



Decision Support Tools for Malaria Prevention and Treatment

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ABBREVIATIONS

ACT	artemisinin-based combination therapy
APE	<i>agente polivalente elementare</i> (community health worker)
DDMS	Disease Data Management System
DSS	decision support system
DST	decision support tool
GIS	geographic information system
GPS	Global Positioning System
inSCALE	Innovations at Scale for Community Access and Lasting Effects
IPTi	intermittent prevention and treatment of infants
IRS	indoor residual spraying
ITN	insecticide-treated net
IVCC	Innovative Vector Control Consortium
LiST	Lives Saved Tool
LLIN	long-lasting insecticide-treated net
MDAST	Malaria Decision Analysis Support Tool
MDSS	Malaria Decision Support System
MEI	Malaria Elimination Initiative
NGO	nongovernmental organization
PROMPT	Primaquine Roll Out Monitoring Pharmacovigilance Tool
QGIS	Quantum Geographic Information System
RACD	reactive case detection
RDT	rapid diagnostic test
SDSS	Spatial Decision Support System
SIS-MA	Sistema de Informação de Saúde de Moçambique para Monitorização e Avaliação
UN	United Nations
WHO	World Health Organization

EXECUTIVE SUMMARY

Introduction

Malaria-endemic countries have experienced a significant decline in malaria burden in recent years, and they are relying on strong health management information systems to provide good-quality data to track progress and measure program achievements. The DHIS 2 software platform has been rolled out in several countries to collect, validate, report, analyze, and present aggregated statistical data using a dashboard for the health system's operations. However, DHIS 2 falls short in providing guidance to program managers on priority actions and the potential impact of those actions. The United States Agency for International Development (USAID) and the United States President's Malaria Initiative (PMI) have identified the goals of malaria prevention and treatment. To support those goals, the USAID- and PMI-funded MEASURE Evaluation conducted a literature review to identify existing decision support tools, synthesize their strengths and weaknesses, and assess gaps.

Methods

The research team searched databases of peer-reviewed and gray literature for decision support tools for malaria control. The reference databases and digital libraries included MEDLINE (via PubMed), Google Scholar, and SCOPUS. In addition, the team performed online searches of websites and online publications to identify decision support tools developed by specific organizations. The following search terms were used in various combinations: “decision tools,” “decision-making tools,” “decision support tools,” “malaria,” “vector-borne disease,” and “mosquito-borne disease.” The research team included literature published in English only between 2006 and 2017; however, a few publications outside of this period were included in areas where the literature is thin.

Key Findings

The research team found 11 decision support tools related to malaria prevention and treatment. Each of these tools focuses on different interventions and outcomes, with some tools focusing on multiple interventions and others focusing on a single intervention. For example, the Malaria Decision Analysis Support Tool includes vector and intervention parameters, population indicators, and economic indicators, and the Disease Data Management System manages entomology data. A summary of common aspects across the tools is described as follows:

- Three tools allow users to **input data estimates** to assess the prevention of morbidity and mortality of disease transmission: the Malaria Decision Analysis Support Tool, the Malaria Decision Support System, the Intermittent Prevention and Treatment of Infants tool, and the Lives Saved Tool.
- Five tools have **geographic information system (GIS) capability** to map at the subnational and national levels: the Spatial Decision Support Systems for malaria elimination in Bhutan and in Vanuatau and the Solomon Islands, the Malaria Decision Support System used in Kenya, the GIS-based Decision Support System to enhance malaria control in Zambia, and the Disease Data Management System for enhancing decision support for vector-borne disease control programs.
- All tools use **health information systems** as part of their data input, and five tools include survey data: the Spatial Decision Support Systems for malaria elimination in Bhutan and in Vanuatau and

the Solomon Islands, the Malaria Decision Support System used in Kenya, the GIS-based Decision Support System to enhance malaria control in Zambia, the Disease Data Management System for enhancing support for vector-borne disease control programs, and the Lives Saved Tool.

- Six tools use **mobile devices for data entry**: the Spatial Decision Support Systems for malaria elimination in Bhutan and in Vanuatau and the Solomon Islands; the Disease Data Management System for enhancing decision support for vector-borne disease control program, Innovations at Scale for Community Access and Lasting Effects (inSCALE), the upSCALE mHealth system strengthening for case management and disease surveillance, and the Primaquine Roll Out Monitoring Pharmacovigilance Tool.
- The **Malaria Decision Analysis Support Tool is the most comprehensive modeling tool**, with input parameters on malaria burden, population stratification, environment, and economics. Although it is comprehensive, it is also complex, and users may have difficulty fully exploiting its functionalities and outputs. It is the only tool that provides up to three projected outcomes and impacts of decisions based on hypothetical scenarios entered by the user.

Conclusion

Some of the decision support tools seek to aid high-level decision making, such as determining the most effective combination of interventions for a specific subnational region. Others focus more narrowly on specific issues, such as entomological information or insecticide-treated net distribution. However, addressing on-the-ground challenges to effectively deliver malaria interventions is still a major need. At the operational level, program managers and subnational decision makers are more concerned about implementation issues and want to identify and address gaps and constraints in providing high-quality malaria services. Existing tools do not fully address these needs; hence, there is a need for a new tool or improved tools, which would include knowledge management components, an inference agent, and more sophisticated use of GIS.

Recommendations

A new tool should be developed to address operational and implementation challenges facing subnational decision makers. A new tool would have the following integral components: (1) a knowledge base that combines knowledge from local stakeholders and experts; (2) data from relevant databases; (3) a learning module that applies machine learning algorithms to update the tool; (4) a situation assessment user-interface linking the tool's components; (5) an inference engine that can identify critical sources and causes of problems; (6) a decision model that prioritizes actions according to their impact and cost-effectiveness; (7) a knowledge management component that adapts solutions on prior cases that were similar; and (8) a monitoring and evaluation component that assesses the results of the actions taken by the user and updates the relevant database. The new tool should be flexible and general enough to be customized to local needs by implementers of malaria prevention and treatment interventions.

INTRODUCTION

The Context of Malaria

Significant progress has been made in the prevention of malaria in recent years, and interventions have been scaled up in many countries. According to the latest global estimates (World Health Organization [WHO], 2017b), between 2000 and 2015, the incidence of malaria was reduced by 41 percent, and malaria mortality rates decreased by 62 percent, saving 6.8 million lives. Yet despite this progress, the magnitude of the disease remains enormous: in 2015, 212 million persons were infected, and 429,000 died. The disease is prevalent in tropical and subtropical regions around the world and is endemic throughout sub-Saharan Africa. Of 31 countries that had more than 1 million confirmed malaria cases in 2014, according to the WHO Global Health Observatory, all but one are in Africa, and Africa accounted for 90 percent of malaria cases and 92 percent of malaria deaths worldwide.

Malaria affects pregnant women and children under five years of age the most severely. Children under five account for 70 percent of all malaria deaths. Although the under-five malaria death rate fell by 29 percent globally between 2010 and 2015, malaria still takes the life of a child every two minutes—including more than 300,000 children in Africa in 2015 (WHO, 2017b). The four main interventions for malaria prevention and treatment are insecticide-treated nets (ITNs), indoor residual spraying (IRS), artemisinin-based combination therapy (ACT), and other antimalarial medicines.

The goals of USAID and PMI are malaria prevention and treatment, and the United Nations (UN) Sustainable Development Goals (2016–2030) identify malaria control as a global priority. Standard antimalarial interventions have been scaled up rapidly over the past two decades, and especially since 2010. This coordinated scale-up has led to substantial reductions in morbidity and mortality, even in tropical countries with high stable transmission. More work is needed to sustain the gains and move toward elimination. However, public health officials and healthcare workers continue to face several challenges in responding to malaria prevention and treatment: cost and logistical constraints; inadequate healthcare systems; a conducive environment for transmission; and the cost of treatment and prevention interventions, which limits access to them.

Policymakers are often disconnected from the “on-the-ground” situation prevailing in a country or region (Paul, et al., 2015). A stakeholder-designed decision tool framework could improve existing policies and the functioning of malaria-related institutions.

Decision Support Tools for Malaria Prevention

Policymakers and health professionals at all levels make difficult decisions about how best to scale up malaria interventions and allocate limited resources in an environment of uncertainty, difficult tradeoffs, and political and ethical concerns (e.g., how interventions are to be distributed geographically and across population groups). To choose the appropriate combination of interventions from the set of all possible interventions, information from diverse sources must be assembled and analyzed to determine the key constraints and critical issues concerning malaria in the national and subnational context. To formulate and implement policy well, policymakers must have access to a wide range of reliable, relevant data as well as the capacity to rapidly incorporate the data in the decision-making process.

Computerized decision support tools (DSTs) have the potential to incorporate and organize a wealth of national data, including “non-health” data, such as entomological surveys, land-use maps, and other geographic information. Although DSTs have been used for many years in clinical practice to support diagnosis and diagnostic processes, medication administration, and other medical procedures, they are less common in public health. DSTs have the potential to improve policymakers’ capacity to predict, prevent, and treat malaria and other infectious diseases. To identify existing DSTs, we conducted a literature review to compile an inventory of DSTs that are malaria-specific or can be adapted for malaria prevention and treatment.

METHODS

We conducted Internet and database searches in Google Scholar, SCOPUS, and PubMed, using the following search terms in various combinations: “decision tools,” “decision-making tools,” “decision support tools,” “malaria,” “vector-borne disease,” and “mosquito-borne disease.” Because gray literature is not extensively catalogued in research databases, we also conducted manual searches of relevant websites, including those of the following organizations: Bill & Melinda Gates Foundation; Malaria Atlas Project; Malaria Decision Analysis Support Tool (MDAST), Duke University; MEASURE Evaluation; President’s Malaria Initiative; Roll Back Malaria Partnership; and WHO.

In addition, we consulted with malaria and public health experts at the World Bank and ICF to identify evident gaps in our research. We also conducted a quick search to see whether we could find additional DSTs in French-language research literature, which we could not. Generally, we limited ourselves to literature published in the past 10 years; however, we included a few earlier publications suggested by experts or in areas where the literature is thin.

This review covers 11 DSTs for malaria control. These tools are compared using a template to summarize information collected from journal articles and gray literature. Where available, sample screenshots of the tools are provided here; please refer to each tool’s referenced source for complete information.

DECISION SUPPORT TOOLS AND THEIR ROLES

We identified 11 DSTs developed in recent years to support malaria control, prevention, and treatment. Some DSTs seek to aid high-level decision making, such as determining the most effective combination of interventions for a specific subnational region. Others focus more narrowly on issues such as entomological information or bed net distribution. Appendix 1 contains a table summarizing the DSTs. This section provides additional details on each tool.

Tool 1: Malaria Decision Analysis Support Tool

Description

MDAST allows decision makers to explore likely impacts of malaria control strategies on health, environmental, and economic outcomes, based on the local context. Users enter parameters describing the local context, including population size, age cohort, malariometric indicators, and the cost of health delivery options such as ITNs and rapid diagnostic test (RDT) kits. Another important feature is that population data and malariometric indicators are stratified in three demographic cohorts: children under age five, pregnant

women, and other adults, because these populations are the most vulnerable. The tool optimizes health delivery across both disease management and vector control options based on the strategic and tactical decisions made.

The MDAST project sought to protect health and the environment, by promoting sustainable malaria control strategies consistent with the Stockholm Convention on Persistent Organic Pollutants. The project was supported by the Global Environment Facility, the UN Environment Programme, and WHO. The key project partners were the UN Environment Programme; the Global Environment Facility; the WHO Regional Office for Africa; the Ministry of Health, Uganda; the Ministry of Health, Kenya; the National Institute of Medical Research, Tanzania; the University of Pretoria; and Duke University.

MDAST employs proprietary decision analysis software (Analytica) and runs with an Oracle database in the back end. The tool is cloud-based and can be accessed through a browser. The tool does not run on Mac OS but does run on VMware Fusion or Parallels running Windows on a Mac. MDAST uses Analytica as the modeling engine, which analyzes different scenarios based on available malaria data and their impacts. Additional information can be found at <https://sites.duke.edu/mdast/>.

Data Inputs

Because the impacts of different decisions depend on the local context, the user enters parameters describing the local context. In the Parameters module, users describe the health, social, and environmental properties of the community for which they seek to develop an evidence-based malaria control policy. MDAST currently includes 81 parameters that the user can change to reflect the attributes of the targeted community. Many of these parameters have default values based on the peer-reviewed scientific literature if the user lacks some of this information. The MDAST model combines parameters describing the malaria context with health delivery decisions to generate estimates of the economic, human health, and environmental outcomes of different health delivery strategies. The parameters are grouped in the following categories, also called submodules:

- **Malaria Burden** (10 parameters available for modification): the Malaria Burden submodule includes:
 - Vector Ecology Parameters (“Recruitment and Mortality” parameters, such as the mean and median baseline vector recruitment per person per year [i.e., number of female mosquitoes emerging per person per year in the absence of vector control for each of the three major malaria-transmitting species] and baseline vector mortality [fraction dying per day], as well as one “Feeding Cycle” parameter, the proportion of female mosquitoes feeding on human blood)
 - Intervention Impact Parameters (seven parameters in various categories, such as “Treatment” “Diagnostics,” “IRS,” “Larviciding,” and “LLINs”)
- **Population** (five parameters): population by age cohort, birth rate, deaths, average household size, number of villages in treatment area
- **Economics** (33 parameters):
 - LLIN Supply/Demand Parameters (“Government Supply” parameters, such as unit cost; “Retail Supply” parameters, such as unit cost, household travel costs, density of retail distribution points; “Information and Awareness Campaign” parameters, such as the

campaign's cost per day and the attributable increase in long-lasting insecticide-treated net [LLIN] use; and "Demand" parameters, such as increase in demand attributable to information campaign, price elasticity of demand for LLINs, average LLIN life in years, baseline LLIN use)

- IRS Costs
- Larviciding Costs
- Treatment and Diagnostics Costs (costs per test, costs per dose, etc.)

Each of the three submodules can be opened to access specific parameters that can be changed by the user. Cost parameters are used for evaluating hypothetical policy choices. Parameters can be changed by directly entering a number, selecting a choice from a dropdown menu, or opening a table whose values can be entered in the cells.

MDAST relies on users' expertise regarding the intensity of malaria transmission in their community and their knowledge of previous malaria interventions. The "Parameters" module of MDAST allows users to input their expertise regarding local malaria transmission, and the "Current Interventions" submodule in the "Control Portfolios" module allows users to provide input on historical control policies that have been implemented.

Structure and User Interface

To provide a platform for systematically comparing alternative malaria control policy combinations over time, the prototype MDAST model incorporates the dynamics of malaria transmission and control over different timeframes; the user can define the number of years for which the output parameters of each malaria control policy combination are estimated. The user can also enter the different variables affecting health delivery decisions, such as vector control and disease management, as shown in Figure 1.

