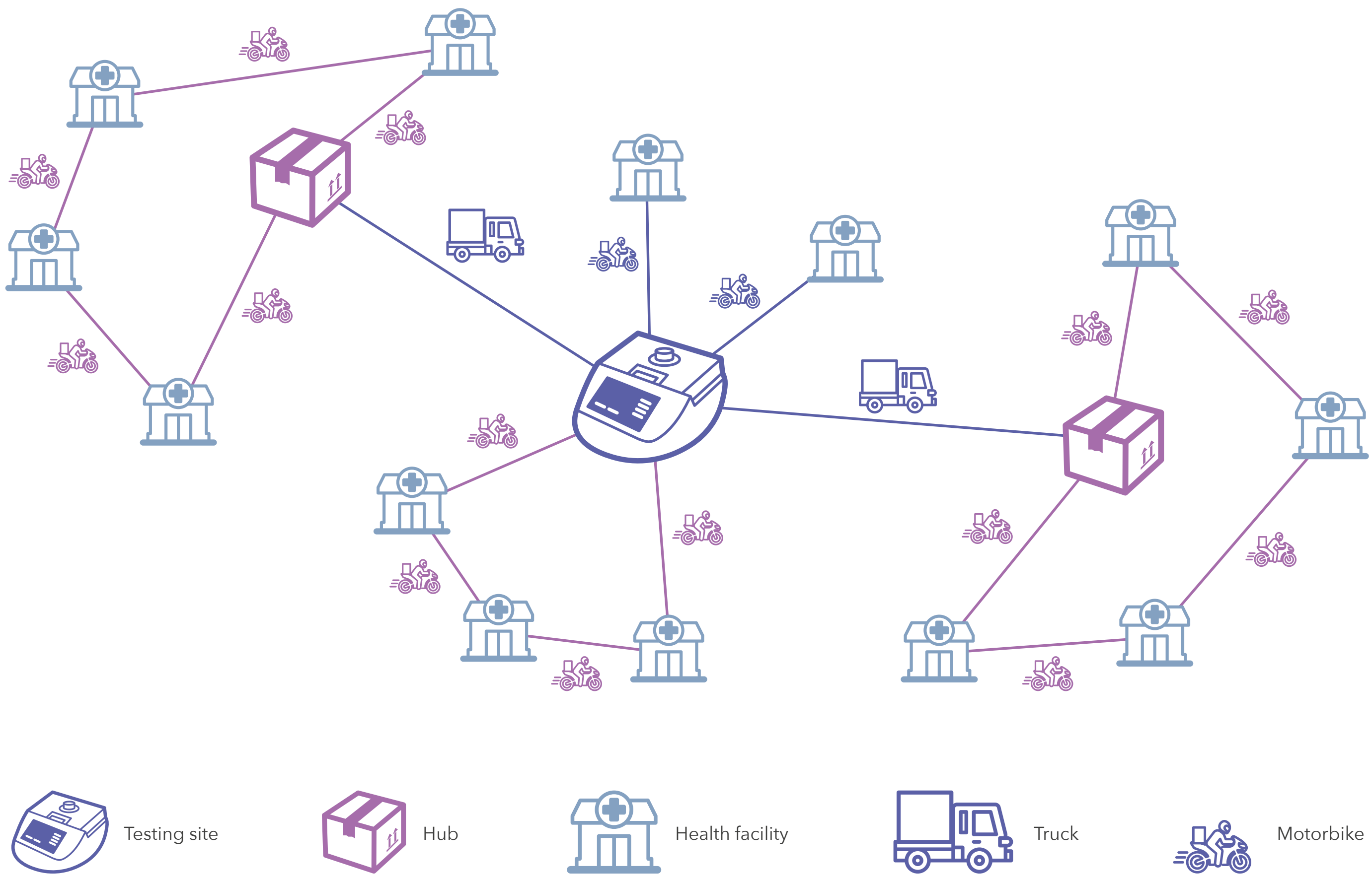
Route optimization (RO, also called route optimization analysis) is an approach to **define routings for vehicles within a diagnostic network**.

RO is closely related to DNO and often preceded by a DNO analysis. It uses many of the same data inputs and takes into account detailed information (including transport mode, speed, daily hours of operation and costs) to **recommend a detailed route plan for sample transportation**.

RO is usually carried out for a smaller geographic area than DNO, which may often be done at the national level. RO can incorporate constraints around the types of vehicles that are suitable for different parts of the country or levels of the health system, and regional differences in costs and transport speed.

Outputs of RO include direct versus multi-stop route allocation, detailed routes and associated costs, and estimation of the fleet (number of vehicles/workforce) required. These inputs can inform tactical and operational planning and budgeting. Figure 6 shows an example of RO to define the optimal sample transport route for the network.

Figure 6: Illustration of a route optimization model demonstrating multi-stop routes to collect samples from health facilities at hubs via motorbikes. Couriers transport samples from hubs to the testing site. Some health facilities closer to the testing site are best served by shipping samples directly to the testing site.



Guiding principles of DNO

In this section, we share some key principles when planning and conducting DNO, namely:

- **Country ownership** of the DNO and capacity to conduct and utilize the DNO analysis is critical to ensure its use is aligned with country goals and strategies, and that recommendations inform action.
- **Engagement with DNO within a multi-stakeholder framework:** DNO works best in a multi-stakeholder framework coordinated and led by Ministries of Health. As DNO can help bring planning and system efficiencies across siloes of disease programmes, agencies and departments, and the public and private sector, it is important to ensure that all programmes, sectors and partners are engaged, contribute relevant inputs and participate in implementing the recommendations.
- **Disease integration:** DNO can help analyse where diagnostic network capacity for one disease could be integrated with testing for other diseases to increase access and efficiency. However, when considering changes to testing services for one disease, experts and representatives from all related disease programmes should be involved in the analysis to ensure all priorities are adequately addressed.
- **Existing skill sets and the need for capacity building:** A multi-disciplinary team including strategic decision-makers, a data analyst/statistician and disease area experts is essential to conduct DNO. The extent of capacity building or external technical assistance required is influenced by multiple factors such as existing skill set, staff time available for training and conducting DNO, and overall timeline. While in-country capacity building might make DNO more sustainable and reduce long-term costs, DNO can typically be conducted more quickly when supported by an external technical assistance partner.
- **Iterative updates:** DNO is most effective when conducted in an iterative manner, embedded in planning/funding cycles, with models being updated as significant developments occur or with any changes in forecasted testing demand. Networks should be assessed or monitored annually, and repeat DNO analysis should be performed when significant gaps are identified. However, DNO is not intended for day-to-day operational planning, routine monitoring of activities, reporting of laboratory results or detailed budgeting.
- **Consideration of immediate and longer-term goals and budgetary requirements:** DNO is most effective when keeping in mind both immediate programmatic and budgetary constraints, as well as longer-term aspirational targets.
- **Alignment with national strategy:** As DNO is only one element of data-driven planning, investments in diagnostic systems need to be conducted at an appropriate time point, compared with other programme interventions and fully aligned with national disease and laboratory system strategies to achieve overall healthcare goals.
- **Development of operational plan:** Each DNO should be accompanied by the development and agreement of an operational plan that outlines how the recommendations will be implemented.

