









SOFTWARE TOOL ARTICLE

An interactive application for malaria elimination transmission and costing in the Asia-Pacific [version 1; peer review: 1 approved, 1 approved with reservations]

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Abstract

Leaders in the Asia-Pacific have endorsed an ambitious target to eliminate malaria in the region by 2030. The emergence and spread of artemisinin drug resistance in the Greater Mekong Subregion makes elimination urgent and strategic for the global goal of malaria eradication. Mathematical modelling is a useful tool for assessing and comparing different elimination strategies and scenarios to inform policymakers. Mathematical models are especially relevant in this context because of the wide heterogeneity of regional, country and local settings, which means that different strategies are needed to eliminate malaria. However, models and their predictions can be seen as highly technical, limiting their use for decision making. Simplified applications of models are needed to allow policy makers to benefit from these valuable tools. This paper describes a method for communicating complex model results with a user-friendly and intuitive framework. Using open-source technologies, we designed and developed an interactive application to disseminate the modelling results for malaria elimination. The design was iteratively improved while the application was being piloted and extensively tested by a diverse range of researchers and decision makers. This application allows several target audiences to explore, navigate and visualise complex datasets and models generated in the context of malaria elimination. It allows widespread access, use of and interpretation of models, generated at great effort and expense as well as enabling them to remain relevant for a longer period of time. It has long been acknowledged that scientific results need to be repackaged for larger audiences. We demonstrate that modellers can include applications as part

Open Peer Review

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	Invited Reviewers		
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- Catherine M. Smith** , University College London, London, UK
- Jon Haël Brenas** , Department of Pediatrics, Oak Ridge National Laboratory, Center for Biomedical Informatics, Memphis, USA
- Maxine Anne Whittaker** , James Cook University, Townsville, Australia

of the dissemination strategy of their findings. We highlight that there is a need for additional research in order to provide guidelines and direction for designing and developing effective applications for disseminating models.

Any reports and responses or comments on the article can be found at the end of the article.

Keywords

Model-based Decision Support System, Interactive application, Malaria, Elimination, Modeling, Modelling, Asia-Pacific, GMS



This article is included in the [Mahidol Oxford Tropical Medicine Research Unit \(MORU\)](#) gateway.



This article is included in the [Predicting the cost of malaria elimination in the Asia-Pacific](#) collection.

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Abbreviations

APLMA, Asia Pacific Leaders Malaria Alliance

DSS, Decision Support System

GMS, Greater Mekong Subregion (Cambodia, Yunnan Province in China, Lao People's Democratic Republic, Myanmar, Thailand and Viet Nam)

METCAP, Malaria Elimination Transmission and Costing in the Asia-Pacific

NMCP, National Malaria Control Programme

Pf, *Plasmodium falciparum*

Pv, *Plasmodium vivax*

WHO, World Health Organisation

Introduction

Malaria cases and deaths in the Asia-Pacific have declined dramatically in recent decades. However, there is a marked rise in the occurrence of artemisinin resistance across the Greater Mekong Subregion (GMS), which threatens to reverse the gains made¹. As a response, leaders in the Asia Pacific region at the highest levels have endorsed a regional goal of making the Asia-Pacific malaria-free by 2030 and many countries across the region are now working towards national elimination of malaria^{2,3}. Malaria Elimination Transmission and Costing in the Asia-Pacific (METCAP) is a cross-disciplinary project aimed at evaluating and comparing potential malaria control and elimination strategies for 22 countries in the Asia-Pacific region: Afghanistan, Bangladesh, Bhutan, Cambodia, DPR Korea, India, Indonesia, Lao PDR, Malaysia, Myanmar, Nepal, Pakistan, Papua New Guinea, People's Republic of China, Philippines, Republic of Korea, Solomon Islands, Sri Lanka, Thailand, Timor-Leste, Vanuatu, Viet Nam. At the core of METCAP is a dynamic epidemiological-economic multi-patch model of the transmission and costing of malaria that project malaria incidence until 2030 across several scenarios (i.e. using several packages of interventions for the elimination of malaria).