Figure 1. Screenshot of the MDAST user interface

Diagram - Prototype Malaria Decision Analysis Support Tool

Input Parameters

a. Demographic & Malarimetric

Total population [Edit Table](#)

Time horizon (years)

Initial endemicity [Edit Table](#)

Initial PR [Edit Table](#)

b. ITN Parameters

Unit cost of ITN (USD)

Unit cost of LLIN (USD)

Retreatment interval of ITN (Year)

Replacement interval of LLIN (Year)

Net coverage rate at baseline

Overlap rate between nets and IRS at baseline

c. IRS Parameters

Ave. cost of IRS with DDT per HH (USD)

Acceptance rate of IRS with DDT

Ave. cost of IRS with pyrethroid per HH (USD)

Acceptance rate of IRS with pyrethroid

IRS coverage rate at baseline

d. Disease Management Parameters

Unit cost of Microscopy (USD)

Unit cost of RDT (USD)

Unit cost of ACT (USD)

Unit cost of SP (USD)

Vector Control Strategy

A. ITN

1. Type of net

2. Subsidy level:

Children Preg. women Adults

B. IRS

1. Type of insecticide

2. Coverage

3. Schedule (per year)

Disease Management Strategy

A. Diagnosis

1. Coverage of diagnosis by type & group

Children<5 Preg. women Adults

Microscopy

RDT

B. Treatment

1. Coverage of antimalarial drug by type & group

Children<5 Preg. women Adults

SP

ACT

[Click here for model details](#)

Results (Over the entire time horizon)

Program Cost Impacts

Parasite Ratio [Calc](#) mid

Total Program Costs (USD) [Calc](#) mid

Program cost per person covered (USD) [Calc](#) mid

Program cost per case avoided (USD) [Calc](#) mid

Program cost per death avoided (USD) [Calc](#) mid

Human Health Impacts

Malaria cases avoided [Calc](#) mid

Malaria deaths avoided [Calc](#) mid

Total Avoided Malaria Burden Costs (USD) [Calc](#) mid

Malaria burden cost avoided per person (USD) [Calc](#) mid

Cases of insecticide-related illnesses [Calc](#) mid

Total Insecticide-related Health Costs (USD) [Calc](#) mid

Environmental Impacts

Loss of crop/fishery/bird due to insecticide use [Calc](#) mid

Cost of groundwater contamination by insecticide [Calc](#) mid

Cost of insecticide resistance [Calc](#) mid

Total Environmental Impact Costs [Calc](#) mid

Total Net Impacts

Total Net Impacts (USD) [Calc](#) mid

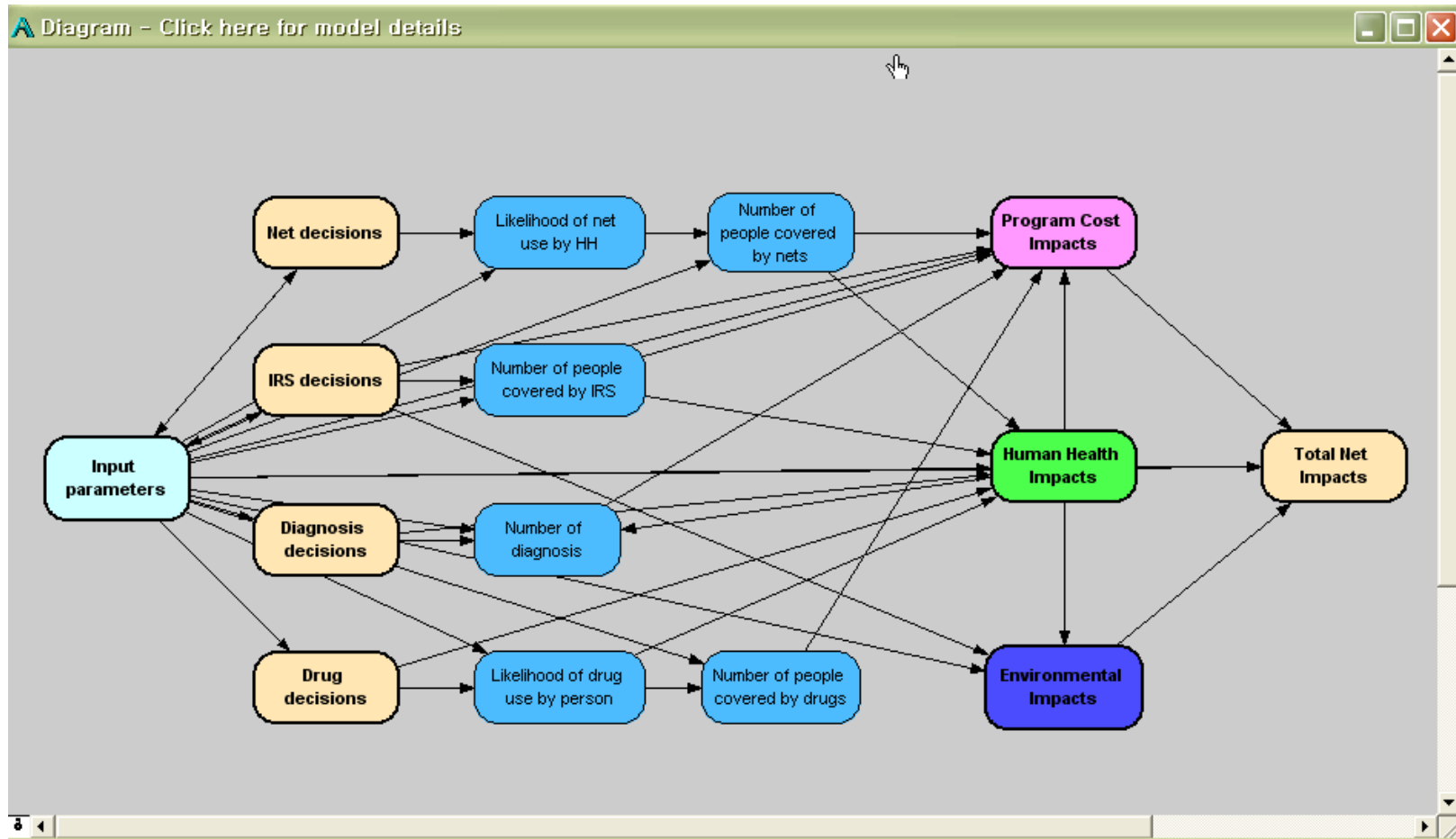
Source: MDAST Project Implementation Report. (August 2013). Retrieved from <https://sites.duke.edu/mdast/files/2013/05/MDAST-Final-Report-Aug-2013.Printed-version.pdf>

DHIS 2 is widely used in Kenya, Tanzania, and Uganda (the countries where MDAST was implemented). Project documents do not explicitly state whether MDAST connects to DHIS 2 or uses any inputs coming from DHIS 2.

Outputs

After the input parameters and health delivery decisions are specified, MDAST calculates the outcomes of the user-defined health delivery strategy by combining parameters describing the malaria context with the health delivery decisions in a systematic modeling framework. The screenshot of the influence diagram for the underlying prototype model is shown in Figure 2. A module was created for each of the three impacts components, where various output parameters are estimated based on theoretical equations and evidence-backed assumptions. The initial versions of the program's cost impacts module and the human health impact module were completed at this stage. There is no visualization capability (graphs or maps) except influence diagrams.

Figure 2. MDAST influence diagram

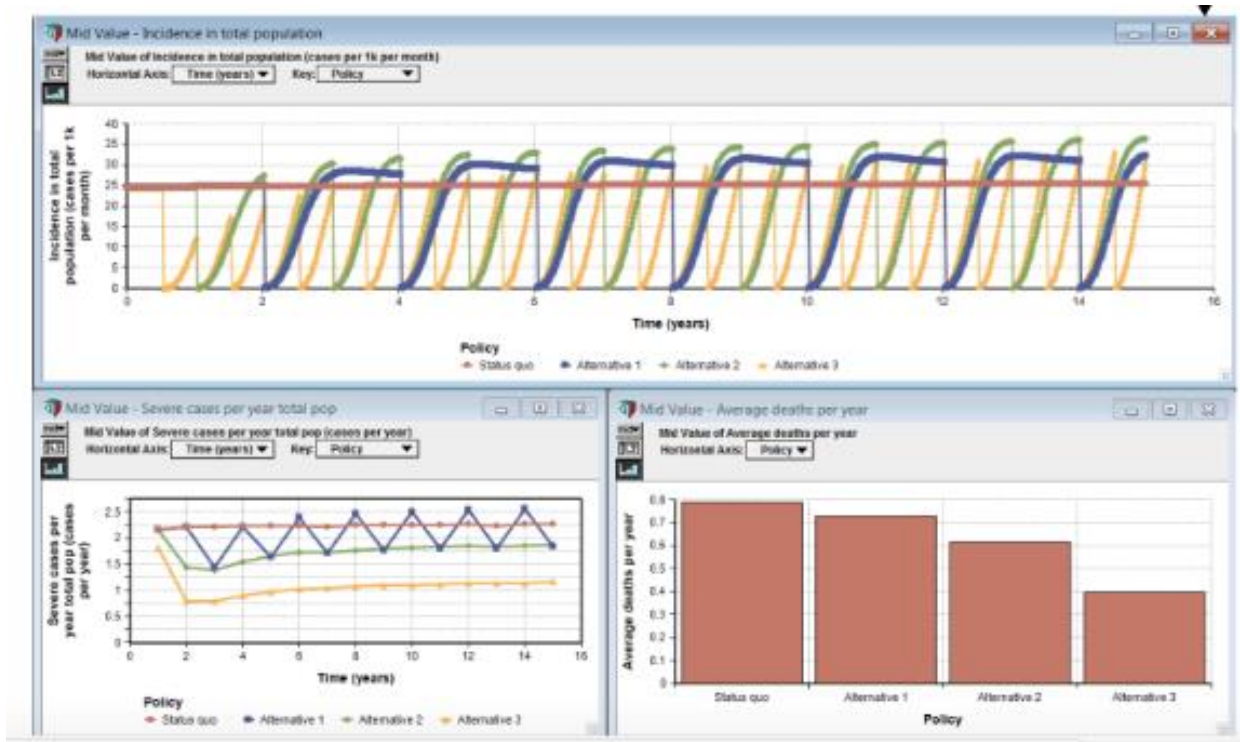


Source: MDAST Project Implementation Report. (August 2013). Retrieved from <https://sites.duke.edu/mdast/files/2013/05/MDAST-Final-Report-Aug-2013.Printed-version.pdf>

As shown in Figure 3, the MDAST modeling tool predicts the health impacts of various policy alternatives, such as the following:

- Alternative 1 = Bendiocarb sprayed every two years
- Alternative 2 = Bendiocarb sprayed every year
- Alternative 3 = Bendiocarb sprayed twice per year

Figure 3. MDAST output



Source: Brown, et al., 2015

Use

MDAST is a scalable tool and can be scaled from the subnational level to the national level. Training for users is available through Analytica, the decision analysis software on top of which MDAST is implemented. Most training tutorials are available at <https://sites.duke.edu/mdast/videos/> and http://wiki.analytica.com/index.php?title=Analytica_Wiki.

MDAST aims to promote evidence-informed, multisectoral malaria control policymaking in Kenya, Tanzania, and Uganda, and the project serves as a pilot for other malaria-prone countries. The tool was used to facilitate informed decision making and evidence-based malaria policy development. The project reduced the barriers among policymakers and shaped decisions based on the information available. See the final implementation report for details (<https://sites.duke.edu/mdast/files/2013/05/MDAST-Final-Report-Aug-2013.Printed-version.pdf>).

Strengths and Limitations

MDAST is a comprehensive tool, allowing up to 48 input parameters. It provides evidence-based default values for the parameters where local data are lacking, unreliable, or unavailable to the user. However, it is unclear for two reasons whether health officials at the district level would be able to use it readily:

(1) MDAST requires substantial training and technical support, and (2) the underlying modeling is highly complex. There are also some technological weaknesses: (1) it does not have GIS or useful visualization capabilities, and (2) it is based on a proprietary subscription-based modeling tool (the Analytica software engine).

Tool 2: Spatial Decision Support System for Malaria Elimination in Bhutan

Description

Bhutan has reduced its malaria incidence significantly in recent years and has set a goal to eliminate malaria by 2020. To assist with the management of the elimination program, the Spatial Decision Support System (SDSS) was developed, with financing from the Global Fund. SDSS uses the open source Quantum Geographic Information System (QGIS) and was piloted to support the distribution of LLINs and IRS in two subdistricts of Samdrup Jongkhar District. It was subsequently used to support reactive case detection (RACD) in the same two subdistricts of Samdrup Jongkhar and two additional subdistricts in Sarpang District.

Paper-based maps have been used for planning malaria interventions at least since the eradication efforts of the 1960s. More recently, electronic GIS, which permits input, storage, manipulation, and output of geographic information, has provided a powerful suite of tools for managing data in the context of the prevention and control of malaria. The free QGIS software was used as the GIS platform for development of the customized SDSS application. Microsoft Excel software was used for additional integrated data management and analysis.

SDSS is based on a database housed within QGIS, with an interactive mapping interface. SDSS can contain modules for planning, monitoring, and evaluating the delivery and coverage of interventions, such as IRS and distribution of LLINs within target populations, and for mapping malaria surveillance data, including identifying and classifying active transmission foci and guiding targeted responses. The development of SDSS required an investment in financial and human resources and an additional investment for implementation and the considerable effort needed to maintain the system. Although it is intuitive that such systems will improve the efficiency of malaria elimination interventions through supporting more effective resource allocation decisions, SDSS's uptake depends on establishing ease of use and utility.

Data Inputs

Data inputs to SDSS are as follows:

- **GIS data**, such as map layers including the geolocation (latitude and longitude) of households, medical facilities, and distribution points
- **Geographic reconnaissance** (household location, total population, entomological data, etc.), involving information captured during geographic reconnaissance and from existing surveys,

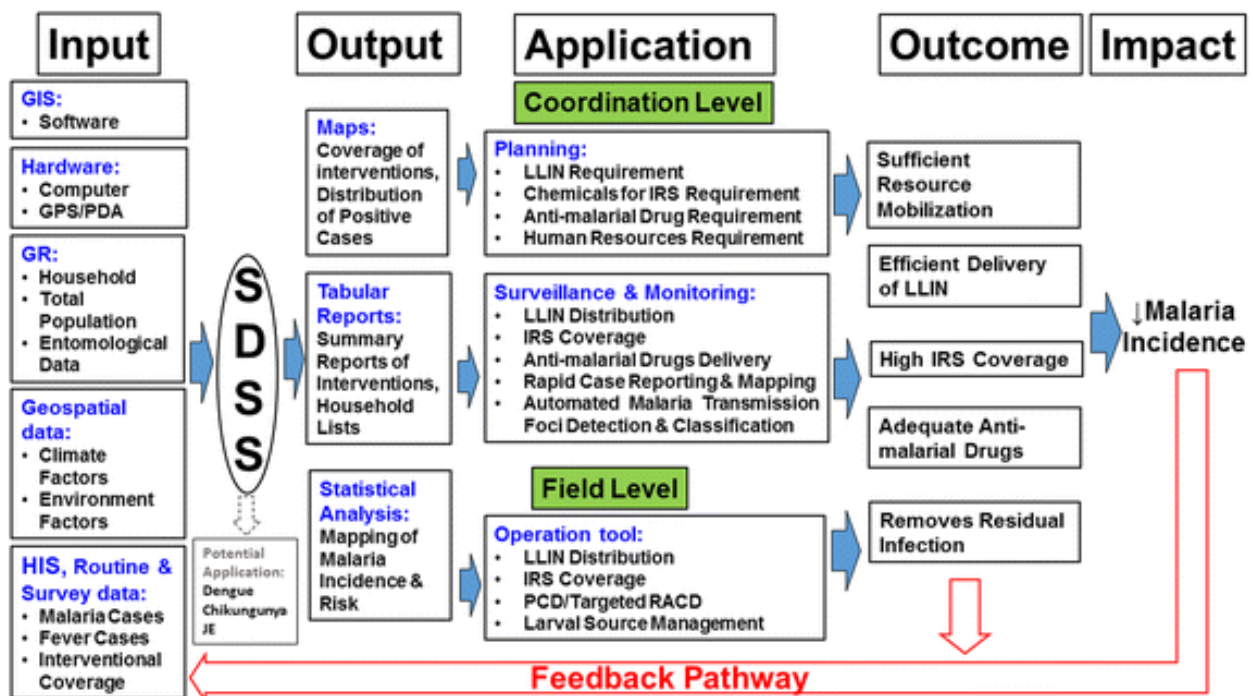
including a unique household identification number, name of the head of family, the type of household, numbers of rooms, total number of residents, and number of children under five years old in each household. Staff from the Vector-Borne Disease Control Program in Bhutan were trained to use handheld computer devices with an integrated Global Positioning System (GPS) for carrying out mapping of the households in August 2013. These trained staff were assisted by the malaria technicians of the respective health centers in the pilot study.