Expected impact of DNO

Over the past few years, countries have increasingly started adopting DNO and other forms of geospatial analysis to inform diagnostic strategy and planning, largely for TB and HIV, and to a limited extent for other diseases,[28] including COVID-19.

For example, in Kenya, DNO was conducted with an aim to increase access to TB testing and improve the efficiency of sample referral.[27] The findings from the DNO[29] have been used to inform Kenya's National Strategic Plan for Tuberculosis, Leprosy and Lung Disease 2019–2023,[30] inform the revision of Kenya's National Integrated SRS guidelines,[31] and have led to the development of a practical guide for county operational planning for integrated SRS,[32] which is already in use to strengthen referral systems in 15 counties and being scaled up countrywide. Recommended device capacity and locations have also been used to inform considerations for funding.

In the Philippines, DNO was conducted to optimize GeneXpert® capacity to better respond to the testing demands and reach the Philippine Strategic TB Elimination Plan: Phase1 targets.[33] DNO outputs informed updates of the Philippine Strategic TB Elimination Plan (PhilSTEP), the Laboratory Network Strategic Plan, and a donor funding request. The National TB Control Program and partners followed DNO results in procuring and allocating GeneXpert devices. Notably, implementing DNO recommendations could enable potential savings in device procurement.

III
DIAGNOSTIC NETWORK OPTIMIZATION: PLANNING AND PROCESS

DNO is a highly contextual and adaptable approach, with numerous use cases based on country-specific needs. While the core implementation framework can be universally applied, the process of conducting a DNO is driven by factors unique to each setting such as the overall purpose, objectives, scope, timing, and the skills and experience of key staff. A typical DNO exercise comprises the following key steps (Table 1):

Table 1: Key steps in a DNO analysis

Step 1 Define scope	Step 2 Collate & prepare data	Step 3 Build baseline & validate	Step 4 Run & compare scenarios		Step 5 Select & implement outputs
			Step 4a Adjust data inputs & apply constraints	Step 4b Analyse & compare scenarios	
Outputs Understanding of priorities and defined overall goal	**Outputs** Compiled, cleaned routine programmatic and survey data ready for entry into DNO tool	**Outputs** Validated baseline network model in DNO tool	**Outputs** Adjusted model for factors such as site locations, capacity, utilization, sample flow, overall costs	**Outputs** Customized optimization scenarios for current and future testing demand	**Outputs** Identification of preferred scenarios and operational plans for their implementation
Activities • Multi-stakeholder project team defines scope, priority questions and budgetary constraints • Additional information gathering on current network	**Activities** • Identify and collate data inputs, including existing country data e.g. routine programmatic data, previous geospatial data analysis • Clean, prepare and validate data for entry	**Activities** • Build digital representation of current diagnostic system including performance and costs, validate baseline and document validation criteria • Identify gaps and refine questions to be examined in future state scenarios	**Activities** • Adjust data inputs and apply constraints e.g. turnaround time/service distance, budget constraints	**Activities** • Run customized optimization scenarios using practical constraints • Assess impact of changing inputs/ constraints in different scenarios on diagnostic capacity, cost and patient access	**Activities** • Refine and re-run scenarios based on stakeholder feedback on priorities, and practical feasibility • Prepare implementation plan for selected outputs including activities, timelines, resources and responsibilities
Tentative duration for each step					
2-3 weeks	4-6 weeks*	4-6 weeks	4-6 weeks		3-4 weeks

* Depending on availability and quality of data and ease of data collation across various sources

The following sections provide a detailed description of each step including recommended activities, resource requirements and examples from previous DNO analyses. Key budgetary considerations for conducting a DNO exercise are explained in Annexure B.

Step 1 – Define scope

DNO is of most value when it is closely customized to the specific setting and context, including the nature of the current services and network. Budgetary constraints may be defined upfront for analyses that are intended to inform near-term investment decisions. When defining the scope, teams should also consider the types of interventions that would be feasible to implement. Examples of factors to be considered include whether existing laboratories or devices must remain as in the current network or can be relocated (or closed), whether cross-border sample referral is feasible, and whether integration of testing on multi-analyte devices can be considered. Where possible, private healthcare providers (both for-profit and non-profit or faith-based) should be taken into consideration on both the demand and supply sides.

Table 2 provides some examples of DNO scope in several countries. More country examples are available at https://www.finddx.org/dno/.

Table 2: Country experiences of implementing DNO highlighting the nature of scope and key questions adopted, outputs generated and impact on programmatic decision-making

DNO scope and objectives	Key questions	Outputs/recommendations	Impact
Philippines: scale up and improve access to molecular TB testing for diagnosis and drug resistance			
• Improve access to molecular TB testing to reach the 2022 NSP targets • Assess the need for additional GeneXpert devices under consideration for procurement, and recommend location to maximize impact • National-level analysis	• How much GeneXpert testing capacity will be needed to reach 2022 patient notification targets, and where should they be placed to achieve optimal access balanced with cost efficiency? • What would be the impact of a 20 km MAD cap between health facilities and laboratories on the need for new devices?	• Current demand met by existing 320 GeneXpert devices in the network, but some long referral legs • A total of 1100 GeneXpert devices recommended to achieve 2022 targets compared with 2500 estimated prior to DNO • Including a 20 km MAD cap would result in 23% more GeneXpert devices recommended compared with no distance constraint • DNO recommended one third of new devices should be placed outside the Big 3 regions* (planned allocation prior to DNO suggested all devices should be placed in the Big 3 regions)	• Informed procurement and placement of GeneXpert devices and design of associated SRS • Reduced the recommended number of GeneXpert devices to be procured when only TB testing was considered, and informed future integration of testing for HIV, HPV and SARS-CoV-2 • Enabled more equitable positioning of planned devices • Informed investment case for Global Fund funding request
Kenya: close the diagnostic gap for TB and integrate testing and sample referral systems			
• Scale up of molecular TB testing to reach NSP 2023 targets and inform integration of HIV EID testing using existing devices • Design an integrated SRS • Assess need for additional TB C/DST/LPA laboratories • Sub-national (county-level) SRS route optimization	• Number and location of GeneXpert devices and associated SRS design, to meet current and future TB and EID targets • Impact of integrating EID on selected GeneXpert instruments • Need for additional C/DST/LPA laboratories to meet current and future demand, and their location	• DNO recommended 450–500 additional GeneXpert sites by 2022 if projected demand level reached • Nationally, EID volumes would increase overall GeneXpert demand by ~40%, with large sub-national variations • Spare capacity exists on GeneXpert devices to accommodate EID testing in many regions, but additional devices may be warranted depending on demand • 4/7 proposed sites for TB C/DST/LPA testing were recommended to achieve capacity in a cost-efficient manner	• Used in preparation of Kenya National TB Strategic Plan 2019–23 • Facility-level placement lists (2021, 2023) informed Global Fund grant preparation • Informed the national integrated sample referral guidelines • Operational planning guide for integrated SRS used to guide budgeting and action planning countrywide