The METCAP model is the first mixed *Plasmodium falciparum* (Pf)/*Plasmodium vivax* (Pv) mathematical model. The METCAP model was built in three stages. First, country-specific information were obtained from several sources, including WHO's annual World Malaria Reports (2008; 2010–2015)⁴, published literature on glucose-6-phosphate dehydrogenase deficiency (G6PDd) prevalence⁵ and the Earth System Research Laboratory website for El Niño Southern Oscillation time series⁶. This data was used to build ranges of plausible estimates of several malaria-related indicators, including annual disease burden estimates⁷. The second stage consisted of modelling several indicators (such as the estimated incidence of all malaria species and reported fatalities) for each country between 2016 and 2030, under scenario-specific assumptions. A total of 80 scenarios were built based on 10 different sets of packages of interventions. These ranged from discontinuing most malaria control activities to a very substantial scale-up of interventions, which could be supplemented by mass drug administration (MDA) or an increase

in insecticide-treated net coverage, meanwhile assuming different trajectories of drug resistance (increasing or stable)⁸. The third and final stage was a full costing of each scenario that was done evaluating the costs of interventions per country, year and component⁹. This multi-patch model was developed in R language¹⁰ with calls to C++ routines to find numeric solutions to the model's ordinary differential equations (ODE).

The applicability of models for decision-making has been questioned by policymakers: with reactions ranging from them believing them completely or mistrusting them completely. Clearly the right place is between the two¹¹. Communicating the results of models effectively so as to eliminate biases and allow policymakers themselves to arrive at wise judgements is a difficult goal to attain¹². Policymakers, especially in developing countries, often report difficulties with the format and style in which research outputs are presented, stating that research reports are often written in an academic style using technical language and include complex statistics that are difficult to understand. On the other hand, researchers may feel that oversimplifying research findings will omit relevant details needed to fully understand the research problem. Researchers may also be concerned about the academic rigor of their work requiring details of research methodology and the use of technical terminology¹³. Decision support systems (DSS) are computer-based information systems that support decision-making activities by giving access to information organised to inform judgments and preferences about a range of intervention options and their trade-offs. Several DSS of different design have been developed and used for malaria control strategies. The objectives driving the development of these DSS include supporting the diagnosis of malaria¹⁴, targeting activities for malaria elimination in Bhutan¹⁵, providing access to global maps of malaria transmission¹⁶ and offering a mathematical modelling platform for population level models of malaria elimination¹⁷.

For clarity, hereafter we will refer to DSSs or interactive application as “apps”, and use “App” with a capital letter when referring to the METCAP application¹⁸.

Methods

Development background

The METCAP project is a multi-disciplinary collaboration with a team comprised of data scientists, modellers, epidemiologists, health economists and other experts. Inputs from this diverse team were instrumental in designing an App to specifically account for the different capacities, preoccupations, perceptions, and needs of its intended users, as well as the characteristics of the institutions in which they are working¹⁹.

For the diverse targeted audience, different capabilities and needs of users were taken into account and several design strategies meant to mitigate hindering factors were developed (Table 1). The main challenge in developing such an app revolves around finding a good balance in the information load, so that the user can access information quickly and conveniently without being overwhelmed. During the App building process, we discussed the target audience for the App, and considered potential trade-offs

Table 1. Potential limiting factors for app use and resolution strategies.

Factors determining the App understanding and use	Details	Strategies for addressing factors
Computer literacy and ease of navigating web interface	User cannot navigate efficiently through the App and becomes discouraged. The seniority of policymakers makes them less likely to be part of a generation that has grown at the time of the computers/internet.	Use conventional navigation elements that are classic and well-known to most users. Use general lessons for web design. Make the App openly accessible through a web interface with a URL that can be shared.
Poor internet connectivity	User has poor or no internet connection, which precludes them from using the software online.	Inform users that authors are available to provide support to install an offline version.
English language literacy	App is used in Asia-Pacific where English is, in most countries, a secondary language	Limit the amount of text in the App.
Technical knowledge of malaria	Too frequent use of technical terms will force the user to do outside research and possibly lead to their discouragement.	Provide a glossary of malaria related terms, and as many reminders of the acronyms as possible. Provided contextual directions directly in the App and links to more detailed information.
Technical knowledge of modelling	The user thinks that use of the App is restricted to people with good knowledge of modelling.	Insert videos to introduce users to mathematical modelling. Provide information on the specific model being developed: overview of methodology, uncertainty associated with the model, etc. Show all steps between data sources, data estimates, model building and calibration.
Attitude/perception/curiosity towards modelling	Modelling is perceived as too abstract and remote from on the ground realities. There is no real perception of the advantages of using modelling.	Insert videos to introduce users to modelling. Make the experience like a conversation by allowing users to use their knowledge (choosing scenarios that make sense from an operational viewpoint). Encourage users to spend more time on the App by making the App engaging (interactive map, choice of colours etc.).
Time constraints	Policymakers' time is limited with competing priorities.	The App navigation should be intuitive and not require excessive reading or consulting a user manual.

between simplifying the presentation of results and providing enough relevant background on the model and methods. At the core of this discussion was the task of identifying which important features are most difficult to communicate to policy-makers. After a prototype was developed, several presentations of the App were made to external audiences during informal meetings including Asian Development Bank, World Health Organisation, Global Fund, APLMA and National Malaria Control Programmes.