- **Geospatial data**, including climate information (temperature, precipitation, etc.) and environmental factors (e.g., flowing and standing water)
- **Health information systems**, routine and survey data (malaria cases, fever cases, interventional coverage)

Structure and User Interface

Figure 4 displays the application of SDSS in a result chain framework. That is, it shows various input and output components as well as application areas, outcomes, and impact.

Figure 4. Structure of SDSS for malaria elimination in Bhutan



Source: Wangdi, et al., 2016

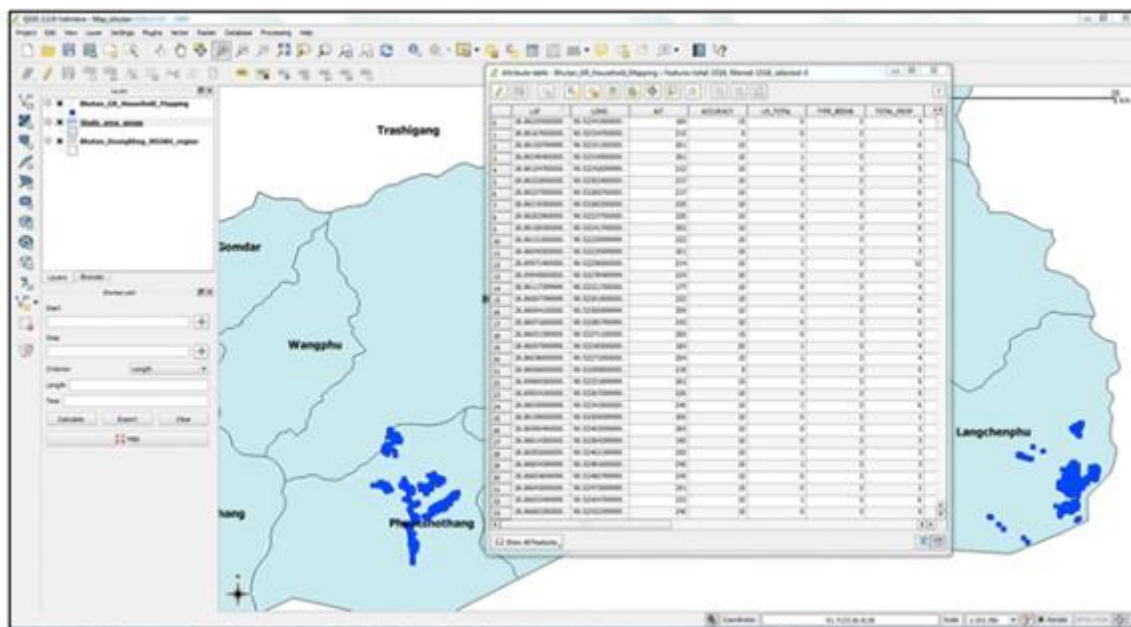
Outputs

As shown in Figure 4, SDSS gives output in the formats of maps, tabular reports, and statistical analysis, which are described as follows.

- **Maps:** The SDSS maps cases at the household level and enables spatial relations among households to be mapped. This is essential for facilitating RACD in buffer zones, which is the main approach to containing transmission. Intervention data were recorded in Microsoft Excel and uploaded to the

SDSS. The data were linked to households using the unique household number to monitor coverage and service distribution via a map interface. Through the automated mapping of LLIN coverage, program managers were able to monitor progress and visualize the spatial distribution of coverage. The managers could provide feedback to malaria technicians in the field on intervention coverage, ensuring adequate and uniform distribution. The ability to view IRS status at a detailed level and automatically extract associated household data for immediate follow-up gave health officials an effective operational tool for monitoring and interactive communication. The SDSS also helped supervisors and managers allocate necessary resources by mapping the coverage and distribution of resources. For example, the coverage of preventive activities, such as LLINs, can be mapped, providing powerful visual evidence of the work done in the field. Figure 5 provides an example of map output. LLIN distribution and IRS data were recorded in Microsoft Excel and uploaded to the SDSS, where they were linked to households using the unique household number so that coverage and service distribution could be monitored via a map interface.

Figure 5. Example of SDSS map output for malaria elimination in Bhutan



Source: Wangdi, et al., 2016

- **Tabular reports:** The SDSS database contains intervention data and household survey information, which can be easily extracted into tabular reports in Microsoft Excel to support planning, implementation, monitoring, and evaluation of LLINs and IRS. This obviated the need to visit each household every six months for IRS planning, as had been done previously in order to record the number of rooms in each household and calculate the amount of chemicals and manpower required for carrying out IRS.
- **Statistical analysis:** The published literature mentions that the SDSS contains statistical analysis modules, which are used at the national level. Unfortunately, the literature gives little information on

the analytical outputs, which apparently include incidence and risk maps as well as simple calculations, such as LLINs per person.

Use

This SDSS is a scalable tool and can be scaled from the district (field) level to the national level. The SDSS was used as part of the malaria elimination program in Bhutan. It was used to support the distribution of LLINs and IRS in the two subdistricts of Samdrup Jongkhar District and was subsequently used to support RACD in the two subdistricts of Samdrup Jongkhar and two additional subdistricts in Sarpang District.

A total of 1,502 households with a population of 7,165 were enumerated in the four subdistricts; a total of 3,491 LLINs were distributed, with one LLIN per 1.7 persons. A total of 279 households representing 728 residents were involved with RACD. Informants indicated that the SDSS was an improvement on previous methods for organizing LLIN distribution, IRS, and RACD, and could be easily integrated into routine malaria and other vector-borne disease surveillance systems. Informants identified some challenges at the program and field levels, including the need for more skilled personnel to manage the SDSS and more training to improve the effectiveness of SDSS implementation and use of hardware. The implementation report can be accessed at <https://malariajournal.biomedcentral.com/articles/10.1186/s12936-016-1235-4>.

Strengths and Limitations

The SDSS provides a modernized, high-resolution mapping capacity to support the operational management of scaled-up interventions. To ultimately eliminate malaria in Bhutan, higher-resolution mapping at the household level may be required to address residual areas of transmission (for example, through establishing accurate buffer zones). The SDSS has been used effectively by national, subnational, and field users. The tool can interface readily with Bhutan's health information system and uses open source software for mapping and the internal database and a standard commercial package (Microsoft Excel) for data management and input. In addition, the SDSS gives supervisors a way to monitor the activities of malaria field technicians.

The initial cost of setting up the SDSS, including procurement of computers and handheld GPS devices, as well as human resource costs (training, payments to fieldworkers, etc.), were high, although in the long run the relative efficiency of SDSS may provide offsetting savings. Much of the data are still collected manually, entered in Microsoft Excel, and then uploaded to the SDSS. Although mapping households using mobile phones or GPS was relatively easy, using advanced features of the SDSS, such as data analysis, was problematic at the field level. Uptake remains a challenge. The major challenges identified in the project review were: (1) inadequate human resources at the program level to manage and implement the SDSS; (2) the need for more training and expertise; (3) the need for more hardware such as computers, laptops, and GPS devices; and (4) inadequate availability of or access (due to cost) to Internet services.

Tool 3: Spatial Decision Support System for Malaria Elimination in the Solomon Islands and Vanuatu

Description

A customized GIS-based SDSS was developed at the provincial level to support progressive malaria elimination campaigns in the Solomon Islands and Vanuatu.

Geographical reconnaissance surveys were conducted in the elimination provinces of Temotu, Solomon Islands, and Tafea, Vanuatu, in 2008 and 2009 to rapidly map and enumerate households and collect associated data on population and household structure, using integrated handheld computers and GPS. An SDSS approach was adopted to guide the planning, implementation, and assessment of frontline focal IRS interventions on Tanna Island, Vanuatu, in 2009. High-resolution surveillance response systems were also developed in the elimination provinces of Temotu and Isabel in the Solomon Islands and Tafea in Vanuatu in 2011. The high-resolution surveillance response helped support rapid reporting and mapping of confirmed cases by household, automatic classification and mapping of active transmission foci, and the generation of areas of interest to conduct a targeted response.

Progressive malaria elimination campaigns are currently being pursued by the governments of the Solomon Islands and Vanuatu, with support from the Australian Agency for International Development, the Pacific Malaria Initiative, WHO, and other partners. GIS-based SDSS approaches have been developed, validated, and adopted by the malaria programs in both countries to strengthen geographical reconnaissance and to facilitate the implementation of vector control interventions, including LLIN distribution and focal IRS.

The SDSS is a functional decision-making tool based around a GIS that integrates database management systems with analytical models, graphical map display, tabular reporting capabilities, and the expert knowledge of decision makers. ArcPad 7.0 (ESRI) commercial software was used for data collection and field mapping operations, with post-fieldwork data storage, backup, and analysis using Microsoft Access and MapInfo Professional 8.0 (Pitney Bowes).

Data Inputs

Data inputs are as follows:

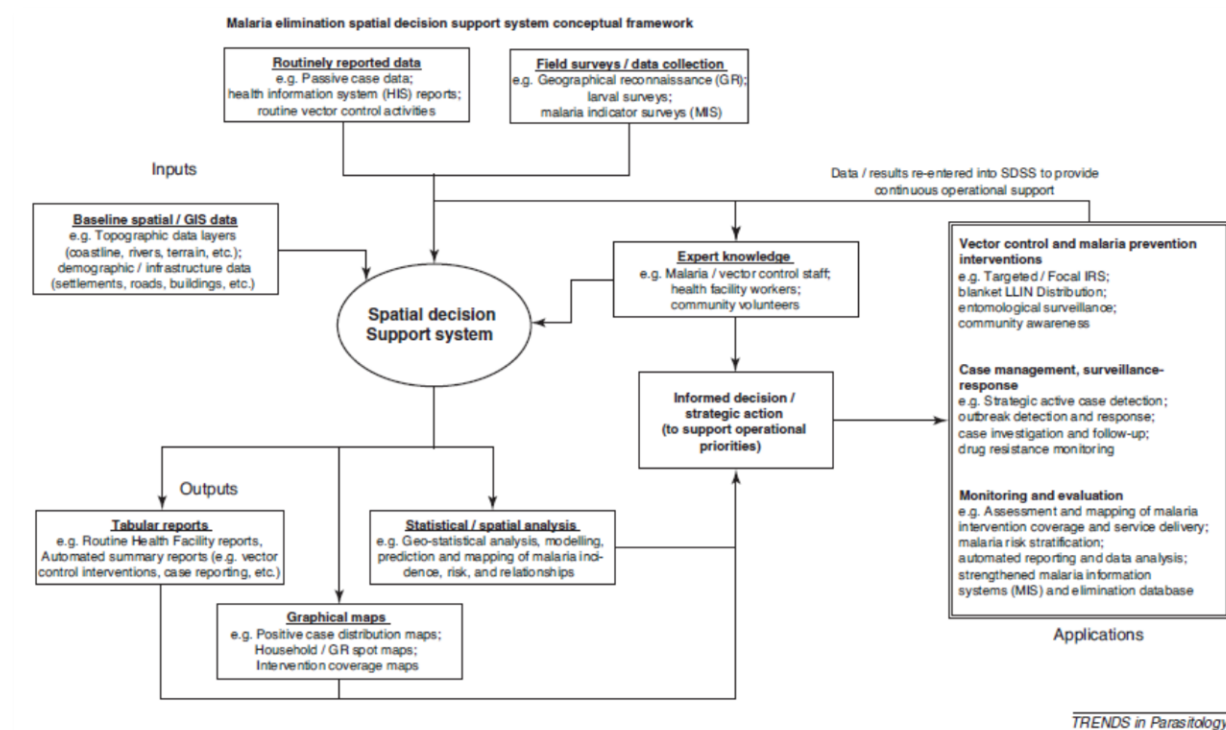
- Routinely reported data (e.g., reports from health information system)
- Data collection and field surveys (e.g., geographical reconnaissance, malaria indicator surveys)
- Expert knowledge (e.g., malaria control staff, health facility workers, community volunteers)
- Baseline spatial data (e.g., topographic, demographic, infrastructure data file)

Structure and User Interface

Figure 6 illustrates a conceptual SDSS design framework highlighting the inputs, outputs, applications, and relationships of key elements of the SDSS in the context of supporting the operational priorities and increased demands of malaria elimination and intensified control. Key elements of the SDSS are: (1) data inputs from a variety of sources, including geospatial data layers; (2) automated outputs to guide informed and strategic decision making for designated applications; (3) application and intervention outcomes reentered

in the SDSS as cyclical input; and importantly (4), expert knowledge, integrated throughout all stages of the SDSS process (Kelly, Tanner, Vallely, & Clements, 2012).

Figure 6. Example of SDSS map output for malaria elimination in the Solomon Islands and Vanuatu



Source: Kelly, Tanner, Vallely, & Clements, 2012

Outputs

As shown in Figure 6, SDSS provides output in the following formats:

- Statistical and spatial analysis:** Advanced GIS-based spatial analysis techniques are available to identify, predict, and map malaria risk at a variety of different scales. On a global scale, the distribution of *Plasmodium falciparum* endemicity has been mapped from parasitological data using geostatistical modeling. Spatial statistical models have also been produced to explore and predict malaria risk at the regional, national, and local levels. From the perspective of eradication, predictive maps illustrate malaria risk and its distribution across a variety of scales (i.e., globally, nationally, subnationally), highlight favorable areas for elimination, and strategically target priority interventions within designated elimination zones.
- Tabular reports:** The SDSS database contains intervention data, demographic data, and household survey information, which can be easily extracted and put into tabular reports in Microsoft Excel to support planning, implementation, monitoring, and evaluation.
- Graphical maps:** The SDSS provides a mechanism to link routinely collected data with associated geographic locations, conduct spatial queries and analysis, and produce automated reports and illustrative maps for relevant areas of interest.

Use

This SDSS is a scalable tool and can be scaled from the district (field) level to the national level. Workshops were conducted in Temotu and Tanna to train participating personnel in the use of handheld personal digital assistant and GPS units. Additional training was also provided for field supervisors on daily data backup and quality assurance, data security, personal digital assistant troubleshooting, and mobile mapping and summary analysis techniques.

The SDSS was used as part of malaria elimination program to support operational priorities in the Solomon Islands and Vanuatu. The SDSS framework demonstrates how geospatial systems can support a progressive malaria elimination campaign. The platform rapidly collects, stores, and extracts essential data throughout key phases of program implementation. The framework helps deliver and manage essential services for optimal levels of coverage in target areas. The framework actively locates and classifies transmission to guide swift and appropriate responses. The implementation report can be accessed at <https://malariajournal.biomedcentral.com/articles/10.1186/1475-2875-12-108>.

Strengths and Limitations

The SDSS makes extensive use of mobile devices for data collection and uploading to the SDSS database. The system helped with rapid reporting of confirmed cases by household for high-resolution mapping of areas of interest for targeted response. The SDSS was used at both the national and field levels.

However, there are some challenges with the system. The SDSS requires purchase of subscriptions because of proprietary software and extensive specialized training needed for data collectors and users as well as system operations and maintenance. In addition, the system does not have a knowledge management component.