DNO scope and objectives	Key questions	Outputs/recommendations	Impact
India: scaling up capacity for detection of drug-resistant TB			
• Support scale-up of high sensitivity diagnostic tests and algorithms and universal DST • National level (with additional 3 state analysis) for 2020, 2021 and 2025	• Capacity, location and SRS linkages of C/DST/LPA testing sites to meet PMDT targets • Cost and impact of the Xpert XDR cartridge rollout to meet additional demand from private sector	• Current trajectory for C/DST testing is insufficient to meet targets • To meet peak testing demand in 2021, DNO indicates a need for 108–164 MGIT instruments spread over nearly all states. If equipment is procured to meet this demand, utilization by 2025 will be low (52%) due to reduced demand compared with 2021, suggesting consideration of private sector engagement to meet peak demand • LPA capacity is sufficient to meet baseline and 2021 demand, but additional capacity is needed by 2025 • Introduction of Xpert XDR testing in place of additional LPA sites is more expensive than LPA but reduces service distance and TAT	• Informed NTEP's procurement and placement plans for GeneXpert and Truenat devices, and consideration for Xpert XDR introduction (delays in implementing plans related to COVID-19 pandemic) • Provided a foundation for detailed operational planning and implementation of SRS initially in 15 states (supported by Global Fund)
Zambia: increase access to integrated HIV and TB testing			
• Improve access to EID and VL testing for pregnant and breastfeeding women and children through integration with TB testing • National-level analysis, including centralized and decentralized molecular testing devices, and TB, HIV, SARS-CoV-2 and HPV testing demand	• What is the most efficient diagnostic device mix to achieve point-of-care or near point-of-care testing for priority VL and EID testing, while maintaining or improving access to TB diagnostic services?	• GeneXpert is used only for TB, and baseline utilization is low. With integration of TB/EID/VL testing, distance travelled on average priority HIV samples decreased 7-fold to 12 km and the proportion tested on-site increased from 8% to 47% • Potential benefits to the TB programme: onsite testing increased to 66% (from 59%) alongside savings in annualized GeneXpert costs of US$ 910 451 (49%) through cost-sharing with the HIV programme • Total cost of combined testing programme can be reduced by 3% through integration and optimization	• Informed country operational plans and budgeting for integrated laboratory systems strengthening • Enhanced network visualization • Facilitated coordination among disease programmes and partners and enabled better decision-making
Zimbabwe: optimize sample referral for integrated TB and HIV testing			
• Ensure samples move in coordinated, efficient and sustainable way with accurate and timely results reporting • Optimize the placement of equipment through various factors including demand and move equipment according to optimization plan	• Which scenario is preferred? 1) optimized: sends samples from health facility to any current testing facility 2) Provincial: sends samples from health facility to district referral centre, then to provincial testing laboratory 3) Central level: sends samples from health facility to central testing laboratory • Where are all the hubs and spokes located?	• Hub and spoke model recommended to improve coordination, timeliness and reduce costs by consolidating various routes into one integrated system and ensuring consistent service to each location • Integrated sample transportation to be incorporated into the existing MOHCC structures using a provincial approach, managed through provincial district structures - local laboratory services will control sample movement to optimize efficiencies	• Rider routes start from the testing hubs, and collection points ("spokes") are visited twice weekly • Increased frequency of sample collection greatly reduced TAT as riders carry available results back to the collection points in the routine schedule • Integrated samples transport, with increased route planning, has greatly reduced costs compared with parallel uncoordinated systems • Reduced transportation time of the samples improved the integrity and quality of the results

C, culture; DNO, diagnostic network optimization; DST, drug susceptibility testing; EID, early infant diagnosis (of HIV); HPV, human papillomavirus; LPA, line probe assay; MAD, maximum allowable distance; MGIT, Mycobacteria Growth Indicator Tube; MOHCC, Ministry of Health and Child Care; NSP, national strategic plan; NTEP, National Tuberculosis Elimination Program; PMDT, Programmatic Management of Drug-Resistant TB; SRS, sample referral system; TAT, turnaround time; TB, tuberculosis; VL, viral load.

*Big 3 regions are: National Capital Region, Region 3 and Region 4A.

Universal DST is defined as all patients notified with bacteriologically confirmed TB who receive at least rifampicin resistance testing.

Step 2 – Collate and prepare data

Table 3 summarizes required data inputs and common data sources that countries might want to explore while collecting data for DNO. An example of a standardized data template is available at www.optidx.org.

Table 3: Data inputs and sources for DNO

Variable	Data requirement	Data sources
Sites	Location and name/unique identifier of health facilities from the Facility Master List (FML)	• District Health Information Software (DHIS) data and/or other health facility lists compiled by MoHs • Private sector health facility database • Testing capacity computed from site operating hours and device-test procedures
Tests	List of facilities with diagnostic devices included in the DNO scope Number of devices and tests currently done at each site Testing capacity, including device-test turnaround time	• LIS data, routine programmatic data on testing or research data
Demand	Health facility catchment area	• Census or electoral data, demographic and health survey data
	Disease prevalence at each health facility	• Disease programme reports
	Number of individuals tested (current state) or projected testing (future state scenarios) by health facility	• Testing volumes from LIS or testing registers (ideally including public and private sectors) • Estimates based on disease programme guidelines and diagnostic algorithms, and demographic and health system surveys
Referral and transport policies	Volume and referral flow of samples to and from health facilities, disaggregated by test type Modes and frequency of transport	• Data sources mentioned under 'tests' • Disease programme, partners or regional authorities implementing sample transport
Costs	Transport costs for sample referral	• Disease programme, partners or regional authorities implementing sample transport • Couriers or other third-party providers
	Device costs: capital and operating costs, HR Test costs: supplies, consumables, reagents Cost per test (calculated using the above for each test-device pair)	• MoH, partners and manufacturer or authorized service providers

HR, human resources, LIS, laboratory information system; MoH, Ministry of Health.