App design

Guiding principles found in reference books on web design were particularly relevant to the design of the App²⁰. When making choices regarding the user interface (UI), the usability of the tool remained the first priority and design decisions were made based on natural, straightforward motivations of accessibility. For example, due to the significant computation time required to run the model, the only practical option was to run models beforehand, save the data locally and then display these already available results. While testing prototypes of the App and trying to adopt the viewpoint of the end user, potential issues in the interpretation of results began to emerge. Several modelling scenarios were changed accordingly, leading to alterations in the App.

Target audience's relevant interests

The target audience for the App is comprised of decision makers at international, regional and national levels with an interest in the control or elimination of malaria in one area or across the whole Asia-Pacific region. This broad target audience can be disaggregated into several more specific groups according to their technical background and previous exposure to the subject of modelling and their main interests relevant to the METCAP project. We define four broad categories of users and summarise what we project as their main interests in the App in [Table 2](#). (One clear limitation of this method is that the heterogeneity within a category can be very significant.)

Before and during the development of a prototype of the App, the development team defined and reframed its objectives and strategies for reaching this audience. We identified four main objectives:

- (1) Engage with a diverse target audience and provide them with an accessible, engaging, not misleading and technically sound presentation of the METCAP model results and underlying data. This presentation should match the audience's interests and provide enough contextual information to allow them to form a sound, balanced, judgment of the data provided.
- (2) Display a large amount of information in a cohesive way through an intuitive interface that maximises accessibility for a variety of audiences. At the same time, provide contextual information on the underlying data (source, quality, uncertainty, etc.) and the methods.
- (3) Provide information on the mathematical model used along with a more general presentation on the topic of modelling and compartmental models. Make explicit the assumptions made and the limitations of the work by displaying the sequence that led to developing the model and by highlighting the potential limitations of the model.
- (4) Allow user to delve into specific contexts according to their interests, such as a specific country or group of countries, a specific set of scenarios or specific indicators. For example, the potential impact on *Pf* incidence of mass drug administration in the GMS.

Implementation

The model was run using R Statistical Software¹⁰, with calls to scripts in the C++ language and the results were stored and saved in R objects. We used R Statistical Software and extended it with the R [Shiny](#) package v1.1.0²¹, an extension that is a "web

Table 2. Anticipated main interests for the four identified audience groups.

Target audience	Anticipated main interests
Donors and high-level policymakers	<ul style="list-style-type: none"> • Optimal long-term strategy for malaria elimination. • Limitations and uncertainty associated with the model. • Associated costs for the "minimal elimination scenario".
Senior staff from National Malaria Control Programs (NMCPs) of the 22 countries	<ul style="list-style-type: none"> • Feasibility of malaria elimination for a specific country. • Optimal scenarios for elimination in a specific country with respect to country strategy (e.g. acceptability of mass drug administration). • Global costs for each scenario.
Technical health agencies (e.g. World Health Organisation) staff	<ul style="list-style-type: none"> • Quality of underlying surveillance data. • Indicators chosen and their relation to elimination. • Strategies for drug resistance containment.
Modellers and other researchers	<ul style="list-style-type: none"> • Underlying data and assumptions made to build the model. • Modelling methods used. • Model results.

application framework” combining R as a backend server and a classic HTML User Interface. Shiny allows for customisation of the App’s UI to provide an elegant environment for displaying user input controls and simulation output, where the latter simultaneously updates with changing input²². Several solutions for developing interactive apps exist but we decided on Shiny for its convenience. Shiny is an open-source, free, package of R—the same language ecosystem that was used in the modelling section.

Operation

The App¹⁸ can be publicly accessed at <http://www.metcapmodel.net> with a recent version of a modern browser (e.g. Firefox, Google Chrome, Safari, Internet Explorer). The App is most responsive when accessed from an internet connection with a download speed of at least 1 megabit per second (Mbps).

Use cases

The App UI is built using a standard framework with a header, navigation sidebar and main body (Figure 1). The UI has several user inputs and some of them are conditional on others. Several outputs are displayed based on the user choices recorded through the inputs. At some locations in the App, contextual information appears upon hovering over an element (e.g. name of a country in the map, value of a parameter in a user input element).