Tool 4: Malaria Decision Support System Used in Kenya

Description

The Malaria Decision Support System (MDSS) is used for the continuous surveillance, monitoring, and evaluation of malaria control programs in Kenya. The MDSS integrates all continuous surveillance, monitoring, and evaluation requirements of a malaria control program. The tool combines best practices for data collection, storage, management, and use and is based on advanced software that is user friendly, flexible, and configurable to meet individual program needs. The MDSS accommodates data from other sources and historical data and empowers the user to extract data through intuitive dynamic and static queries. The tool includes automated tools supporting intervention planning, disease outbreak alerts, and resource allocation. The reporting interface includes a simple tool that can generate customized reports for program needs and other stakeholders to assist with decision making at all levels.

The MDSS is supported by the Innovative Vector Control Consortium (IVCC). The IVCC is a partnership dedicated to developing vector control products and information systems, bringing together expertise and technical resources. It was established with an award from the Bill & Melinda Gates Foundation.

The MDSS is a functional tool based on an open source web-based integrated system that includes the following:

- PostgreSQL: A highly scalable, SQL compliant, open source object-relational database management system
- PHP: Free, open source scripting language that is especially suited for web development and can be embedded into HTML
- PostGIS: An extension to PostgreSQL that allows GIS objects to be stored in the database

Data Inputs

The MDSS has both import and export functionality. Data can be imported from health information systems, archived data sets, and other sources. Data can be exported from the MDSS to other systems. Input parameters are as follows:

- **Entomology:** MDSS records insecticide resistance, insecticide resistance mechanisms, vector mosquito abundance, and infectivity data (for example, sporozoite rate), as well as efficacy of insecticides on treated surfaces. The entomology team can analyze species variation over space and time and recommend insecticides based on their effectiveness in a local context, taking account insecticide resistance levels in the vector population and resistance mechanisms. Entomology information can also be used to monitor the impact of the control program on mosquito populations and transmission risk.
- **Health information:** Data imported from health information systems or uploaded by users
- **Epidemiology:** Data from malaria case surveillance and prevalence data collected from the Malaria Indicator Survey and parasitemia
- **Intervention coverage and usage:** Data from case surveillance, household surveys, and entomology modules

Structure and User Interface

Figure 7 illustrates the conceptual MDSS framework, highlighting key input (malaria case surveillance data, household surveys and prevalence data, entomology surveillance data, stock control, etc.) and output (reports, graphs, maps) components.

Figure 7. Structure of MDSS used in Kenya



Source: Innovative Vector Control Consortium, n.d.

Outputs

The MDSS contains dynamic query tools that allow users to interpret and present data in formats tailored to their needs. As shown in Figure 7, data can be visualized in map, graph, table, and custom report formats, which are described as follows.

- **Reports:** The MDSS can track intervention activities and compare them to set targets. The flexible reporting and writing capability of the MDSS highlights delays against national plans, poor performance of teams or individuals, and inconsistencies of application rates. It also compares coverage rates against recommended standards. The MDSS has a comprehensive intervention tracking module that can monitor the delivery of ITNs at facility and community-level distribution and other interventions such as intermittent preventative treatment.
- **Graphs and tables:** The MDSS can present data from household surveys, surveillance systems, inventories of stocks (e.g., netting, insecticides, medicines), and other sources in the form of graphs

and tables in a localized format to support decision making in subnational and national malaria control (e.g., outbreak tables at the community level) or in a standardized format to support regional analysis.

- **Maps:** The MDSS has a strong GIS component that helps users visualize data geographically. Users can define their own mapping criteria and view the results (e.g., disease hot spots, intervention progress and coverage, vector distribution and prevalence data). They can also overlay intervention and impact data onto maps.

Use

The MDSS is a scalable tool and can be scaled from the district (field) level to the national level. User training sessions on the tool are provided by the MDSS Project Manager. IVCC launched the MDSS at the Fifth Pan-African Multilateral Initiative conference in Nairobi, Kenya in 2009. MDSS is a best practice, continuous surveillance system that integrates monitoring and evaluation data from a malaria control program and presents them in a web-based, real time geographic format to assist with intervention planning in Kenya.

Strengths and Limitations

The MDSS is a highly customizable tool that aids decision making at subnational and national levels. The tool provides continuous surveillance, monitoring, and evaluation of malarial control programs, including automated alerts. The MDSS is integrated with other health information systems for data input and output, such as DHIS 2. However, the tool does not have a knowledge management component and lacks models to assess the relationships among various factors.

Tool 5: GIS-Based Decision Support System to Enhance Malaria Control in Zambia

Description

The GIS-based decision support system (DSS) integrates operational and logistical data for malaria control program planning with epidemiological data to strengthen the epidemiological analysis and the planning and execution of malaria control programs. The system facilitates the integration of quantitative malaria determination and control data with data obtained from maps, satellite images, and aerial photos. The GIS-based DSS provides opportunities for formulating rational policy and using limited resources effectively for enhanced malaria vector control. The tool uses a Microsoft Excel database in addition to an internal GIS database; however, it is unclear whether it is open source or proprietary.

Data Input

The input parameters are as follows:

- **Entomology** (e.g., surveillance data on species characterization, insecticide resistance status, parasite prevalence)
- **Health information** (e.g., national malaria indicator survey, cross-sectional surveys at sentinel sites in the treatment areas, clinical reports)

- **GIS** (e.g., geo-referenced operational and logistical data, map layers derived from existing maps, satellite images, aerial photos)

Structure and User Interface

The malaria menu includes a section for intervention monitoring related to use of intermittent preventive treatment (with anti-malarial drugs) of pregnant women. This, together with the capability outlined below to specify different label names for a data entry field by disease, provides system flexibility in that the user can adapt the default system to make use of functionality originally developed for one disease in another disease. It also provides an economy of scope as new diseases downstream can be added to the system at decreased cost through reuse of already existing functionalities.

The user interface is highly customizable. The user can select whether to show or hide a data entry field. This provides the user with the option to hide default data entry fields that are not considered relevant in a given geographical area where the system is implemented, and thus produce a streamlined user interface.

The data entry fields can display different label names. For example, an individual disease case can display as the dengue virus serotype in the dengue menu but malaria type in the malaria menu. The user can change these disease-specific display labels in a local spreadsheet that can be exported, edited, and then imported back into the system to execute the changes. This local spreadsheet can also be used to develop display labels, by disease, for another language, including language dialects (i.e., languages or dialects based on the Latin character set). The user can switch between languages to be displayed by changing the browser locale.

The system can customize system roles and permissions. The system is delivered with a set of default roles (administration, entomology, medical, vector control, stock, etc.), but these can be configured.

Outputs

The GIS-based DSS gives output in the following formats:

- **Maps:** For example, maps of spatial prevalence of malarial infection, spatial distribution of insecticide resistance
- **Graphs:** For example, graphs of the prevalence of infection in children by reported intervention (e.g., IRS, ITN, IRS and ITN, no intervention)

Use

The GIS-based DSS is a scalable tool and can be scaled from the district (field) level to the national level. The tool was used in monitoring malaria control programs in Zambia to introduce new dimensions to the understanding, prediction, analysis, and dissemination of spatial relations between disease, time, and space. It integrates geo-referenced data with local knowledge in relational databases to accurately display complex interactions in simple formats. The tool provides an opportunity to integrate up-to-date information, local knowledge, and historical trends to identify areas where assistance is needed most and options for action. This shows that GIS can be used not only as a tool for data analysis but also for information management and decision making, thus facilitating policy formulation.

The GIS-based DSS was used in Zambia to detect spatial trends of parasite prevalence after frontline vector control interventions were extensively deployed. Cross-sectional surveys showed a continuous increase in the prevalence of malaria among children between 2008 and 2010 in Chongwe district. In Kafue, Kapiri Mposhi, Mazabuka, and Mumbwa districts, prevalence dropped between 2008 and 2009 but increased in 2010; however, malaria prevalence reduced in Chibombo, Kabwe, and Monze districts from 2008 to 2010. The most important benefit of the GIS-based DSS is that it stratifies areas, leading to better distribution of resources and tailored interventions. More details can be found at <https://www.hindawi.com/journals/jtm/2012/363520/>.

Strengths and Limitations

The GIS-based DSS effectively uses spatial analysis using GIS technology to control and predict vector-borne malaria transmission, monitor insecticide resistance and impact of interventions, integrate operational and logistical data, and improve regional stratification, leading to better distribution of resources and interventions.

However, the tool limits the availability of accurate raw data; limits its focus to vector control; does not have models to identify environmental, social, and other constraints; and does not offer a knowledge management component.

Tool 6: Disease Data Management System for Enhancing Decision Support for Vector-Borne Disease Control Programs

Description

The Disease Data Management System (DDMS) is a tool designed to meet the data management and decision support needs of vector-borne disease control programs as they transition through control to elimination. The system was developed by a team led by the Liverpool School of Tropical Medicine. The company TerraFrame engineered the software, including the system's GIS platform. The IVCC provided funding for the system's initial development. Funding for implementation was provided by the President's Malaria Initiative and the Zambia Integrated Systems Strengthening Program through the United States Agency for International Development, Medical Care Development International, the Bill & Melinda Gates Foundation, and WHO.

The DDMS is a functional decision-making tool that uses open source technology that can integrate with other widely used health information systems, such as DHIS 2. The DDMS can augment current DHIS 2 functionality by providing unique tools that support daily decision making in vector-borne disease control programs. Data can enter the system via the DDMS and be exported for use in other applications, including into databases such as DHIS 2 for integration with higher-level health system data.

Data Inputs

Data inputs include:

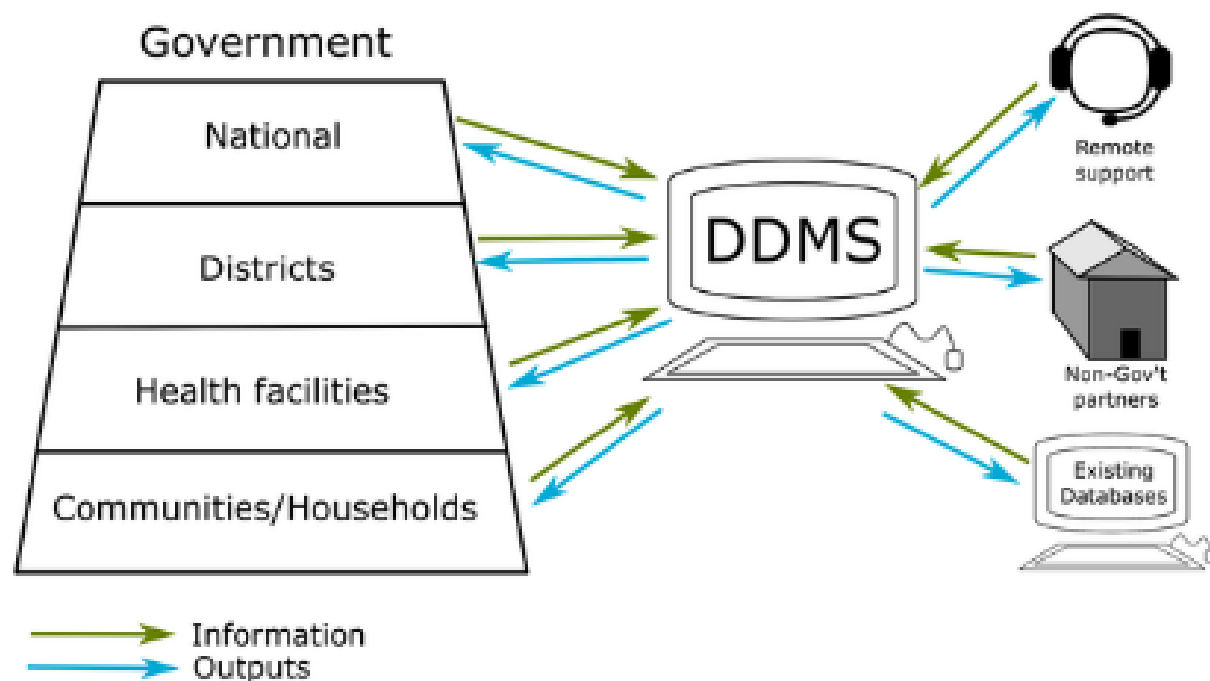
- User input (spreadsheets, survey data, geo-locations, etc.)
- Existing health information systems (DHIS, DHIS 2)

- Information tree: One of the most powerful points of adaptation in the system is the user-configurable vocabulary term tree. The term tree is based on ontological principles, following the Open Biomedical Ontologies: <https://www.nature.com/nbt/journal/v25/n11/full/nbt1346.html>.

Structure and Interface

Figure 8 shows a typical setup for implementation of the DDMS. The server can sit at any level with a reliable Internet connection, but usually it is at the national level (Ministry of Health) or with a nongovernment partner. It can also be offsite on an international server and is therefore compatible with cloud computing.

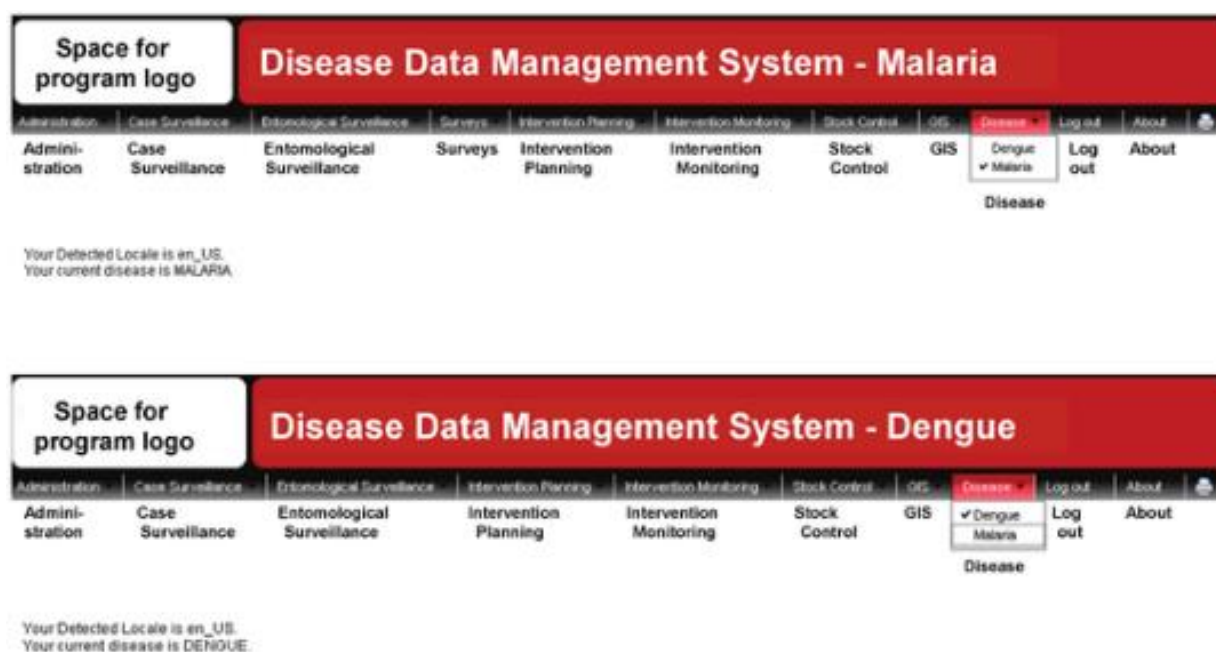
Figure 8. DDMS conceptual framework



Source: Thomsen, et al., 2016

A screenshot of the user interface is displayed in Figure 9. One adaptability in the system is the disease of interest. This is handled through a menu item called Disease, through which the user can select the disease of interest. Current options include dengue and malaria.