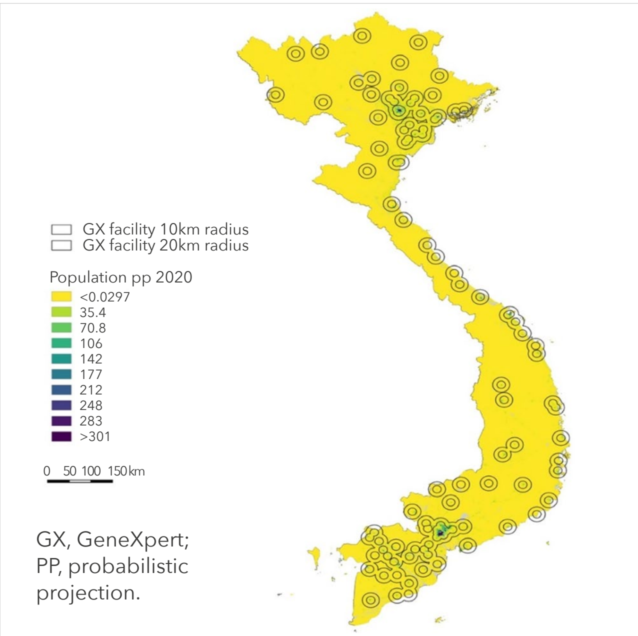
Step 3 – Build a baseline model

A baseline model helps assess the overall layout of the diagnostic network across the country (or region, if the scope is sub-national) and analyse the demand for testing and utilization of existing capacity. It helps identify gaps such as laboratories running over- or under-capacity or health facilities sending samples over long distances. A baseline model also helps compare the current state against the targets/goals defined as per current programme plans. For example, can the current demand for testing be served using the existing device footprint? Is diagnostic access equitably distributed, or are some areas underserved compared with others? This section provides examples of how baseline models can be visualized using outputs generated by various analytics tools.

Viet Nam

In July 2020, the National TB programme in Viet Nam completed a laboratory spatial analysis to expand and decentralize the GeneXpert diagnostic network and shift to GeneXpert as the initial diagnostic test for all presumptive TB patients. The analysis aimed to project the capacity (GeneXpert cartridges and modules) needed to replace microscopy with GeneXpert testing, analyse the population coverage and accessibility of the GeneXpert diagnostic network, and test several scenarios for expansion of the number of existing GeneXpert facilities. Figure 7 shows the location of existing GeneXpert facilities (n=125) in Viet Nam and a 10 km and 20 km radius around the facility.[i]

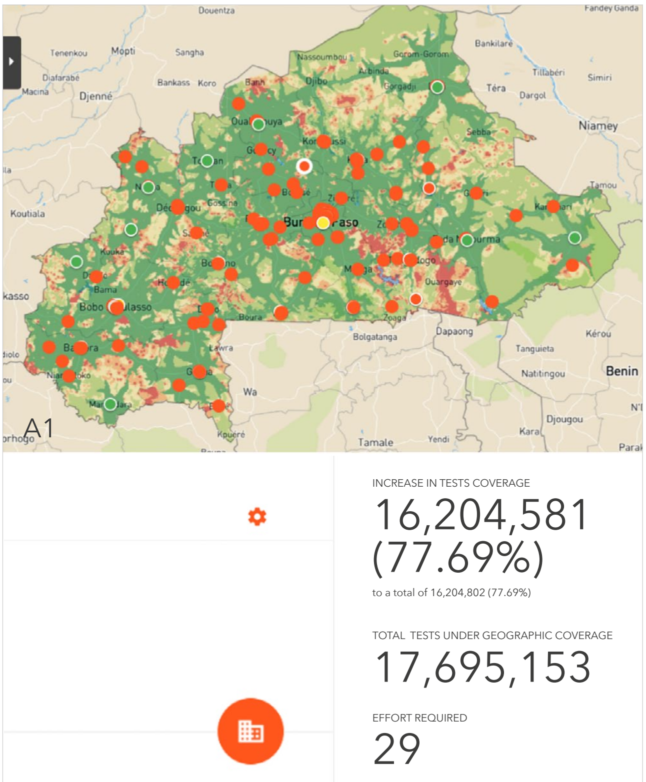
Figure 7: Distribution of GeneXpert testing sites in Viet Nam mapped as a part of laboratory spatial analysis to support shift to GeneXpert as the initial diagnostic test. Population coverage within 10 and 20 km from sites was calculated using the Zonal Statistics tool and mapped on QGIS 3.6.



Burkina Faso

As a part of the LabMaP program led by ASLM in Burkina Faso, the proportion of population residing within 2 hours of an HIV viral load (VL) laboratory was mapped and analysed using QGIS and Planwise (See Figure 8). The system recommended 27 laboratories for upgrades, which would help maximize population coverage of HIV VL testing within 2 hours of driving distance, from 59% at baseline to 78% in the optimized scenario.

Figure 8: Mapping of population in Burkina Faso residing within 2 hours of driving distance from an HIV VL testing laboratory, conducted as a part of the LabMaP program led by ASLM. Areas highlighted in red show low coverage compared with areas that have optimized coverage depicted in green.



[i] Population distribution is estimated for 2020, adopted from worldpop.org. Population distribution data were not available for several islands and could not be included in the analysis.