The App contains five main sections, as shown in panel 1 of Figure 1. The section “What is METCAP?” provides contextual information on modelling and the METCAP project with text and videos. “Baseline Data: Data Collation” shows an interactive map and time-series graph of the values of indicators used to build the model. The section “Model Stage 1: Build

estimates” shows the health seeking estimates, estimated clinical burden and model calibration for *Pf* and *Pv* species. “Model Stage 2: Model Scenarios” section displays either the model’s prediction for a selected indicator or global prediction of elimination for all of the scenarios. The user can browse a map and a table on the predicted conservative intervention package to achieve malaria elimination by 2030. The last section, “Model Stage 3: Scenario Costing”, displays the cost per year of each scenario and of the predicted conservative intervention packages for achieving malaria elimination. Each of these 5 sections open with an “About” sub-section that provides the user with the basic knowledge required to understand the data provided in the section and an instructional video to guide the navigation of the section. In four of the five sections, the intended navigation is made explicit with the insertion of a picture representing the menu flow and highlighting what stage of development of the model the user is looking at (Figure 2).

The process of building the estimates is presented in a dedicated section, “Model Stage 1”, in order to show the extensive impact of the assumptions in subsequent model results. All time series graphs and most of the estimates (model predicted values, costs, years of elimination, etc.) are shown as a range of values (minimum, medium and maximum estimates) or with interquartile estimates.

Discussion

We created an App that provides users with convenient access to the results of modelling malaria elimination in the Asia-Pacific¹⁸. The App is developed with open source technologies and could be updated with new models and adapted to other settings (e.g. other regions, new indicators). The App is

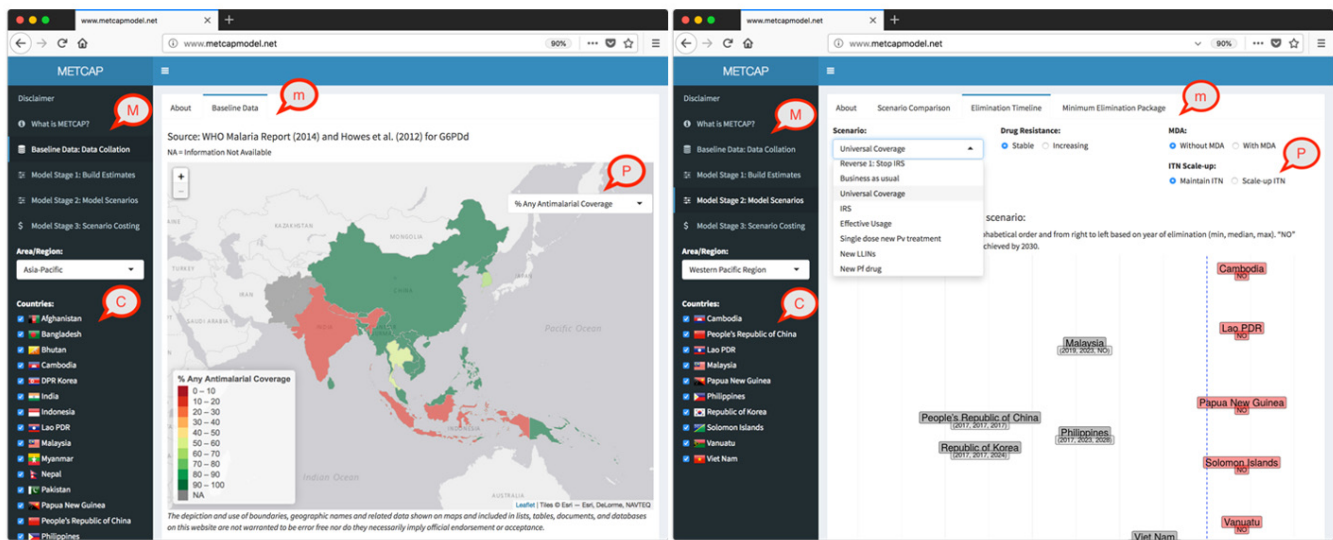


Figure 1. Screenshots of the METCAP App. The header shows the name of the App and allows the user to reveal and hide the sidebar to leave more space for the main body. In the sidebar located on the left, the main navigation panel (M) gives access to the 5 main sections of the App; below it, the user can select a subset of the 22 countries in the Asia-Pacific (C). At the top of the main-panel, a bar provides links to the sub-sections (m); below it, the user can select specific input parameters (P). When using the App, some information on parameters appears on hover.