Figure 9. DDMS user interface



Source: Eisen, et al., 2011

Outputs

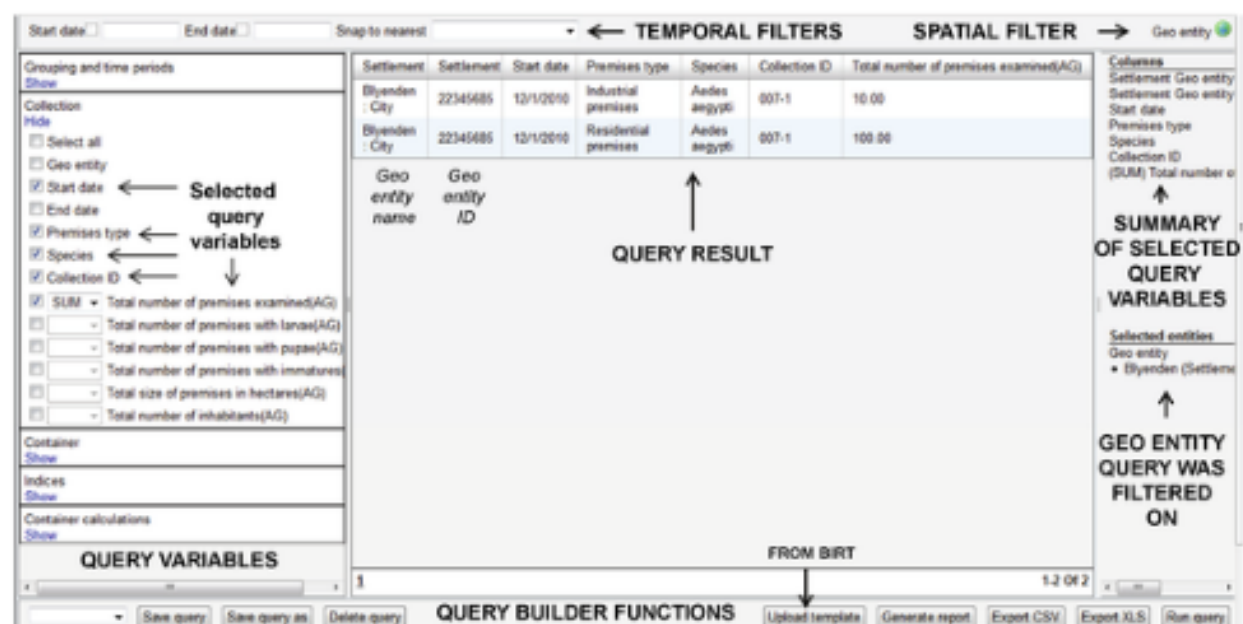
The DDMS gives output in the following formats, which are also shown in Figure 10:

- Reports:** Each module in the system (e.g., case surveillance, entomological surveillance, IRS planning, IRS monitoring, stock control) has its own query builder, allowing users to run reports simply and quickly, with just a few clicks.

The DDMS dashboard is typically configured in a real-time format that presents a set of automatically updated graphs. For example, the Zambia dashboard, focused on IRS, has a set of graphs for several topics: operational coverage, application ratio, and planned coverage. Each topic has separate graphs, presenting data by province, by team, and by week.

The system also has programmed thresholds for outbreaks and epidemics, which, when reached, trigger automatic alerts (e-mail and text messages) to all relevant personnel.
- Maps:** A GIS module allows users to query data to generate and overlay map layers to present data in geographic format. The maps can combine data from any module or group of modules.

Figure 10. Output of DDMS



Source: Eisen, et al., 2011

Use

The DDMS is a scalable tool from the district (field) to national levels and has been implemented in seven countries: Benin, Equatorial Guinea, Ethiopia, Ghana, India, Mali, and Zambia.

The DDMS is a tool designed to meet the data management and decision support needs of vector-borne disease control programs as they transition from malaria control to elimination. The DDMS offers several unique features that can support the global goals of malaria elimination and control. First, as a multi-disease system, the DDMS facilitates the integration of vector control programs, which can bolster neglected tropical disease elimination efforts. Second, because of standardized data formats, the DDMS facilitates cross-border collaboration and collective decision making. The feasibility of this has already been demonstrated through the Africa IRS project. Third, the DDMS has a sophisticated alert system that responds in real time as individual cases are entered. Lastly, the DDMS uses open source technology that can integrate with other widely used health information systems, such as DHIS 2. The DDMS can augment current DHIS 2 functionality by providing unique tools that support daily decision making in vector-borne disease control programs. DDMS data can be imported to DHIS 2 for integration with higher-level health system data.

The DDMS implemented in Zambia was a good example of how the system can impact decision making, despite its challenges. The DDMS has not been used in Zambia since November 2014, primarily due to a loss of momentum because the responsibility of maintaining the system shifted between malaria control partners. This has highlighted the need to bolster the capacity of related systems (organizational data culture, data collection procedures, information technology infrastructure) to support DDMS implementation. More details can be found at <http://journals.plos.org/plosntds/article?id=10.1371/journal.pntd.0004342#sec005>.

Strengths and Limitations

The DDMS is flexible and can be adjusted for any vector-borne disease control program. The tool can support decision making from malaria control through elimination phases. It offers reporting and spatial visualization components for multiple diseases that are integrated into a single tool and can be integrated into DHIS 2. Users can customize reports to meet their needs.

There were some challenges in the use of the tool, however. In at least one country (Zambia), the tool was not able to maintain momentum, in part due to support and maintenance issues, and is no longer used. DDMS's versatility sometimes causes untrained users to perceive the system as being overly complex. In addition, the DDMS cannot integrate data captured directly via mobile devices. Thomsen, et al. (2016) contains additional discussion of challenges and opportunities of DDMS (see: <https://doi.org/10.1371/journal.pntd.0004342>).

Tool 7: Intermittent Prevention and Treatment of Infants Decision Support Tool

Description

The intermittent prevention and treatment of infants (IPTi) DST is a web-based, interactive tool intended to aid national and subnational policymakers in assessing whether IPTi is a locally appropriate intervention by providing information to support IPTi-related policy discussions. The tool was developed as a collaborative effort between the London School of Hygiene and Tropical Medicine and the Swiss Tropical and Public Health Institute on behalf of the IPTi Consortium with funding from the Bill & Melinda Gates Foundation and the UK Department for International Development. Additional information can be found at <http://ipti.lshtm.ac.uk/>.

Data Inputs

Data inputs are as follows:

- **Transmission intensity:** The most recent estimates of the annual entomological inoculation rate were used, supplemented by data extracted from systematic reviews of the malaria literature. Given the large gaps in entomological and parasitological data, estimates were made based on models developed by the Malaria Atlas Project.
- **Seasonality:** Seasonality of malaria transmission was extracted from the published literature where available. If this information was not available, the Mapping Malaria Risk in Africa database provided a classification based on season of climate suitability for malaria transmission. Some of these data may not accurately reflect the current transmission setting that applies to a given area, so the system includes an opportunity for users to input data or their opinion, based on professional experience in the field.
- **Age patterns:** Continuous probability distributions were fitted to six transmission scenarios using data on the age distribution of malaria morbidity and mortality based on a systematic literature review of epidemiological research studies in sub-Saharan Africa.
- **Cases averted:** An individual-based stochastic model of IPTi was used to predict the number of cases and deaths likely to be averted with IPTi using sulphadoxine-pyrimethamine for the six transmission scenarios.

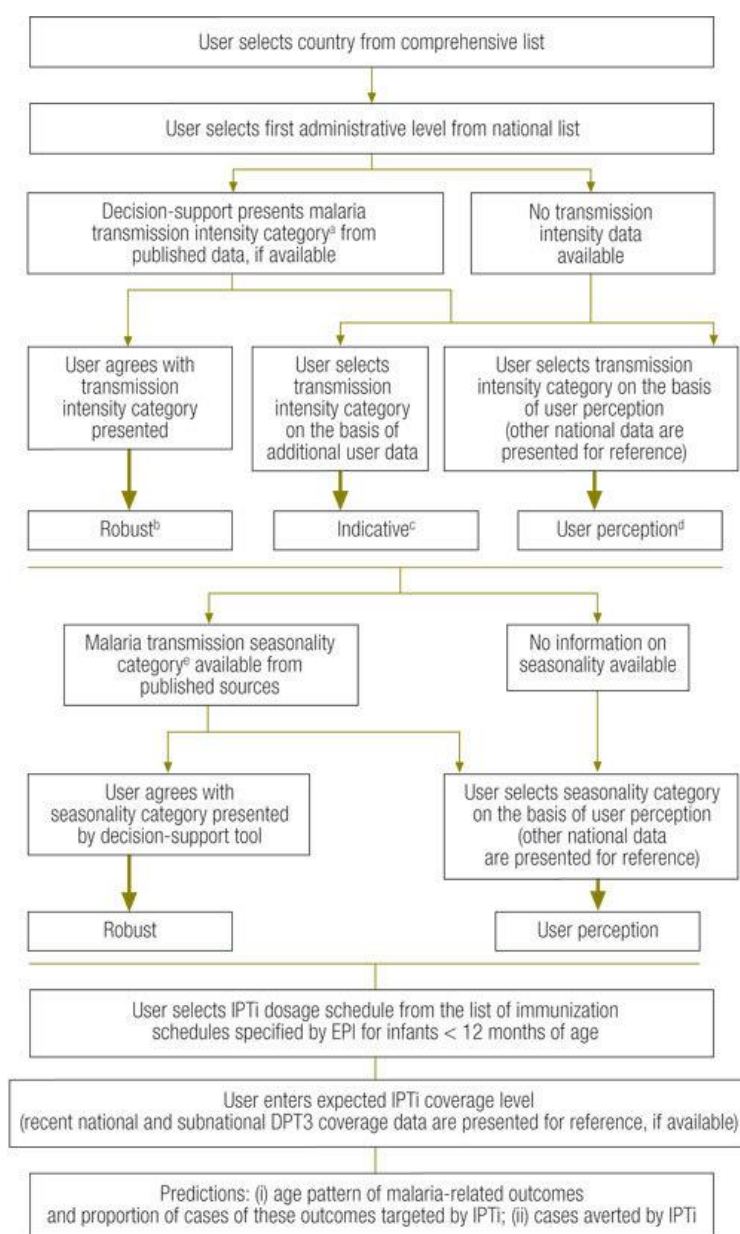
- **Cost effectiveness:** After calculating the morbidity and mortality averted, the tool estimates the costs and savings to the health system associated with introducing IPTi.

Structure and User Interface

For a scenario specified by the user, the IPTi DST provides graphical information on the predicted age distributions of patients with clinical malaria, those admitted to hospital with malaria parasites, and those who will die due to malaria. In addition, the percentage of cases of each malaria-related outcome in children under 10 years of age that would be targeted by the IPTi strategy is estimated. The stochastic model produces estimates of the predicted number of cases of each malaria-related outcome that would be averted if IPTi were implemented, while taking into account the expected treatment program coverage and using the assumptions about health system coverage, the effectiveness of treatment, and the level of drug resistance described above.

Figure 11 illustrates the structure of a DST for predicting the effect of IPTi for malaria in different scenarios in sub-Saharan Africa.

Figure 11. Structure of DST for IPTi effects



Notes: DTP3, third dose of diphtheria–tetanus–pertussis combined vaccine; EPI, Expanded Program on Immunization.

^a Malaria transmission intensity is categorized as low, medium, or high according to whether the entomological inoculation rate is < 10 (low), 10–100 (medium), or > 100 (high) infective bites per person per year.

^b The selected data are described as “robust” when based on screened epidemiological data.

^c The selected data are described as “indicative” when based on additional unscreened data provided by the user.

^d The selected data are described as based on “user perception” if not based on epidemiological data.

^e Malaria transmission is categorized as seasonal when at least 75 percent of clinical episodes occur within a period of six months or less.

Source: Carneiro, et al., 2010

Outputs

The tool provides the following outputs:

- A graph of the age pattern of malaria morbidity and mortality for a given subnational administrative area and an estimate of the proportion of infants that would be targeted by IPTi. There are six possible malaria age patterns, based on the expected transmission intensity and seasonality for that setting.
- The number of cases averted for each of these transmission settings adjusted for the level of sulphadoxine-pyrimethamine drug resistance and the coverage of IPTi.
- The cost-effectiveness of introducing IPTi, using estimated local costs.

Use

The tool can be used at the national and subnational levels and is easy to use without any specific training. The tool is restricted to sub-Saharan Africa countries that have endemic transmission of *Plasmodium falciparum* malaria. It is unknown which countries have used the tool, but specialists from 19 African countries participated in the tool's development: Angola, Burkina Faso, Cameroon, Côte d'Ivoire, Gabon, The Gambia, Ghana, Guinea Bissau, Kenya, Malawi, Mali, Mozambique, Nigeria, Sao Tome, Senegal, Sudan, Tanzania, Uganda, and Zambia.

The tool can identify whether a malaria control intervention that targets infants is appropriate. It can be used by national malaria control programs, which want to have maximum impact on illness and death attributable to malaria and need to design interventions for the most vulnerable age groups.

Strengths and Limitations

The IPTi DST is based on estimates, and its use is limited to infant populations. This could be considered a strength because the tool provides a good coverage of the issues related to infants. At the same time, this is a limitation of the tool because it can be applied to only a small segment of the population.

Tool 8: Lives Saved Tool

Description

The Lives Saved Tool (LiST) is free PC-based software for modeling child and maternal mortality. LiST has been used by government agencies and nongovernmental organizations (NGOs) in more than 90 countries to estimate the impact of future health and nutrition interventions and model on child survival, maternal mortality, and birth and nutrition outcomes. LiST was developed by the Institute for International Programs at Johns Hopkins Bloomberg School of Public Health and funded by the Bill & Melinda Gates Foundation as a model to estimate the impact of scaling up health and nutrition interventions on maternal, newborn, and child health, and stillbirths. LiST is a functional DST that is part of the Spectrum software package, an integrated suite of policy modules. Spectrum allows the user to link LiST and other analytic tools, including: Demproj (demography), LiST costing (costs of interventions in LiST), and Malaria (malaria interventions and impact). The LiST database includes preloaded default data, based on available scientific literature and global

data sources. The default data are updated regularly to ensure that coverage is up to date. The user can also load custom data.