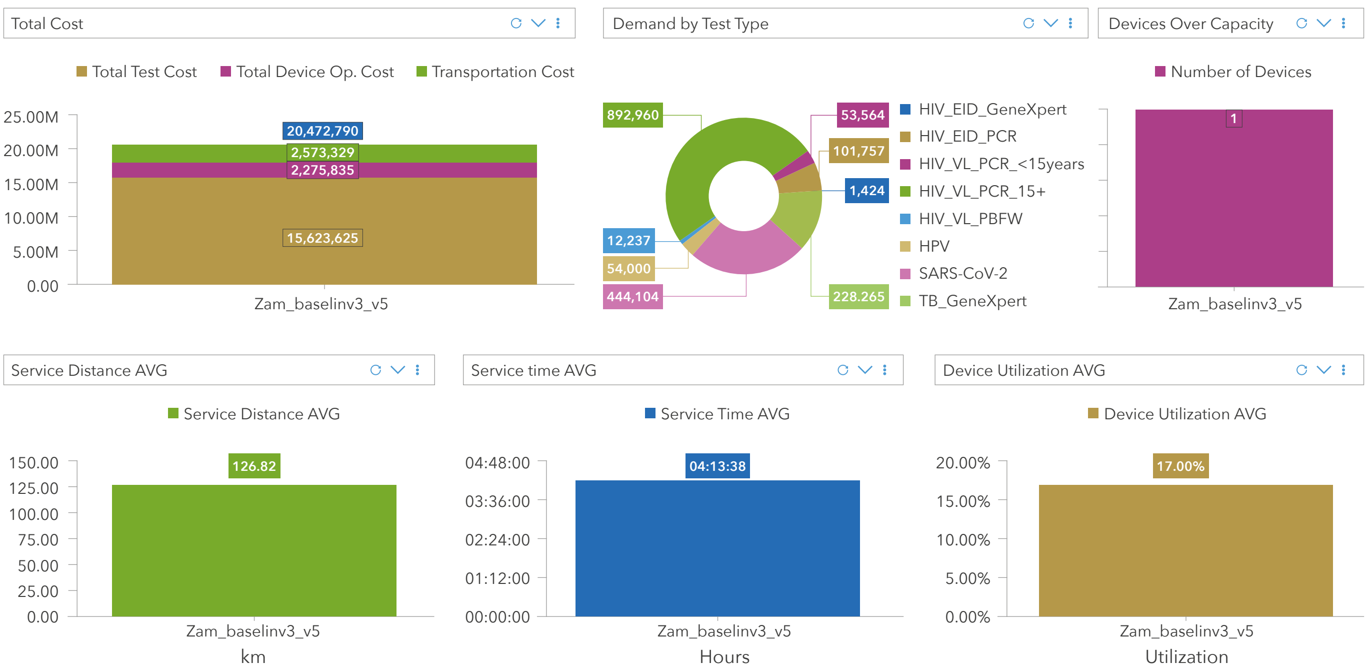
Zambia

Zambia modelled the integration of priority HIV VL and early infant diagnosis with TB testing on GeneXpert platforms, using OptiDx, a web-based open access platform for network optimization. The analysis predicted the capacity needed for the integrated testing approach and demonstrated that the approach would increase access to TB and HIV testing at reduced costs for both programmes, compared with the baseline (where TB tests were only conducted on the GeneXpert network).

A digital representation of the baseline diagnostic network was created using historical 2020 testing demand, referral linkages, testing sites, platforms, and costs for TB and HIV testing respectively, and compared against various optimized scenarios. Figure 9 shows the summary dashboard view of the baseline model in OptiDx, including total test volumes, average device utilization, average service distance and time travelled by samples in the network.

Figure 9: Summary of the current state (baseline) diagnostic network for TB and HIV in Zambia showing network performance for various parameters, generated using OptiDx, an open-access software to conduct DNO and RO.

The DNO in Zambia aimed to model integration of priority HIV VL and EID with TB testing on GeneXpert platforms. Top row (L-R): 1) **Total cost** of operating the network including total test cost, total device cost and transportation cost; 2) **Demand by test type:** slices of pie chart depicting number of tests required by each test type; 3) **Devices over capacity:** number of devices running at over 100% testing capacity per day, potentially leading to testing backlog and delays. Bottom row (L-R): 4) **Service distance AVG:** average distance over which samples are being transported from health facilities to laboratories; 5) **Service time AVG:** average time taken to transport samples from health facilities to laboratories; 6) **Device utilization AVG:** average utilization of devices based on testing volumes as a proportion of total testing capacity. This summary view presents results across all test types and at an overall network level. Disaggregated views by each test type and province were also generated.

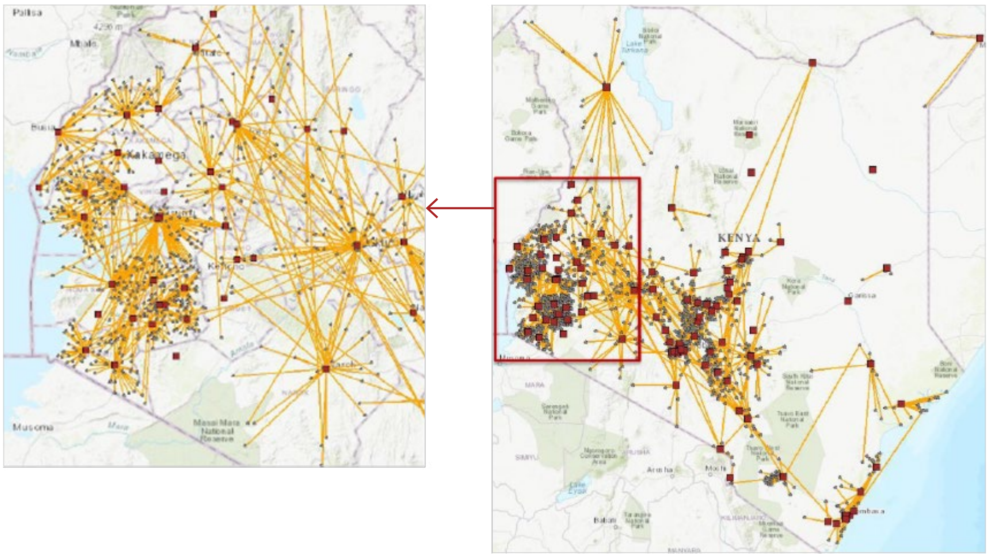


AVG, average; EID, early infant diagnosis (of HIV); Op, operational; PBFW, pregnant and breastfeeding women; PCR, polymerase chain reaction; VL, viral load; HIV_EID_GeneXpert: early infant diagnosis conducted on GeneXpert devices; HIV_EID_PCR: early infant diagnosis conducted on PCR devices, HIV_VL_PCR_<15years: HIV viral load tests conducted on PCR devices for population under 15 years of age; HIV_VL_PCR_15+: HIV viral load tests conducted on PCR devices for population above 15 years of age; HIV_VL_PCR_PBFW: HIV viral load tests conducted on PCR devices for pregnant and breastfeeding women; HPV: total number of HPV tests; M, millions of US$; SARS-CoV-2: total number of COVID-19 tests; TB_GeneXpert: total number of TB tests on GeneXpert devices.

Kenya

In Kenya, the Supply Chain Guru X™ supply chain modelling software and DataGuru software were used to model the TB sample referral network in the country, as part of a larger TB DNO analysis. Figure 10 shows Kenya's TB sample referral network at baseline (in 2017) generated using these tools. This helped identify key issues such as long transport legs in the north-eastern provinces contributing to testing delays and ad hoc referral flows, and led to recommendations for establishing demand-driven sample referral to minimize service distance.[34]

Figure 10: A partial snapshot of the TB sample referral network in Kenya based on data from 141 GeneXpert sites in 2017, generated using Supply Chain Guru V.8 (Coupa Inc). Sites with long transport legs can be seen in the north-east and eastern regions of the country.