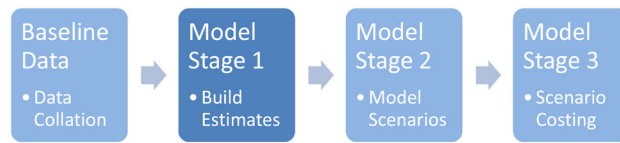


Figure 2. Menu flow appearing in several “About” sub-sections. Baseline Data is followed by three ordered modelling stages.

stable and easy to access through a web browser. Alongside the modelling results, we tried to show limitations related to uncertainty in the provided data and the nature of modelling. A more systematic analysis of user perceptions of the models could be achieved through observation techniques, task analysis, and other feedback methodologies. This would provide useful evidence for assessing which design Apps are better at communicating key messages and pitfalls.

All research in public health is done with the objective that the knowledge gained will somehow be used to improve health outcomes, and knowledge dissemination is recognised as an important component of the research process. The publication of scientific results in peer-reviewed journals is the unavoidable metric that dominates most researchers’ investment of resources in communicating their results. In order to make scientific articles more useful to policy makers, several journals have publication guidelines that request the inclusion of short sections to put research in context (e.g. Authors should state the implications for practice or policy of all research papers submitted to any journal in the Lancet family²³). There is a wide range in the types of papers which have considerable use to informing policy¹¹ but there are also practical limits to the amount of data that can be included and conveniently communicated within a paper following the pervasive format of an academic publication. Even if most papers include figures or tables that support data visualisation, they are typically static and, by design, do not allow the reader to interactively explore them. The format of the academic publication is especially limiting to the field of modelling where the amount of data used, the degree of data uncertainty, the voluminous complexity and variability of results and the range of questions that practitioners may need to apply to test the assumptions of the model or explore dimensions of the results can be considerable. If summarising is essential, providing direct access to data is required in such circumstances. Perceptions of the nature, uses and quality criteria of mathematical modelling in epidemiology are contradictory, even among the community of published authors in this field²⁴. The development of this discipline merits a framework for providing recommendations and guidance at various steps in the process, from design to reporting²³. It is vital that researchers pursue improvements in how they prepare and report research for the end users. The ability to communicate data, findings, and reports in commonly used language will aid decision makers in using all available evidence and tools for decision-making²⁵.

The recent implementations of free, open-source extensions for the most popular software platforms for data science (e.g. R, Python) allow the development of graphical user interfaces and web apps within these platforms (e.g. Shiny package for R²¹,

Dash framework for Python²⁶). The development of these extensions allows modellers to develop basic apps by themselves without requiring the support of expert software designers. We think that apps can offer a tremendous contribution by helping to build more relevant models for policymakers and supporting the communication of results. The design and development of dissemination tools concurrent with conducting modelling work means that policymaking questions are integrated in the early stages of model development and encourages considering and designing around what is most relevant to target audiences. An app can be provided alongside an article (as supplementary material) to be explored by the policy-maker on their own. Furthermore, this format of presentation could enhance the communication of concepts and data during interpersonal communications where the modeller, the policymaker and program level decision maker can interactively explore different options. The malaria ERAdication (malERA) group—the authoritative consultative group on modelling for malaria—has identified the development of interactive apps for models as a priority area for research in statistical modelling²⁷.

In order to promote the use of models more effectively, modellers must understand the needs of policymakers and be able to explain how modelling can support the decision-making process. Modellers must also be able to inform various audiences of the uncertainty of a model’s results, explain why a complex model is not necessarily superior to a simpler model, and generally help users navigate the added values and limitations of particular models. In addition to the generally challenging nature of communicating the models that we describe here, the sophistication of the METCAP model, the structural uncertainty of the underlying surveillance data and the high stakes of related decision-making (deciding between costly strategies), add a new dimension to the challenges in communication. We designed and developed the App with the goal of offering convenient access for an audience that might not otherwise have the time, resources or inclination to explore the METCAP project data and modelled results. Producing a cohesive, effective interface for an app is not a trivial task. To develop apps that are highly effective and have the maximum contribution to evidence-based policy-making, it is important to understand what factors have the potential to maximise an app utility and usefulness for end-users. We could not find any general guidance related to the design, development or dissemination of apps for public health. The rapid pace of development of technologies may explain why research is nascent in this area. Insights into the process of dissemination of apps are also of importance since they are relatively new in the field of public health and are thus not yet widely used, thus their adoption can be analysed through existing diffusion of innovations frameworks²⁸. Several techniques could be used to evaluate apps UI such as heuristic evaluation,

usability testing, guidelines or cognitive walkthroughs²⁹. Since apps have a critical impact on the process-oriented aspects of decision-making, a combination of both outcome- and process-oriented evaluation measures is highly important for apps evaluation^{30,31}. This is another area where research could be developed to help better understand what evaluation measures are the most relevant and could be applied.