Data Inputs

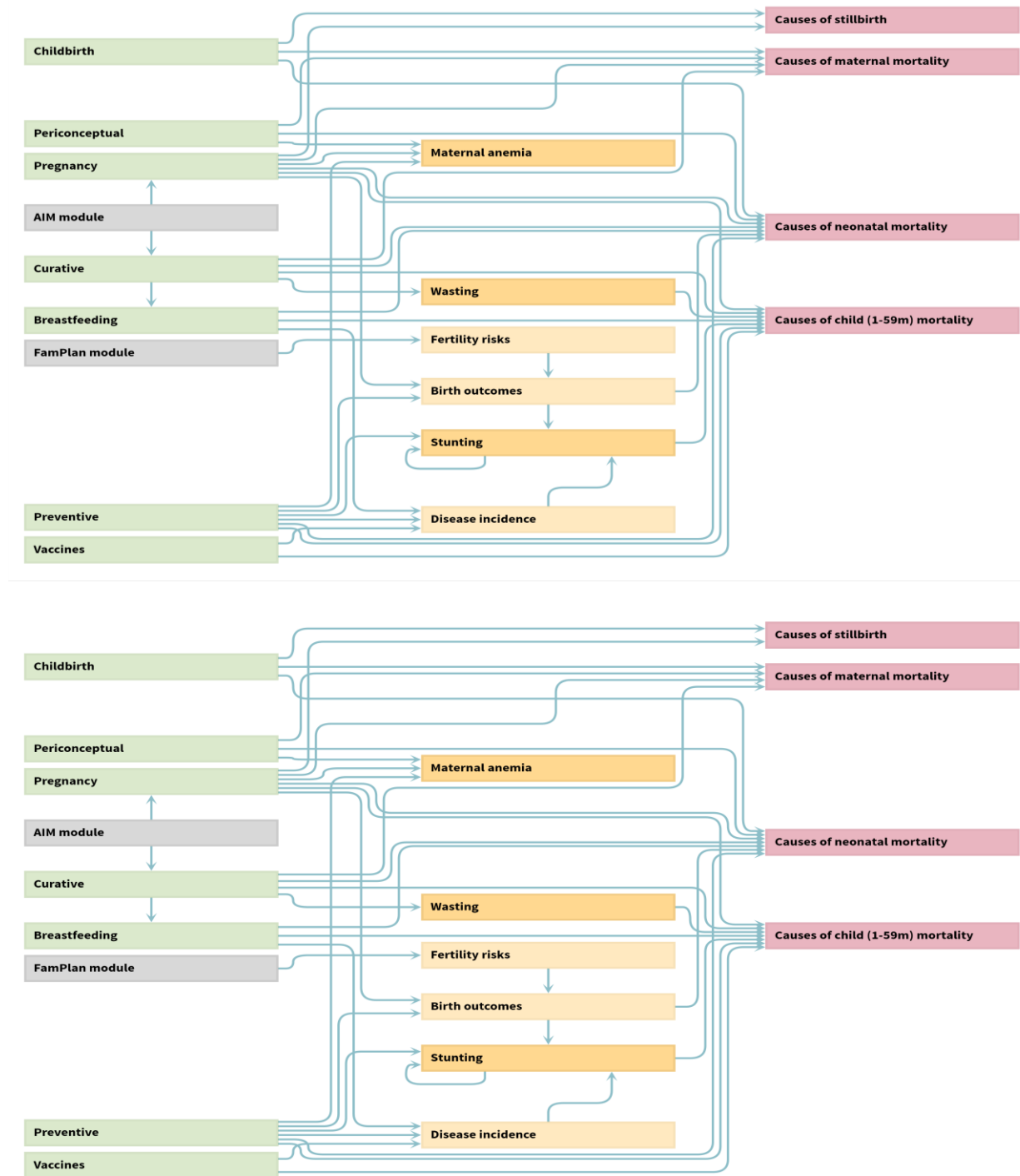
- **Demography** details that are either read directly from demographic projections produced by the United Nations Population Division or derived from national or subnational demographic estimates
- **Cause of death** information for neonates, children under five, mothers, and stillbirths, from country-specific WHO profiles or estimated by using local data sources
- **Coverage** levels for a variety of key health interventions that affect child and maternal mortality
- **Health status** indicators for a national or subnational setting
- **Effectiveness** estimates for neonatal, child, and maternal interventions from the latest scientific reviews and literature

Data are routinely derived from the Demographic Health Surveys, Multiple Indicator Cluster Surveys, and other nationally representative household surveys, including Malaria Indicator Surveys.

Structure and User Interface

The LiST framework is shown in Figure 12. This model displays the interdependencies among key outcomes (stillbirth, maternal mortality, child health, and neonatal mortality), intervening factors (e.g., fertility risks, disease incidence, stunting, maternal anemia), and various input factors (e.g., information on childbirth, family planning, breastfeeding, pregnancy, vaccines).

Figure 12. Structure of LiST



Source: The Lives Saved Tool [Brochure]. (n.d.) Retrieved from <http://www.livessavedtool.org/images/documents/20161104--two-pager.pdf>

Outputs

The LiST module produces estimates of global health impact by modeling outcomes such as:

- Neonatal and child mortality
- Maternal mortality
- Stillbirths
- Birth outcomes (preterm, small for gestational age, low birth weight)
- Nutrition outcomes (stunting, wasting, anemia)

Use

The tool can be used at the national and global levels and is available online. LiST has been used by ministries of health, NGOs conducting evaluations at the program level, and in-country organizations for prospective program planning and retrospective analysis. The tool was also used to examine which interventions contributed to a change in mortality based on coverage measured in DHIS 2 and Multiple Indicator Cluster Surveys and to support advocacy at the local, national, and global levels.

Strengths and Limitations

LiST has a user-friendly intuitive interface and provides research-based default data. However, the tool is integrated into a proprietary software package (Spectrum) that limits access. In addition, the LiST model does not include environmental, economic, and social factors and does not use an inference mechanism to identify key constraints.

Tool 9: Innovations at Scale for Community Access and Lasting Effects

Description

Agentes polivalentes elementares (APEs) are community health workers who have been deployed since 2010 in Mozambique and Uganda to improve access to basic health care in remote areas. The five-year research project Innovations at Scale for Community Access and Lasting Effects (inSCALE) is intended to improve APEs' quality of care and extend the program nationally. Details for inSCALE can be found at: <http://www.malariaconsortium.org/inscale/pages/inscale-project>. Information about the implementation of inSCALE in Mozambique can be found at <http://www.africanstrategies4health.org/uploads/1/3/5/3/13538666/inscale.pdf>.

The project's implementation started in 2013 and its implementation partners were the Malaria Consortium, Dimagi, Inhambane provincial health directorate, the Mozambique Ministry of Health, the Uganda Ministry of Health, the London School of Hygiene & Tropical Medicine, and University College of London. The two main features of inSCALE are the APE CommCare support tool and the CommCare HQ web-based, real-time dashboard for program planners.

Data Inputs

The inSCALE mobile phone software collects aggregated community patient data—such as number of patients treated, births, and deaths—as well as APE drug stock levels and, in Mozambique, the number of

community health talks conducted. These data are submitted to a server on a weekly basis. The data are made accessible online to district statisticians for forecasting and to use to integrate in regional and national health information systems. In Mozambique, using a smartphone that is capable of more advanced features allows for individual patient data to be submitted in real time to a server using a 2G or 3G network.

Structure and User Interface

The application was built using CommCare, an open source mobile health platform that consists of two main elements: CommCare Mobile and CommCareHQ. The handset application, CommCare Mobile, enables easy electronic data collection, decision support, patient and case management, workflow, and behavior change communication across large numbers of users. APEs use the mobile application during patient visits as a data collection and educational tool, and it includes audio and image prompts. The backend, the CommCareHQ web application, provides reports, dashboard analytics, user and domain management, data viewing, and performance management analysis to create actionable insight into the collated data. CommCare uses XForms, a World Wide Web Consortium international standard with a significant footprint across mobile platforms that are used in low-resource settings, including OpenXData, EpiSurveyor, JavaRosa, and OpenDataKit. The data collection forms are also fully configurable on the backend interface and can be sent from there to the handset. The interface also has a provision for managing versions of the phone application to make it easier to download new iterations of the software for users when they update their systems.

Outputs

Outputs from the tool are as follows:

- The CommCare application provides image and audio guidance for APEs to assess, classify, treat, or refer patients.
- CommCare HQ provides weekly and monthly summary reports on diagnosis, treatment, and follow-up of patients to facility- and district-based supervisors. This information can guide supervision meetings and assist in reaching performance-based competency goals.

Use

The scalability of the tool depends on size of APE unit deployed to a given remote area. Minimum theoretical requirements are one APE worker with a compatible mobile phone and access to the Internet. Malaria Consortium provided user training, but additional training was required in Android phones and AppLocker applications. The data are collected by an APE, transmitted to a server, and then analyzed by supervisors to aid in improving APE efficiency and performance. In addition to the benefits of data aggregation and data-driven management, inSCALE strengthens communication by allowing each APE a monthly credit allowance for calls to peers and supervisors. Implementation began in six districts in Inhambane Province, Southern Mozambique, in June 2013.

Strengths and Limitations

The tool is highly flexible and scalable. It relies on mobile phones, which are ubiquitous, even when electricity may not be, as documented by the Pew Research Center (2015). The tool has a few challenges, however, including a non-functional search option, and it is dependent on the availability of electric power and a stable

Internet connection. Furthermore, the tool is highly dependent on the ability of national-level officials to use the aggregated data.

Tool 10: upSCALE mHealth System Strengthening for Case Management and Disease Surveillance

Description

This tool is an extension of the previous inSCALE project (Tool 9) which uses mobile health (mHealth), using mobile phones and wireless technology, to improve APEs' quality of care, extend the program nationally, and provide aggregated data to national policymakers. The tool is currently in development. (Official documents list the project length as February 2016–March 2017.) The tool consists of two parts: an APE app, which renames and extends the inSCALE CommCare mobile app, and mHealth system developments (e.g., government reporting application). The APE-level indicators are stored in DHIS 2.

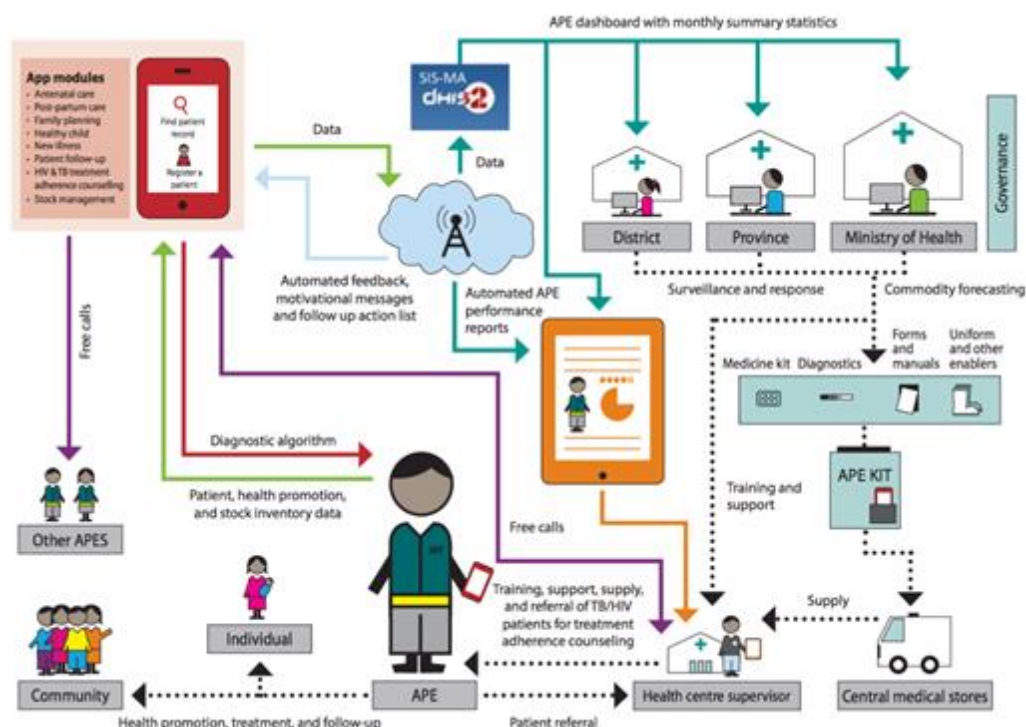
Data Input

Patient data are collected by an APE, transmitted to a server, and then analyzed by supervisors to aid in improving APE efficiency and performance. The documentation lists patient-focused rather than disease-focused service as a new goal of the improved mHealth mobile app. Limited information is available about specific changes.

Structure and User Interface

To build the APE mHealth system, APE-level indicators will be integrated in Mozambique's electronic DHIS 2 platform, known locally as Sistema de Informação de Saúde de Moçambique para Monitorização e Avaliação (SIS-MA). The APE-level indicators in SIS-MA will be populated in real time from data collected by APEs and submitted directly to SIS-MA. Government health officials will be able to view these data on the APE dashboard in a user-friendly format. This system will assist with data-driven decision making regarding APE program investments, surveillance, and responses to malaria, and early detection of disease outbreaks. APEs will submit data directly to SIS-MA using the APE app, an interactive mobile phone application that guides community health workers through the diagnostic process, provides treatment recommendations, issues targeted behavior change messages for patients, and collates input data. Dedicated modules within the application will also be developed to better assist stock management needs and preparation for community health talks. The overall conceptual framework is summarized below in Figure 13.

Figure 13. Conceptual framework of the APE mHealth system



Source: upSCALE: mHealth system strengthening for case management and disease surveillance [Project Brief]. (2016, December). Retrieved from <http://www.malariaconsortium.org/media-downloads/850/upSCALE:%20mHealth%20system%20strengthening%20for%20case%20management%20and%20disease%20surveillance>

Outputs

- The APE dashboard provides data aggregation as before, but for a different audience (government officials).
- The CommCare application provides image and audio guidance for APEs to assess, classify, treat, and refer patients.
- CommCare HQ provides weekly and monthly summary reports on diagnosis, treatment, and follow-up of patients to facility- and district-based supervisors. This information can guide supervision meetings and assist in reaching performance-based competency goals.

Use

upSCALE is an extension of inSCALE and follows similar restrictions. As with inSCALE, the app will be designed to be scalable. The scalability of the government reporting system may depend on the deployment of health management software. The training plan has not been specified. In its previous version, inSCALE, Malaria Consortium trained trainers who were able to share information with APEs and supervisors in their respective areas.

The upSCALE platform is currently being implemented in the Mozambique provinces of Inhambane, Cabo Delgado and soon in Zambezia, but it is unclear whether it has been fully deployed.

Strengths and Limitations

The tool is highly flexible and scalable. It relies on mobile phones, which are ubiquitous, even when electricity may not be. The tool is highly dependent on ability of national-level officials to use the aggregated data delivered by the tool to shape successful policies.

Tool 11: Primaquine Roll Out Monitoring Pharmacovigilance Tool

Description

WHO recommends low-dose primaquine to prevent *P. falciparum* malaria transmission. Despite this recommendation, few countries have adopted it as a national treatment policy. Countries remain concerned about the risk of hemolysis (destruction of red blood cells) in individuals with glucose-6-phosphate dehydrogenase deficiency. Although the risk exists, a low enough dosage of glucose-6-phosphate dehydrogenase can maintain the benefits of treatment while mitigating side effects. The Malaria Elimination Initiative (MEI) developed the Primaquine Roll Out Monitoring Pharmacovigilance Tool (PROMPT) to support the rollout of primaquine treatment by monitoring the safety of the WHO-recommended low dose. MEI is a program at University of California, San Francisco. PROMPT is a medication efficacy monitoring tool based on Microsoft Excel.

Data Input

Data inputs for the tool are as follows:

- Medication information: Medication name, dosages, quantity given
- Hemoglobin levels: Day 0 vs. Day 7 from medication administration
- Urine sample: Day 0 vs. Day 7 to check for hemolysis
- Other related analytic figures: Binary field for whether the hemoglobin value dropped more than 30 percent from Day 0 to Day 7

PROMPT mentions the possibility of data collection from a third follow-up up to four weeks after administration (but after Day 7).

Structure and User Interface

PROMPT comprises: (1) a standardized form (on either a paper or electronic platform) to support the surveillance of possible adverse events following treatment with single low-dose primaquine; (2) a patient information card to enhance awareness of known adverse drug reactions to the use of single low-dose primaquine; and (3) a database compiling recorded information, such as patient characteristics and malaria diagnosis and treatment.

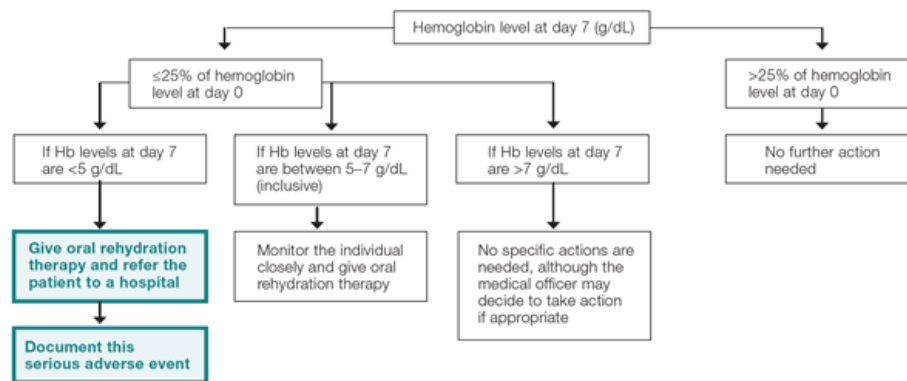
Output

PROMPT outputs are as follows:

- Treatment options for healthcare providers to mitigate the consequences of hemolysis (see Figure 14 for the algorithm)

- Guidance on the effectiveness of rollout on a national scale to management

Figure 14. Algorithm for comparing hemoglobin at Day 7 to Day 0



Source: MEI, University of California, San Francisco, n.d.