Step 4 – Run and compare scenarios

Once a baseline model has been developed, DNO helps create various versions of the model referred to as scenarios i.e. alternative potential configurations of the diagnostic network, as outlined in Figure 5. Different scenarios can be created by adjusting factors such as site locations, capacity, utilization, sample flow, and applying constraints such as a maximum turnaround time (TAT) or maximum allowable distance (MAD) (Step 4a). Analysing these scenarios helps visualize and compare the impact and cost efficiency of the potential network changes in addressing specific objectives such as increasing access to testing or introducing a new test. Critical appraisal of outputs from initial scenarios by stakeholders will also lead to insights that help refine the scenarios; this iterative process is a fundamental aspect of DNO to develop the most appropriate interventions.

Table 4 provides an illustrative list of scenarios that might be considered, along with the programmatic needs that might be addressed by each scenario.

Table 4: Example DNO scenarios and country examples

Parameters	Potential changes	Relevance for programme analysis/planning	Country examples*
Inputs			
Sites	Allow/restrict new sites or relocation	Adding new testing sites or relocating devices between existing sites to increase/maximize current capacity. Costs of new sites or relocation are factored into the analysis.	*Multiple countries:* relocation of existing sites was challenging where outside administrative boundaries or where there are sophisticated laboratory infrastructure requirements.
Demand	Increase or decrease in demand between two or more time points	Demand for different tests can fluctuate due to changes in disease incidence, testing algorithms and population growth. Building scenarios based on various demand assumptions can help plan optimal capacity, accounting for uncertainty of future projections.	*India:* C/DST demand was expected to peak in 2021 and subsequently fall given reduction in expected patient notifications. This informed DNO recommendations (e.g. leveraging private sector versus public sector procurement to meet needs).

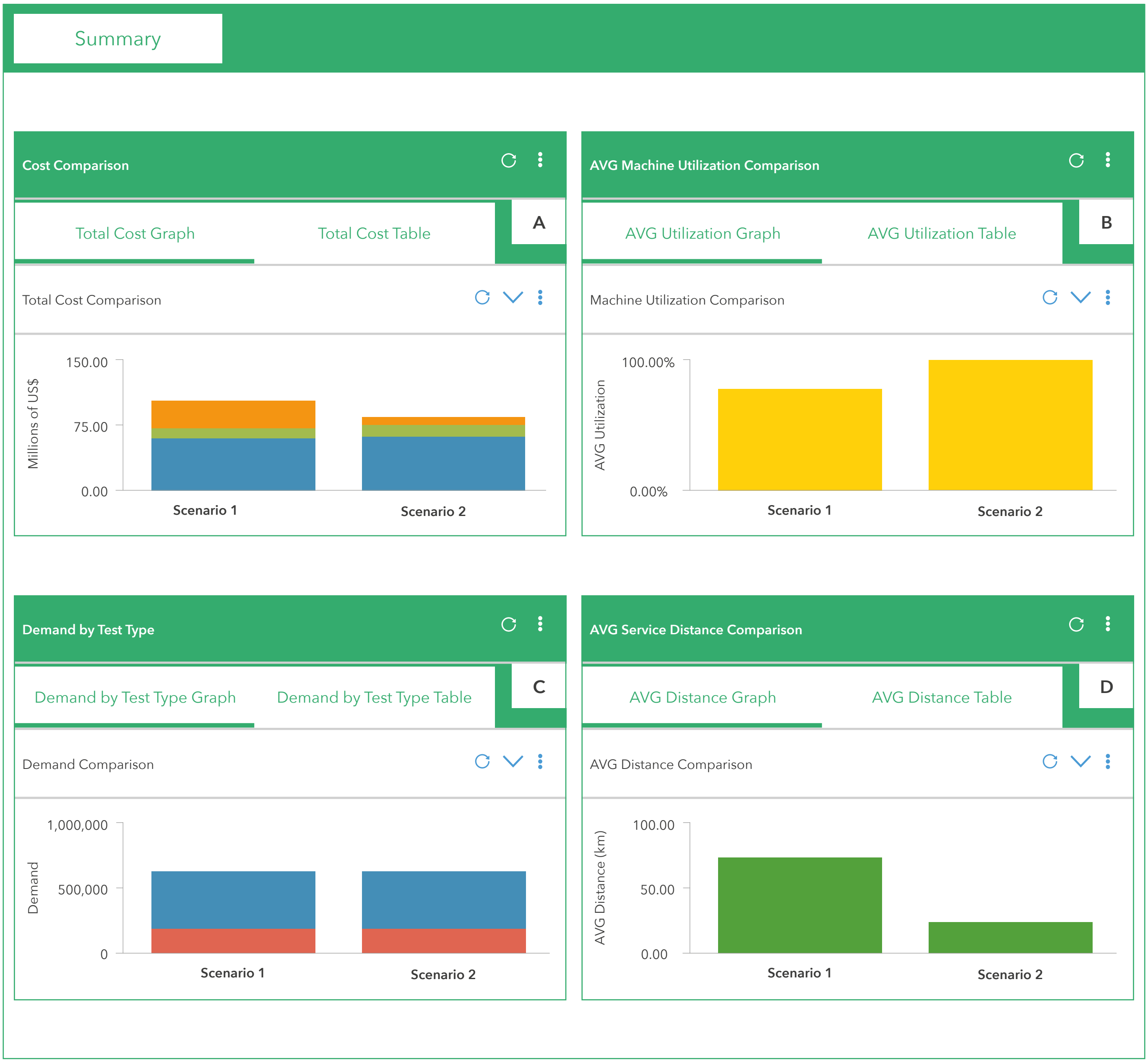
Parameters	Potential changes	Relevance for programme analysis/planning	Country examples*
Tests	Add a new test to an existing device	Integration of new tests on multi-disease platforms may be considered to improve access to services and existing testing capacity. Alternative strategies may consider more highly centralized or more decentralized (point-of-care) testing or a mixed approach, based on the local context.	*Zambia* assessed feasibility of integrating HIV VL testing for pregnant and breastfeeding women and children and EID testing using existing GeneXpert devices previously used for TB testing, together with continued use of centralized testing capacity.
	Increase or decrease in number of devices or number of shifts	Can existing devices meet current/future testing demand within the shortest TAT? Or are new devices needed and where should they be placed? Is it feasible to implement additional shifts at certain testing sites? Can private sector capacity be brought into the network?	*Philippines* had adequate capacity to meet current demand. DNO recommended the optimal number and candidate locations for adding GeneXpert devices to meet future demand.
Costs	Increase or decrease cost per test	Various factors affect the cost per test. Changes in consumable costs e.g. through reagent rental agreements, or change in transport costs can be explored in different scenarios to determine effect on the DNO-recommended network design.	*Multiple countries:* fluctuations in exchange rate for imported reagents and supplies can have significant impact on local costs. Transport costs are impacted by inflating fuel costs.
Constraints			
Access	Impose MAD or time between health facilities and laboratories	Incorporating result TAT or maximum referral distance restrictions into capacity planning can help ensure access goals are met, for example in hard-to-reach areas.	*Philippines:* though current testing capacity was adequate, additional 23% of GeneXpert devices recommended once 20 km MAD was applied to improve result TAT, compared with no service distance restriction. *Zambia:* imposed MAD to force facilities to utilize more expensive devices that were closer than referring tests to cheaper centralized laboratory to improve access and TAT.
Addition of new laboratories or devices	Allow/restrict new sites, laboratories or new devices	Budgetary constraints that restrict the addition of new sites or devices need to be considered.	*India:* DNO included a constraint to allow new devices only at existing laboratories for C/DST/LPA testing, due to high infrastructure cost for adding and maintaining new laboratories.
Sample flows	Increased referral frequency, include alternative transport modes, allow or restrict inter-district routes, add/remove hubs	An optimized sample referral network can help to make better use of available network capacity. Contextual factors need to be accounted for including appropriate modes of transport or preferred routes due to terrain or security reasons.	*Kenya:* used DNO to build an optimized SRS model using different referral frequency for easy and hard-to-reach regions, and selective application of cross-border referrals where feasible.
Budget	Budgetary constraints may involve restricting addition of new sites or devices in scenarios, or comparing overall cost of different scenarios	Funding requests (domestic or donor related) may have an overall budget cap, or may have restrictions placed on capital investment.	*Kenya:* explored a scenario incorporating use of additional shifts at selected GeneXpert testing sites to increase capacity without device procurement.