Apps may be misleading through being excessively complex, poorly constructed, or not providing sufficient background information. This also strongly motivates a systematic evaluation of their potential use.

Conclusions

An interactive app for the exploration of mathematical models is an effective dissemination tool and may help to bridge the gap between evidence generation through modelling and policymaking. These are not intended to replace but rather to accompany peer-reviewed publications and to present scientific findings more effectively to policymakers. We have demonstrated that it is possible to develop an app that provides a substantial amount of data from the model in formats more accessible and useful to the typical decision maker. At every stage in the METCAP App's development, the diverse audience of users was prioritised. We emphasize that with additional user research, we could develop more effective apps and encourage a multidisciplinary effort to a more systematic use of mathematical models.

Data availability

All data underlying the results are available as part of the article and no additional source data are required.

Software availability

Software available from: www.metcapmodel.net.

Source code available at: <https://github.com/ocelhay/METCAP/>.

Archived source code at time of publication: <https://doi.org/10.5281/zenodo.2437908>¹⁸.

License: [GNU General Public License, version 3](https://www.gnu.org/licenses/gpl-3.0.html).

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Jon Haël Brenas 

University of Tennessee Health Science Center, Department of Pediatrics, Oak Ridge National Laboratory, Center for Biomedical Informatics, Memphis, TN, USA

This submission presents an interactive application to display the results of mathematical models in the context of malaria elimination in the Asia-Pacific sphere. This tool aims to address the concerns of a great variety of actors from funding agencies to local staff, to modelers. These different actors have different expectations from the application and different obstacles need to be cleared for them to maximally benefit from it. The submission clearly establishes what these expectations and problems are and presents ways to address them.

The interactive application seems to be but a part in a massive and timely project and is connected to three more submissions to this publishing platform that present different but complimentary aspects. In my opinion, this does not prevent this submission from having an interesting narrative on its own. That said, the actual description of the application itself is somewhat lacking. Several times in the course of the method section (e.g., "Several modeling scenarios were changed accordingly, leading to alterations in the App", last sentence of subsection "App design"), discussions, presentations and exchanges are mentioned but no detail is given on what were the results. Similarly, target audience's relevant interests and factors limiting their optimal use of the application are listed and some strategies to address them are given but little to nothing is said on how it impacted the development of the application, its distribution or its use. For instance, in subsection "App design", it is explained that the application only displays the pre-computed results of models to save time, which is very a very important decision, but doesn't not discuss how it impacts how users access and use the result and whether it is a problem to limit their ability to fine-tune aspects of the model or not.

Overall, the evaluation of the application is limited and the actual description of the code created is too short to form an accurate picture of the application development, distribution and use. This submission works very well as a statement of intention to develop the application but not as much as a presentation of its actual development. Most of the discussion section, that I expected to deal with the evaluation of the application, actually explained why such an application is important and not why this specific application solves the problem. To be fair, the submission explains that there is no universally accepted benchmark to evaluate such an application but even a qualitative evaluation is better than no evaluation.

In my opinion, this submission tried to cast too wide a net and, as a result, fails to answer most of the questions that arise in a satisfactory manner. In my opinion, a much more focused "Use cases" section that would only consider what are the needs of a specific group of users, what are the problems that they encounter and how each one of the five main sections addresses them would make the submission much clearer and provide the missing proof that the application is actually successfully being used.

Minor remarks:

- 1) Table 1 is too prominent, in particular given the fact that it is not used to connect strategies to specific parts of the application .
- 2) On the other hand, Figure 1 probably should be bigger to better showcase the actual app.
- 3) A paragraph in section "Discussion" describing what problems are left and ideas on how to solve them would be interesting.

Is the rationale for developing the new software tool clearly explained?

Yes

Is the description of the software tool technically sound?

Partly

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?

Partly

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?

Yes

Are the conclusions about the tool and its performance adequately supported by the findings presented in the article?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Semantic web technologies, malaria, logic, modeling.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 27 Jun 2019

Richard Maude, Mahidol University, Bangkok, Thailand

We would like to thank the reviewers for their constructive comments and suggestions for the manuscript. We believe that the comments have identified important areas which required improvement. After completion of the suggested edits, the revised manuscript has benefitted from an improvement in the overall presentation and clarity, notably with a much more focused "Use Case" section.

Below, you will find a description of how each comment was addressed in the manuscript. Original reviewer comments in boldface, responses in regular typeface.