Use

The tool is highly scalable and depends on local healthcare providers' access to technological resources (computer, Microsoft Excel). Internet is required to submit data for national-level aggregation. Support for using the tool can be obtained by contacting MEI's Amanda Chung (Amanda.Chung@ucsf.edu). PROMPT has been used as a pilot in Swaziland. It began in two hospitals which reported the most malaria patients in the country. Data were collected from 100 patients to determine the safety of the WHO guidelines for primaquine. In the pilot, dosage safety was confirmed, and Swaziland's National Malaria Control Program was empowered to adopt the WHO recommendation.

PROMPT is a surveillance tool. For proper implementation, healthcare providers must regularly track treated malaria patients and enter their information into a database. Collected data must be regularly sent to a national body to provide data that can empower officials to adopt the WHO guidelines.

Strengths and Limitations

PROMPT's primary purpose is assisting in the national adoption of primaquine treatment, making it flexible, scalable, and lightweight. Its intended deployment seems to be a limited sample size, as in Swaziland. In the long term, PROMPT may be able to assist in treating primaquine side effects through its flow chart treatment algorithm (see Figure 14). However, the cost of maintaining the program in terms of person-hours will likely outweigh the benefit.

DISCUSSION

Analysis of Tools

In the context of malaria, DSTs have been prototyped and field-tested, primarily in Africa. Some of these tools are meant to aid high-level decision making. MDAST, for example, developed at Duke University and piloted in Kenya, Tanzania, and Uganda, is “designed to assist policymakers in considering multiple interventions and impacts in concert” (Paul, et al., 2015). Other DSTs are focused more narrowly on a specific issue within prevention or surveillance. The DDMS, for example, has been used to manage entomology data in Ethiopia, Ghana, Madagascar, Mali, Mozambique, Zambia, and Zimbabwe.

Although DSTs are engaged with different aspects of malaria control, they share similarities. All were financed by international organizations and draw data primarily from national health information systems. Some DSTs draw on GPS and GIS data, which put data in comprehensible and communicable visual formats.

In fact, geospatial tools using GPS and GIS technology were developed to aid visualization and quick comprehension of malaria’s spatial context. Geospatial analysis permits the addition of map layers that integrate other sorts of relevant data, beyond what are typically available in a health information system, such as geo-tagged climate and land-use data. Fairly significant literature has emerged on the topic of geospatial analysis for malaria control (Booman, et. al., 2000; Martin, Curtis, Fraser, & Sharp, 2002; Robinson, Harris, Hopkins, & Williams, 2002; Chanda, et. al., 2012; Wangdi, et. al., 2016). These systems, when designed and applied effectively, provide health programs with a powerful, user-friendly operational tool for evidence-based decision making to support management issues with a spatial or geographical focus. As elimination activities intensify and the malaria incidence approaches zero, higher-resolution mapping at the household level may be required in residual areas of transmission.

Of the 11 tools inventoried, three can be categorized as DSTs allowing inputs of data estimates that are then used to develop outcome scenarios for decision making regarding the prevention of morbidity and mortality and disease transmission: MDAST, IPTi DST, and LiST. MDAST is a comprehensive modeling tool that takes into account input parameters on malaria burden, population stratification, environment, and economics. Although it is comprehensive, it is a complex tool, and users may find difficulty in fully exploiting its functionalities and outputs. It is the only tool that provides up to three projected outcomes and impacts of decisions based on hypothetical scenarios entered by the user. For several parameters, default values are given, which the user needs to understand. The Analytica software engine is the modeling tool used, and the transparency of the modeling algorithms is not clear.

The IPTi DST is geared for prevention of malaria among infants based on estimated data inputs on epidemiology and the transmission intensity, seasonality of such transmission, age patterns, and local cost data on prevention and interventions. The tool provides an estimate of the cases that can be averted.

LiST is generalized modeling software for estimating the impact of scaling up health and nutrition for neonatal and maternal health. It is a retrospective model based on historical data of child mortality, stillbirths, etc., and has been successfully used for research, as well as by ministries of health and NGOs.

Many DSTs use GIS. Detailed maps are a powerful tool for field users as well as those at the district and national levels. Five DSTs (the SDSS for malaria elimination in Bhutan and in the Solomon Islands and Vanuatu, the MDSS used in Kenya, the GIS-based decision support system to enhance malaria control in Zambia, and the DDMS for enhancing decision support for vector-borne disease control programs) use GIS effectively in the monitoring and surveillance, control, and elimination of malaria in countries worldwide, including Kenya, Mozambique, and Zambia in Africa; Bhutan and India in Asia; and the Solomon Islands and Vanuatu in the Pacific. Few tools rely on geographical reconnaissance in collecting geo-locations and household survey data on malariometric parameters at the household or higher levels and then map them to the GIS. Success stories in Bhutan and the Solomon Islands testify to the effectiveness of GIS-based tools for decisions on the prevention and control of malaria. These tools interface with health information systems or other digital data input (e.g., Microsoft Excel files). Some of these tools, such as the MDSS used in Kenya, may be integrated with other health information systems in the country. This can, in theory, enable easy transfer of data inputs and outputs into and out of the MDSS.

The Malaria Elimination ToolKit—PROMPT—is one tool for data collection for malaria control in low transmission areas. Data on hemoglobin levels in the subjects are collected seven days apart, using mobile devices and transmitted to cloud servers for analysis. Depending on the levels, a simple decision tree determines the interventions required.

The tools discussed cover a wide range of applications, from comprehensive data inputs (e.g., malaria burden parameters such as vector ecology, interventions and their impact, or economics such as costs of LLINs and costs of interventions) and outputs (e.g., tables or charts, influence diagrams, maps), to estimates of future scenarios (e.g., MDAST), to simple and targeted interventions and decisions (e.g., PROMPT).

All the DSTs described in this report have a few challenges in common: start-up costs; ease of use and attractiveness to users; and the need for extensive training, technical support, and system maintenance. Under these circumstances, it may be difficult to maintain momentum. The DDMS, for example, although used effectively in at least seven countries, has been discontinued in Zambia, evidently due to a loss of momentum as the responsibility of maintaining the system shifted from one malaria control partner to another.

Technology Considerations

Most of the tools are based on open source software, ensuring long-term sustainability and cost efficiency. With an open source technical solution, program managers can have nearly all the capabilities of commercial products but will not have to worry about lapsed licenses or the purchase of an initial license. In regard to mapping software, for example, low-cost, high-quality mapping software is available from BoundlessGeo (boundlessgeo.com), essentially for free. It is a powerful software package, combining best-of-breed open source GIS software in a powerful suite (OpenGeo Suite) supported by a network of GIS professionals. Because the technology complies across the board with standards of the Open Geospatial Consortium, the organization that governs all GIS technical standards and practices, it can handle data produced by nearly any system.

This is not to suggest that open source software is a panacea. Developing countries that implement open source software will need information technology expertise in the open source arena to support ongoing

system operations and maintenance. Moreover, even though there appears to be a preference for open source software, most, if not all, of the tools we reviewed incorporate proprietary database software, such as Oracle or Microsoft Excel. Although the use of a high-end database management system, such as Oracle or Microsoft SQL Server, would involve high licensing costs, standard commercial software such as Microsoft Excel may still be a preferred choice despite its cost, simply because it is so commonly used and does not require much training.

TOWARD A NEW DECISION SUPPORT TOOL

Some of the DSTs that we have reviewed seek to aid high-level decision making, such as determining the most effective combination of interventions for a specific subnational region. Others are focused more narrowly on issues such as entomological information or ITN distribution. Addressing on-the-ground challenges to effectively distribute and deliver malaria interventions is still a major need, however. At the operational level, program managers and subnational decision makers are more concerned about implementation issues and want to identify and address gaps and constraints in providing high-quality malaria services. For example, uncertainty in demand projections can cause supply shortages or contribute to drug storage problems. Decision makers want to make sure that their estimates for malaria products such as ACTs and RDTs accurately reflect demand and that the products are tracked and optimally distributed. They also want to identify and address other important constraints, such as trained healthcare providers, healthcare facilities, and access to professional advice.

Existing tools do not fully address these needs; hence, there is a need for a new tool or improved tools, which may include forecasting, labor management, inventory tracking, supply planning, and knowledge management components, as well as a more sophisticated use of GIS.

Attributes of an Ideal Tool

The most important consideration in developing a tool is its intended users. Even if a tool has all sorts of superior features and a solid underlying model, great graphics, and so forth, it would be of little value if the intended users are not willing or able to use it. Therefore, an ideal tool:

- **Knows its users:** addresses users' actual needs
- **Takes users' inputs** into account during its design
- **Answers users' questions on what, why, and how:** *what* (e.g., what are the critical constraints? do we have enough lab technicians for the population?), *why* (e.g., why has distributing more bed nets not reduced the level of mortality?), and *how* (e.g., how can we best reduce mortality due to malaria?)

Some of the most important features of such a tool are as follows:

- Is **technologically simple** from the standpoint of maintenance and support
- Is **transparent** (has a clear underlying model and assumptions)
- Is **scalable** (should be able to address context-specific issues)
- **Enables** multidisciplinary discussions among stakeholders
- Is **easy to use** by different types of users
- Offers **visualization** capability
- **Learns** from experience as it is being used
- Has **access to prior case studies** (has a knowledge management component)

Thoughts on a Framework for a New or Modified Tool

A distinguishing feature of a new tool should be its focus on addressing important operational and implementation challenges facing subnational decision makers. Such a tool will build on and take advantage

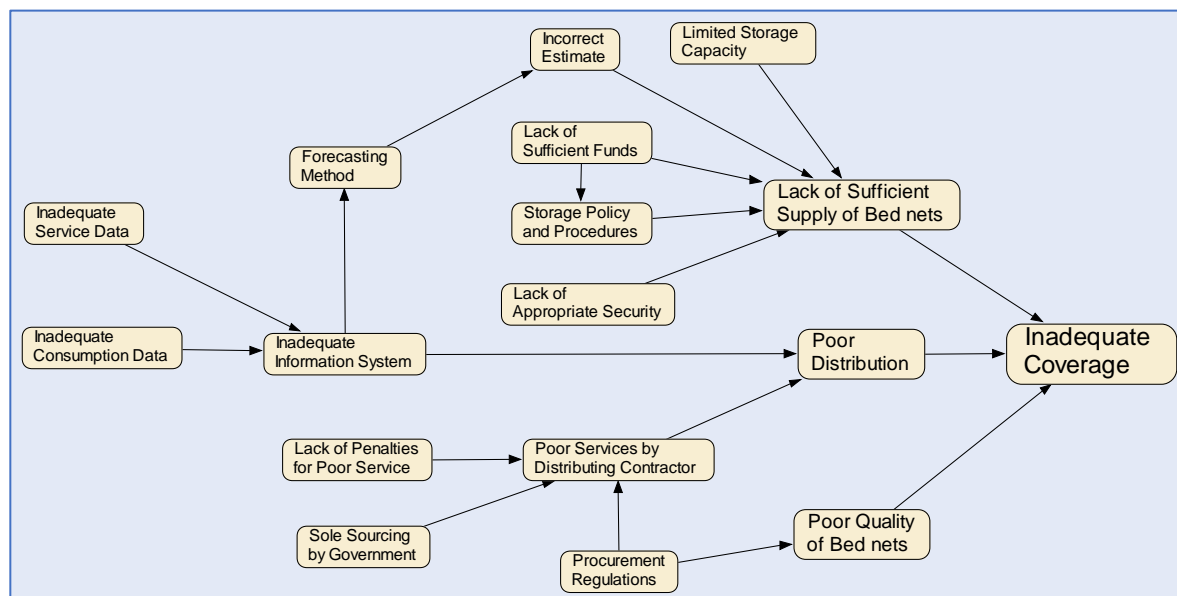
of the knowledge base of existing DSTs such as MDAST and will potentially establish links to those tools. This would require a thorough understanding of other tools, their underlying models, and technical capabilities.

Approach for a Potential Tool

The focus will be to develop a tool that helps solve problems in local contexts through interaction with stakeholders. As the tool is used by decision makers, it will learn from experience and modify its knowledge base accordingly.

Through active discussions and facilitated sessions with local stakeholders, we will develop a logical model that captures stakeholders' local knowledge and their understanding of various challenges and constraints. The methodology that we employ to capture such knowledge is problem-driven. We help stakeholders break down a problem into subproblems and then suggest or construct solutions for those problems. For example, suppose the problem at hand is inadequate coverage of bed nets for a certain population (shown as the “Inadequate Coverage” node in Figure 15). This could be due to lack of sufficient supply, poor distribution, or simply poor quality of bed nets procured. Lack of sufficient supply in turn might be due to inadequate funding for ordering bed nets or an inaccurate estimate, or a storage capacity limitation, etc. Poor distribution might occur because of issues with the distributing contractor (which in turn could be due to procurement regulations), or lack of good record keeping and information systems, and so on. Figure 15 below presents a diagram showing how one problem might be broken down into subproblems causally connected one to another. For an example of the application of this approach in a different context, identifying appropriate interventions to achieve better schooling outcomes, see Moussavi and McGinn, 2010.

Figure 15. Graphical representation of breaking down problems



Source: Causal Links, LLC, September 2017

This approach emphasizes that problems often have multiple causes, and, depending on the context, different solutions are needed. The point of this logical framework is to arrive at solutions based on a good

understanding of critical bottlenecks and constraints rather than following an externally defined “best practice.” After a solution for a problem is designed, it can be implemented and evaluated. This would give rise to active, experiential learning and the iterative feedback of lessons into new solutions (Andrews, Pritchett, & Woolcock, 2012). The tool that we envision is a tool that learns as it is used.

Models like the one shown in Figure 15, which represent stakeholders’ knowledge, would constitute an important part of the tool that we envision. The tool’s visualization component would enable subnational and national users to develop such graphical representations of problems on their own and engage in a debate on how to improve overall functionality. This would help them clearly communicate assumptions and constraints and identify entry points to address various problems.

Components of the Proposed Tool

In order to develop a tool that helps subnational decision makers with the implementation of malaria control interventions and specific operational challenges, it is essential that the stakeholders participate in its design. Thus, a main requirement of developing such a tool is extensive face-to-face dialogue with local actors and decision makers. What we describe below is a theoretical framework for such a tool.

Figure 16 shows the scope of the proposed approach and tool. We envision a tool that has the following integral components:

- A **knowledge base** that combines the specific knowledge of local stakeholders with the general knowledge of experts as well as learning from existing local data. This knowledge base would be represented in terms of a graphical model (see Figure 15) where causes and effects are identified and the inter-dependencies among various issues are represented and, to the degree possible, quantified based on the knowledge of stakeholders and the evidence available.
- **Data** from relevant databases that have information on logistics, inventory, demographics, procurement, and other relevant datasets.¹ It is assumed that the information systems that generate those databases include modules such as a forecasting model (e.g., for supply planning of products such as ACTs and RDTs).
- A **learning module** that applies machine learning algorithms to update and quantify the tool’s knowledge base and its underlying model (e.g., the model shown in Figure 15).
- A **situation assessment user interface** that links various components of the tool to one another. This could be standalone or web-based software, simple (e.g., Microsoft Excel) or sophisticated, that would enable the user to assess a problem at hand and drive to solutions based on a systematic review of critical issues and constraints as well as a review of prior cases. The inputs to this interface are the data from various databases, the knowledge base, prior cases, and the user’s input. The situation assessment user interface would pose questions to the user to learn about the situation at hand. The interface would also allow the user to inspect the knowledge of the tool and its reasoning behind recommended actions and decisions. This transparency is an important feature of the tool.
- An **inference engine** that would rely on the information provided through the situation assessment interface and would identify the most critical sources and causes of the problems.