C, culture; DST, drug susceptibility testing; DNO, diagnostic network optimization; EID, early infant diagnosis (of HIV); LPA, line probe assay; MAD, maximum allowable distance; SRS, sample referral system; TAT, turnaround time; TB, tuberculosis; VL, viral load.

*Detailed case studies available at https://www.finddx.org/dno/.

Figure 11 shows how scenarios can be compared using display outputs generated in OptiDx, based on data from the Kenya DNO analysis (outputs modified for training purposes). Using the 'Compare Outputs' function in OptiDx, users can assess the impact of potential network configurations between two scenarios on access to testing and the cost efficiency of the network. In the first scenario, TB tests are conducted on GeneXpert platforms and HIV tests on centralized PCR devices. In the second scenario, the model was allowed to use the GeneXpert network to meet HIV test demand along with TB test demand. A high-level summary comparison view showed that integrated testing could help achieve cost savings for the integrated network (panel A), maximize device utilization (panel B) and significantly reduce service distance for sample referral thus making testing more accessible (panel D).

Figure 11: 'Compare scenarios' view in OptiDx to assess differential impact of two scenarios on total costs, device utilization, total demand met and average service distance for sample referral. Scenario 2 which depicts an optimized, integrated network could significantly reduce service distance for sample referral and improve device utilization at a lower total cost of operating the network compared with scenario 1.



Scenario 1: TB tests are conducted on GeneXpert platforms and HIV tests on centralized PCR devices. Scenario 2: optimized model allowing HIV demand to be served by both GeneXpert and centralized PCR devices. AVG utilization: average utilization of all devices based on testing volumes as a proportion of total testing capacity. AVG service distance: average distance over which samples are transported from health facilities to laboratories (in km).

While building scenarios one can either allow the software to freely recommend changes to the network design or apply specific constraints, based on detailed programmatic requirements. For example, a model might recommend closing certain testing sites in remote areas and serving those health facilities through SRS, as this may be cheaper than the running costs for the testing site. However, it might not be feasible to implement SRS in certain sites due to difficult terrain or seasonal flooding. In that case, constraints can be selectively applied to account for the local context. Multiple scenarios can be run where key inputs and assumptions are subject to uncertainty (e.g. future demand), for example in low, medium and high testing volume projections. These models should be updated once actual data become available.

Step 5a – Select outputs

At this step, all relevant stakeholders should review the DNO outputs and determine the network design that balances the utilization of available testing access (service distance and TAT), cost and utilization. The weighting of these elements will depend on the local context and priorities, incorporating the broader disease programme and overall health strategy. For example, transfer of all testing to decentralized devices may incur a higher per-test cost, require addition of new devices to the network (with sustainability to be considered), but enable greatest access to services. However, an alternative scenario that uses available capacity on centralized platforms near to referring health facilities, but decentralized devices where service distance to centralized testing sites prevents rapid TAT may result in a lower overall cost, fewer additional devices and a more sustainable device footprint, while enabling an adequate TAT/service distance. DNO allows stakeholders to adjust inputs and constraints and weigh up different elements of each scenario to identify the preferred solution for their context.

Step 5b – Implement, monitor and update

Based on the outputs shortlisted in Step 5a, different interventions might be needed to implement the recommendations. For example:

- funding considerations with donors/government agencies;
- developing guidelines to implement integrated disease testing or a new sample referral network;
- assessing training needs and organizing capacity building workshops for healthcare workers to implement the new guidelines;
- procurement of additional instruments, vehicles for sample transport, or contracting courier services;
- establishing memorandums of understanding with partners to implement interventions such as leveraging private sector testing capacity; and
- creating micro-plans for relocating devices or rerouting sample referrals between selected sites.

Detailed workplans and budgets need to be created for interventions based on the prioritized activities. Depending on the nature of activities to be implemented, interventions may be deployed in selected regions followed by a wider scale-up. The implementation and impact of DNO outputs is contingent upon external factors such as the success of funding requests and the evolving priorities of health departments. To ensure DNO is sustainable and responsive to on-the-ground change, it is crucial to track and assess the extent to which recommendations translate into action.

It is also essential to continue monitoring the performance of the diagnostic network following a DNO analysis. Network performance can be monitored at a national and laboratory/device level with indicators such as testing capacity compared with testing need (demand), testing coverage and TAT. If gaps are identified during monitoring, countries should investigate the root cause and apply process improvements. An updated DNO analysis may be warranted where there are significant gaps in or inequitable distribution of capacity, coverage and/or TATs, which are not addressed by process improvement efforts. The network model should be periodically updated, particularly when assumptions and inputs undergo considerable change (for example, due to the impact of the COVID-19 pandemic). Investing in building local capacity to conduct DNO and making user-friendly accessible tools is crucial for ensuring sustained use of DNO.