We look forward to hearing from you and to respond to any further questions and comments you may have.

Review #2

This submission presents an interactive application to display the results of mathematical models in the context of malaria elimination in the Asia-Pacific sphere. This tool aims to address the concerns of a great variety of actors from funding agencies to local staff, to modelers. These different actors have different expectations from the application and different obstacles need to be cleared for them to maximally benefit from it. The submission clearly establishes what these expectations and problems are and presents ways to address them.

The interactive application seems to be but a part in a massive and timely project and is connected to three more submissions to this publishing platform that present different but complimentary aspects. In my opinion, this does not prevent this submission from having an interesting narrative on its own. That said, the actual description of the application itself is somewhat lacking. Several times in the course of the method section (e.g., "Several modeling scenarios were changed accordingly, leading to alterations in the App", last sentence of subsection "App design"), discussions, presentations and exchanges are mentioned but no detail is given on what were the results.

The building of the App was a non-linear process developed due to an identified need and several discussions with countries and partners that spanned several months. We have added to the *Methods* section two examples of alterations made from the first prototype onwards as the team consulted: the addition of maps to the App and the selection of countries by region.

Similarly, target audience's relevant interests and factors limiting their optimal use of the application are listed and some strategies to address them are given but little to nothing is said on how it impacted the development of the application, its distribution or its use. For instance, in subsection "App design", it is explained that the application only displays the pre-computed results of models to save time, which is very a very important decision, but doesn't not discuss how it impacts how users access and use the result and whether it is a problem to limit their ability to fine-tune aspects of the model or not.

The decision to display pre-computed result is indeed very important. We now discuss this decision in the *Methods* section and have added in the *Discussion* on on-going work with an app that allows users to build their own package of interventions.

Overall, the evaluation of the application is limited and the actual description of the code created is too short to form an accurate picture of the application development, distribution and use. This submission works very well as a statement of intention to develop the application but not as much as a presentation of its actual development. Most of the discussion section, that I expected to deal with the evaluation of the application, actually explained why such an application is important and not why this specific application solves the problem. To be fair, the submission explains that there is no

universally accepted benchmark to evaluate such an application but even a qualitative evaluation is better than no evaluation.

We agree that a formal qualitative evaluation of the App would have provided useful insights. This is a limitation of this manuscript. However, we have informal feedback from country level users and partners including through APLMA and APMEN.

In my opinion, this submission tried to cast too wide a net and, as a result, fails to answer most of the questions that arise in a satisfactory manner. In my opinion, a much more focused "Use cases" section that would only consider what are the needs of a specific group of users, what are the problems that they encounter and how each one of the five main sections addresses them would make the submission much clearer and provide the missing proof that the application is actually successfully being used.

We rewrote the Use Case section to explain how the model and App were used by researchers from UCSF to assess the economic rationale of malaria elimination in several national and regional settings. This links the App with the creation of one of five "Elimination investment cases" reports investigating the costs (and economic benefits) of malaria elimination. This provides an example of a practical application of the App. Furthermore, during the dissemination of the Investment cases, demonstrations of the app and the its utility to visualize transmission timelines and costs were found to be extremely useful by the country level users.

Minor remarks:

1) Table 1 is too prominent, in particular given the fact that it is not used to connect strategies to specific parts of the application .

We shortened Table 1 and cut some elements.

2) On the other hand, Figure 1 probably should be bigger to better showcase the actual app.

Figure 1 was replaced with four figures to better showcase the different stages of the App.

3) A paragraph in section "Discussion" describing what problems are left and ideas on how to solve them would be interesting.

The discussion section has been expanded to discuss how a country level approach is starting to be used.

Competing Interests: No competing interests were disclosed.

Reviewer Report 09 April 2019

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Catherine M. Smith 

Institute of Health Informatics, University College London, London, UK

This article describes the development of a web-based interactive application to display results of mathematical models for malaria elimination. The app is intended for a range of users including policymakers, staff working in malaria control programs, and researchers. The authors provide a very clear rationale for development of this app, and how other research projects may benefit from development of other similar tools. The app itself is well thought-out, with inclusion of graphics and videos to help users navigate the interface and provide background information. The code is open source and published in an online repository.