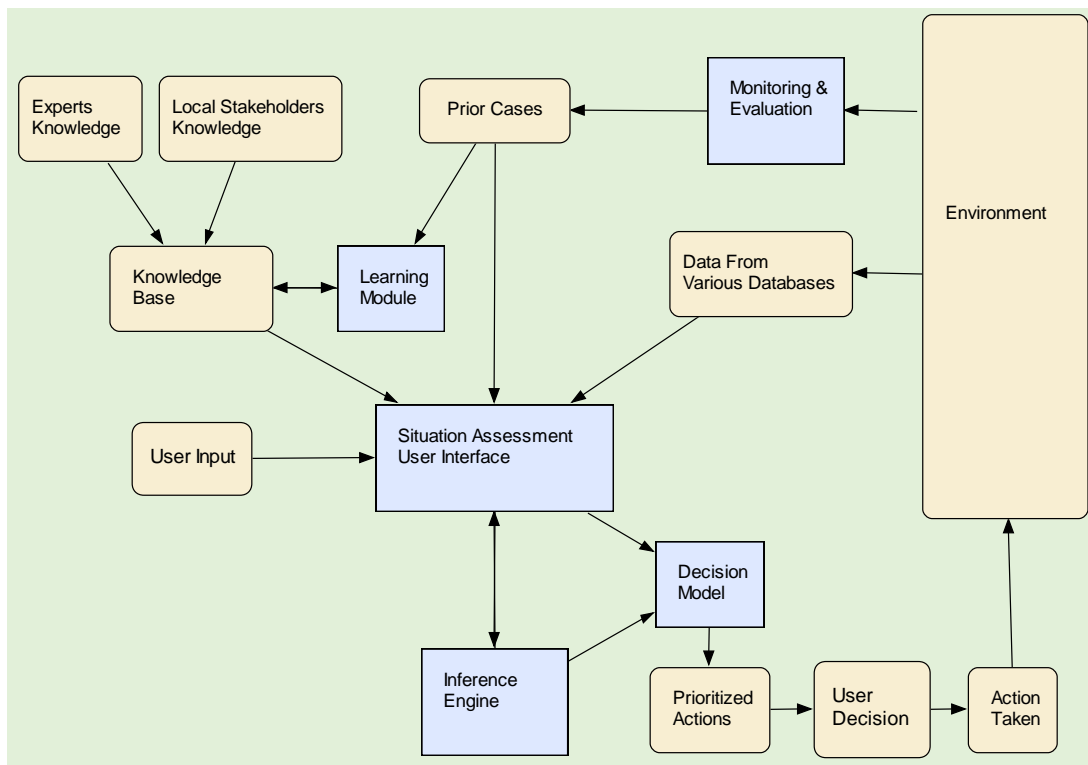
¹ It is assumed that the systems that populate those databases, such as a forecasting model (e.g., for supply planning of products such as ACTs and RDTs) are already in place. Otherwise, such components will be included as part of tool.

- A **decision model** that prioritizes necessary actions according to their impact and cost-effectiveness based on the diagnostics performed by the inference engine. This model would include a list of pre-identified actions and decisions (by stakeholders as well as those suggested in the research literature) so that a user could select one or more actions that address the identified problem. However, the decisions taken do not have to be limited to the set of pre-identified ones. The tool would allow for experimentation and inclusion of new actions.
- A **database of prior cases (knowledge management component)** that would include prior local cases as well as relevant cases and solutions from other districts or even countries. In a new situation, the tool might be able to adapt a solution based on a similar prior case.
- A **performance (monitoring and evaluation) component** that assesses the results of actions taken by the user and updates the relevant databases.

To design a well-functioning tool, appropriate to the operational landscape, it is crucial to inform policies and practices by systematically integrating all available evidence in an analytical framework that first identifies the most critical challenges and constraints in a given context and then evaluates various interventions that address those challenges. The common features of malaria programs around the world, as well as their successes, failures, and predicted development path, provide the context for a new framework for DSTs that can assist national and subnational program managers with establishing priorities on the basis of evidence and customizing their approach to malaria prevention and treatment.

At the same time, the framework presented above is flexible and general enough that it can be customized depending on the local needs. Some components of the tool envisioned might not be as relevant or essential at the field level. For example, in a country where the databases and existing information systems are not modern and up to date, the knowledge base component can still be developed, and the tool can be used at a high level to provide some guidance on what actions to take. Thus, the tool would be able to operate at different levels, depending on the level of data available.

Figure 16. Schematic diagram of the architecture of the tool



Source: Causal Links, LLC, September 2017

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APPENDIX 1. SUMMARY TABLE OF 11 DECISION SUPPORT TOOLS

1. Malaria Decision Analysis Support Tool

Funded by	Global Environment Facility, United Nations Environment program, World Health Organization (WHO)
Where used	Kenya, Tanzania, and Uganda
Uses	To facilitate informed decision making and evidence-based malaria policy development
Open source?	Proprietary
Database	Oracle
Data inputs	<ul style="list-style-type: none"> • Demographic and malariometric • Insecticide-treated net parameters • Indoor residual spraying (IRS) parameters • Disease management parameters
Data outputs	<ul style="list-style-type: none"> • Influence diagram
Strengths	<ul style="list-style-type: none"> • Comprehensive tool, up to 48 input parameters • Can compare up to three different strategies over a time horizon • User can input some parameters data and use default values for the rest
Weaknesses	<ul style="list-style-type: none"> • Complex modeling tool, not clear if usable in the field and district levels • Would require comprehensive training and support to use • Use of Analytica software engine as the proprietary modeling tool • No Graphical Information System (GIS) capability for visualization • No knowledge management (KM) component to suggest solutions based on others' experiences • Currently no environmental and social constraints and barriers identification model

2. Spatial Decision Support System (SDSS) for malaria elimination in Bhutan

Funded by	The Global Fund
Where used	Bhutan
Uses	To assist with the management of the Bhutanese malaria elimination program
Open source?	Open source
Database	Microsoft Excel; database housed within GIS
Data inputs	<ul style="list-style-type: none"> • Geographic reconnaissance (household location, total population, entomological data, etc.) • Geospatial data (climate and environmental factors) • Health information systems, routine and survey data
Data outputs	<ul style="list-style-type: none"> • Maps • Tabular reports • Statistical analysis
Strengths	<ul style="list-style-type: none"> • Focused on malaria elimination thru long-lasting insecticide-treated net (LLIN) and IRS interventions • Used effectively by field, subnational and national users • Uses Quantum GIS (QGIS) (open source) for mapping and internal database; Excel for data management and input • Can interface with health information system for data

2. Spatial Decision Support System (SDSS) for malaria elimination in Bhutan (cont.)

Weaknesses	<ul style="list-style-type: none"> • Malaria data are collected manually thru household surveys, entered in Excel, and then uploaded to the SDSS • Geo location (coordinates) are manually collected and mapped into QGIS • Not clear whether it has an inference engine that can assess the situation and identify policy barriers and constraints
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3. SDSS for malaria elimination (Vanuatu and the Solomon Islands)

Funded by	Australian Agency for International Development, Pacific Malaria Initiative, WHO, others
Where used	Vanuatu and the Solomon Islands
Uses	To support malaria elimination in Vanuatu and the Solomon Islands
Open source?	Open source
Database	Microsoft Access; GIS with interactive mapping interface
Data inputs	<ul style="list-style-type: none"> • Data collection/ fieldwork • Expert knowledge (e.g., relevant staff) • Baseline spatial data (e.g., GIS data file)
Data outputs	<ul style="list-style-type: none"> • Statistical spatial analysis • Tabular reports • Graphical maps
Strengths	<ul style="list-style-type: none"> • Focused on malaria elimination thru IRS and LLIN interventions • Rapid reporting thru the system of confirmed cases by household and mapping of active areas of interest for targeted response • Used effectively by field and national users • Extensive use of personal digital assistants and mobile devices for data collection and upload to the SDSS database
Weaknesses	<ul style="list-style-type: none"> • Use of proprietary software—Microsoft Access, ArcPad (ESRI, Redland WA, USA) and MapInfo for GIS • Need for specialized training for SDSS data collectors and users as well as for system operations and maintenance • No KM component

4. Malaria Decision Support System (MDSS)

Funded by	Innovative Vector Control Consortium (IVCC)
Where used	Kenya
Uses	To assist with intervention planning in Kenya
Open source?	Open source
Database	PostgreSQL, PostGIS
Data inputs	<ul style="list-style-type: none"> • Entomology • Health information • Epidemiology • Infectivity • Intervention coverage and usage
Data outputs	<ul style="list-style-type: none"> • Reports • Graphs • Maps

4. Malaria Decision Support System (MDSS) (cont.)

Strengths	<ul style="list-style-type: none"> • Provides continuous surveillance, monitoring, and evaluation of malaria control programs in Kenya • Integrated with other health information systems for data input and output • In addition to reports and charts, has query options for ad hoc queries • Decision making at subnational and national levels
Weaknesses	<ul style="list-style-type: none"> • Customized software for local requirements; not clear whether MDSS can be easily ported to other countries or regions • No model to assess the relationships among various factors and no inference engine • No KM component

5. GIS-Based Decision Support System

Funded by	No information available
Where used	Zambia
Uses	To facilitate policy formulation through data analysis, information management, and decision making
Open source?	Unknown
Database	Excel database and internal GIS database
Data inputs	<ul style="list-style-type: none"> • Entomology • Health information • GIS
Data outputs	<ul style="list-style-type: none"> • Graphs • Maps
Strengths	<ul style="list-style-type: none"> • Use of spatial analysis using GIS technology to control and predict vector-borne malaria transmission • Integrates with operational data for malaria control planning • Geared mainly for vector progression, insecticide resistance profiles, etc. • Better stratification of areas leading to better distribution of resources and interventions
Weaknesses	<ul style="list-style-type: none"> • Limited focus on vector control • No model to identify environmental, social, and other constraints • No built-in KM component

6. Disease Data Management System

Funded by	IVCC, President's Malaria Initiative, United States Agency for International Development, WHO, Gates Foundation, and others
Where used	Benin, Ghana, Ethiopia, Equatorial Guinea, India, Mali, Zambia
Uses	To support vector-borne disease control programs as they transition through control to elimination
Open source?	Open source
Database	Entomological database, DHIS 2 data
Data inputs	<ul style="list-style-type: none"> • User input (spreadsheets, survey data, geo locations, etc.) • Existing health information systems (DHIS/DHIS 2) • Information tree • Non-government partners
Data outputs	<ul style="list-style-type: none"> • Reports • Maps

6. Disease Data Management System (cont.)

Strengths	<ul style="list-style-type: none"> • Multi-disease decision support system • Highly configurable for any vector-borne disease control • Query builder allows users to go beyond canned reports and dashboards • Software components from other diseases are re-usable • Integrates with DHIS 2
Weaknesses	<ul style="list-style-type: none"> • No model to identify key policy constraints (environmental, social, economic, etc.) • No explicit decision model, no influence diagram • No KM component

7. Intermittent Prevention and Treatment of infants

Funded by	Gates Foundation, UK Department for International Development
Where used	Sub-Saharan African countries with endemic malaria
Uses	To identify malaria control interventions targeting infants
Open source?	Unknown
Database	Unknown
Data inputs	<ul style="list-style-type: none"> • Transmission intensity • Seasonality • Age patterns • Cases averted • Cost effectiveness
Data outputs	<ul style="list-style-type: none"> • Graphs (national, subnational areas) • Statistical reports • Cost-effectiveness estimator
Strengths	<ul style="list-style-type: none"> • Focused use for infants • Modeling tool for estimating malaria cases averted
Weaknesses	<ul style="list-style-type: none"> • Limited use for infant population

8. Lives Saved Tool

Funded by	Gates Foundation
Where used	43 malaria endemic countries in sub-Saharan Africa
Uses	To aid prospective program planning, facilitate retrospective analysis, assess impact, and support advocacy
Open source?	Proprietary
Database	Unknown
Data inputs	<ul style="list-style-type: none"> • Demography • Cause of death • Coverage • Health status • Effectiveness

8. Lives Saved Tool (cont.)

Data outputs	<ul style="list-style-type: none"> • Neonatal and child mortality • Maternal mortality • Stillbirths • Birth outcomes • Nutrition outcomes
Strengths	<ul style="list-style-type: none"> • Model-based tool for scaling up health and nutrition interventions for infants, children, and women • Used effectively by ministries of health and nongovernmental organizations
Weaknesses	<ul style="list-style-type: none"> • Uses proprietary Spectrum software • Basically, a tool to assess the impact of certain interventions rather than decide on what interventions are most needed • No model to assess the situation with regard to various factors (environmental, social, economic) • No inference engine to identify key constraints

9. upSCALE mHealth System Strengthening for Case Management and Disease Surveillance (Mozambique)

Funded by	Malaria Consortium, Gates Foundation
Where used	Mozambique
Uses	To assist decision making on program investments, surveillance, and responses to infectious diseases, including malaria
Open source?	Open source
Database	Online dashboard
Data inputs	<ul style="list-style-type: none"> • Antenatal care • Postpartum care • Family planning • Healthy child • New illness • Patient follow-up • HIV and tuberculosis treatment
Data outputs	<ul style="list-style-type: none"> • Governance • Commodity forecasting • Surveillance and response • Health center supervisor management
Strengths	<ul style="list-style-type: none"> • Information is easily scalable to national levels compared to the inSCALE mHealth decision support tool
Weaknesses	<ul style="list-style-type: none"> • Highly dependent on whether national-level officials are able to use the aggregated data delivered by this tool

10. inSCALE; Innovations at Scale for Community Access and Lasting Effects (Uganda)

Funded by	Malaria Consortium, Gates Foundation, London School of Tropical Medicine and Hygiene, institute for Global Health
Where used	Uganda
Uses	To integrate community health worker indicators with DHIS 2; produce district, provincial, and national aggregates
Open source?	Unknown
Database	Unknown
Data inputs	<ul style="list-style-type: none"> • Community health worker coverage • Input of results
Data outputs	<ul style="list-style-type: none"> • Landscape analysis • Formative research • Preliminary results • Lesson learning
Strengths	<ul style="list-style-type: none"> • Use of mobile phones for data collection and transmission to the server makes this a very efficient tool
Weaknesses	<ul style="list-style-type: none"> • Availability of electric power and stable Internet connection • A tool for sharing information but not a tool to assess the situation and suggest actions

11. Malaria Elimination Toolkit—Primaquine Roll Out Monitoring Pharmacovigilance Tool(PROMPT)

Funded by	Malaria Elimination Initiative, University of California, San Francisco Global Health Group
Where used	Swaziland
Uses	To treat malaria, track related adverse events among patients, collect and aggregate data for national malaria control programs
Open source?	Open source
Database	Microsoft Excel
Data inputs	<ul style="list-style-type: none"> • Baseline hematologic values • Subsequent monitoring values • Hemolytic events
Data outputs	<ul style="list-style-type: none"> • Track potential adverse events (for prevention) • Flag adverse events
Strengths	<ul style="list-style-type: none"> • Focused on national adoption of Primaquine treatment as the primary intervention • Simple and lightweight tool
Weaknesses	<ul style="list-style-type: none"> • Deployment, as in Swaziland, is for a limited population • Cost of maintaining PROMPT program using this tool can be quite high

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