IV
DNO SOFTWARE TOOLS/APPROACHES

Various software tools, including open source, open access and commercially available proprietary solutions, are available to support different geospatial analysis, DNO and RO requirements. Table 5 provides an illustrative list of these tools and their key functions. Selection of the appropriate software is based on a number of factors including tool functionality relative to the intended scope of analysis, the skills and proficiency of the users, cost and partner support. Further details on each tool can be accessed via the links in the product name.

Table 5: Key features and functions of DNO tools

Product name	Specific to diagnostics	Data collation	Data visualization	Geospatial analysis	Network optimization	Route optimization	License cost
OptiDx	✓	✓	✓	✓	✓	✓	
Supply Chain Guru		✓	✓	✓	✓	✓	$
PrimeThought		✓	✓	✓	✓ (partial)	✓	$
RoOT		✓	✓	✓	✓ (partial)	✓	$
AccessMod 5		✓	✓	✓	✓ (partial)		
Equitarg		✓	✓	✓	✓ (partial)		
LabMaP-Planwise	✓	✓	✓	✓	✓		
Excel, Tableau, Power BI		✓	✓	✓ (partial)			$ (partial)
ArcGIS		✓	✓	✓	✓	✓	$
QGIS		✓	✓	✓	✓	✓	
USAID TB Lab Spatial Analysis*	✓	✓	✓	✓	✓		
CDC DNO Network assessment package	✓	✓	✓ (partial)				

✓ (partial) Denotes partial capability $ (partial) Denotes some paid features

* USAID TB Lab Spatial Analysis exercises use a combination of ArcGIS, QGIS and Excel-based support software.

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ANNEXURE A

Diagnostic network optimization – Glossary of terms and definitions

Term	Definition
Access	Access is the measure of diagnostic services within reasonable reach of those who need them. For DNO, the focus is on physical accessibility of services and equitable distribution to the population in need. However, there are also other key social and behavioural dimensions of service accessibility.
Adaptability	Adaptability measures the ability of a diagnostic network to adjust to changing needs, whether the result of adding a disease programme, new technology, specimen type or disease outbreak.
Baseline or current state	Baseline or current state depicts the diagnostic network as it currently functions. It includes the location and capacity of testing sites, device utilization and referral linkages and sample flows between referral health facilities and laboratories or testing sites. Analysis of the baseline aims to identify gaps that can be addressed through optimization scenarios.
Constraints	Constraints refer to limits placed on variables in the process of optimization. In DNO, constraints could include capping the total number of instruments, number of testing sites, actual equipment capacity, total costs, or ability to refer samples across administrative boundaries within a country.
Device/equipment capacity	Device (or equipment) capacity is the instrument's maximum theoretical testing capacity (i.e. maximum number of tests that can be conducted in a given time period). Actual available equipment capacity should take into account the human resource availability and operational conditions, and is usually less than the theoretical maximum capacity. Equipment capacity is used as the denominator when calculating device utilization.
Diagnostic network optimization	A geospatial analytics approach to analyse the current diagnostic network and recommend the optimal type, number and location of diagnostics and an associated sample referral network that enable greatest access to services, while maximizing the overall cost efficiency of the system within applied constraints.
Efficiency	Efficiency is the comparison between health system outputs and resource inputs (e.g. human resources, infrastructure, equipment). For DNO, outputs are the number of tests conducted (within a defined turnaround time) and device utilization.
Hubs	A hub is an intermediate location in the sample referral network where specimens may be pooled after leaving the referring health facilities on the way to the referral laboratory. Hubs may provide certain testing services and offer quality checks and documentation points for specimens.
Integrated testing	Integrated testing or multiplexing uses the same device platform (also known as polyvalent testing platforms or multi-analyte analysers) for several assays and/or across diseases. It can lead to more efficient testing services at a reduced cost. Further, testing integration can help to simplify and streamline other systems, such as specimen referral, human resources and quality assurance.
Mapping	Mapping refers to geospatial visualization of networks supplemented by other data, namely testing demand, testing capacity and referral linkages between locations; however, importantly, mapping is not synonymous with "network optimization."
Route optimization	Route optimization (also known as vehicle route optimization) is the process of determining the most efficient routing for a sample referral system. It accounts for a range of factors such as the number and location of referring health facilities and laboratories, frequency, and size of shipments.

Term	Definition
Scenarios	Scenarios (also referred to as future state or optimization scenarios) are potential changes to the network that can be explored using DNO. Scenarios may include changes in inputs and assumptions related to the network. Common examples include changes in testing demand, relocation or addition of tests or devices, or establishing or changing referral linkages.
Sites	Sites are the physical locations within a diagnostic network, and may be laboratories or testing sites, hubs or referring health facilities where specimens are collected from an individual requiring a diagnostic test (also known as specimen collection points). Where diagnostic testing is offered on-site, the specimen collection site and laboratory or testing site may be located at the same physical location.
Turnaround time	Turnaround time (TAT) is the time between specimen collection and return of the results to the facility or client and use of results for treatment initiation or clinical management. Intermediate measures of TAT, including sample transport TAT and testing (within laboratory) TAT are important to understand functioning of service delivery.
Utilization	The level of equipment usage within a set time period compared with the maximum device capacity within the same period, e.g. actual number of tests conducted as a proportion of the total number of tests that could have been conducted on a particular device.

DNO, diagnostic network optimization; TAT, turnaround time.

ANNEXURE B

Budgetary considerations for conducting diagnostic network optimization

Term	Budgetary considerations
Planning and coordination	• Workshop for stakeholder engagement, planning and budgeting for DNO • Technical workshops for defining DNO scope, presentation and feedback of preliminary findings, and final reporting*
Data collection	• HR and local travel to compile and clean data
Software	• License costs (where applicable)
Training and capacity building	• Training and coaching sessions for use of DNO software (where analysis to be conducted by country team)* • Printing and dissemination of training materials
Human resources	• HR and associated costs for in-country core DNO team. May include project coordinator, data analyst and subject matter experts
Technical assistance	• Partner costs to conduct analysis, and/or provide training and capacity building for country team to perform DNO • Costs may include consultancy fees and travel
Implementing DNO recommendations	• Workshops/HR to develop budgets and action plan to implement DNO recommendations • Budget for implementation may include device procurement, device relocation, HR, sample referral supplies, transport costs, infrastructure upgrades, and reagents and supplies

DNO, diagnostic network optimization; HR, human resources.

* Costs will vary based on format of workshops, training and coaching (remote, in-person or mixed approach).