I have only a few suggestions:

- In general, I found that the visualisations produced by the app were easy to use and understand. One exception to this was the “Elimination Timeline” within “Model Stage 2” – I found the “NO” labels confusing when listed alongside the other estimated dates of elimination – is there a reason that the dates could not be shown when they are after 2030? These labels are also a bit redundant for the countries after the 2030 line, which are additionally shown in red. (I would suggest the authors consider adapting this in future versions of the app, although it is not required for this publication).
- In the introduction and discussion, the authors present a strong case for interactive tools like this one as a means of improving communication of complex public health analyses. Since one of the objectives of the app is to engage with a diverse target audience, I would also be interested in how they plan to disseminate the tool to the potential users, and whether they have plans for assessing the impact of the tool. This might include number of hits to the website, questionnaires of users (or people who decided not to use it) or interviews. Evidence of impact would help other researchers assess whether they should invest in creating similar apps.
- Another challenge with this sort of project that is not mentioned is the ongoing support that might be needed to assist users or answer queries. In Table 1, it also says that in case of poor internet connectivity, authors are available to provide support to install an offline version. Could the authors comment on the resources available for support and how long it is expected to be maintained for?

Is the rationale for developing the new software tool clearly explained?

Yes

Is the description of the software tool technically sound?

Yes

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?

Yes

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?

Yes

Are the conclusions about the tool and its performance adequately supported by the findings presented in the article?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Infectious disease epidemiology, health data science

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 27 Jun 2019

Richard Maude, Mahidol University, Bangkok, Thailand

We would like to thank the reviewers for their constructive comments and suggestions for the manuscript. We believe that the comments have identified important areas which required improvement. After completion of the suggested edits, the revised manuscript has benefited from an improvement in the overall presentation and clarity, notably with a much more focused "Use Case" section.

Below, you will find a description of how each comment was addressed in the manuscript. Original reviewer comments in boldface, responses in regular typeface.

We look forward to hearing from you and to respond to any further questions and comments you may have.

Review #1

In general, I found that the visualisations produced by the app were easy to use and understand. One exception to this was the "Elimination Timeline" within "Model Stage 2" – I found the "NO" labels confusing when listed alongside the other estimated dates of elimination – is there a reason that the dates could not be shown when they are after 2030? These labels are also a bit redundant for the countries after the 2030 line, which are additionally shown in red. (I would suggest the authors consider adapting this in future versions of the app, although it is not required for this publication).

The Elimination Timeline graph was updated, removing the labels "NO" for countries that will not achieve elimination by 2030. In the explanatory text provided above the graph, it is now emphasized that "*NO means elimination was not predicted to be achieved by 2030 — the last year projected by the model.*" The year 2030 represents the last year for which results are available. The model's author predicts that going beyond 2030 would create results with too much uncertainty attached to them to be useful.

In the introduction and discussion, the authors present a strong case for interactive tools like this one as a means of improving communication of complex public health analyses. Since one of the objectives of the app is to engage with a diverse target audience, I would also be interested in how they plan to disseminate the tool to the potential users, and whether they have plans for assessing the impact of the tool.

We have amended the *Discussion* to include how the app was disseminated. Given that the app was part of a larger project to develop the evidence base for resource mobilization for elimination in the Asia Pacific region, the dissemination of app followed the plan for dissemination of the entire package of evidence. Opportunities for dissemination were identified in collaboration with APLMA and APMEN. These included during "malaria week" In Bangkok in 2017, APMEN annual and working group meetings In 2017 and 2018, partner meetings (for example, Regional Artemisinin Initiative steering committee meetings), WHO meetings and the World Malaria Congress in July 2018. The APMEN meetings included country level malaria programs as well as partner institutions..

This might include number of hits to the website, questionnaires of users (or people who decided not to use it) or interviews. Evidence of impact would help other researchers assess whether they should invest in creating similar apps.

We did not plan from the start to monitor the use of the app. We have added to the discussion an explanation on why the application usage metrics collected do not help us form an accurate picture of the app usage. We agree that collecting quantitative or qualitative data from users would have provided useful data on the impact of the App. It is unfortunate that we did not mobilize resources to do so. An assessment plan is already in place for current projects focusing on the application for malaria elimination.

Another challenge with this sort of project that is not mentioned is the ongoing support that might be needed to assist users or answer queries. In Table 1, it also says that in case of poor internet connectivity, authors are available to provide support to install an offline version. Could the authors comment on the resources available for support and how long it is expected to be maintained for?

We have added to the *Software Availability* explanations on why the App should remain accessible for the foreseeable future. The grant supporting the project has ended but authors are involved in several similar projects where users will be trained in the use of the applications, and the applications themselves can be updated with new data, ensuring the relevance of App. In other projects, maintenance grants are being sought to sustain support for the applications for an additional period. At the same time, support is available through APMEN and APLMA as this was one of the products developed as part of a larger project and dissemination planned in collaboration and in support of their member countries.

Competing Interests: No competing interests were disclosed.