# A 21st century approach to tackling dengue : crowdsourced surveillance, predictive mapping and tailored communication

Lwin, May Oo; Theng, Yin-Leng; Vijaykumar, Santosh; Fernando, Owen Noel Newton; Cheong, Siew Ann; Rathnayake, Vajira Sampath; Lim, Gentatsu; Chaudhuri, Subhasis; Foo, Schubert

2014

https://hdl.handle.net/10356/104217

https://doi.org/10.1016/j.actatropica.2013.09.021

# A 21st century approach to tackling dengue: Crowdsource surveillance, predictive mapping and tailored communication

May O. Lwin[a], Santosh Vijaykumar[b,*], Owen Noel Newton Fernando[b], Siew Ann Cheong[c], Vajira Sampath Rathnayake[b], Gentatsu Lim[b], Yin-Leng Theng[b], Subhasis Chaudhuri[e], Schubert Foo[d]

[a] *Center of Social Media Innovations for Communities (COSMIC), Nanyang Technological University, HSS-06-16D, 14 Nanyang Drive, 637332 Singapore*
[b] *Center of Social Media Innovations for Communities (COSMIC), Nanyang Technological University, HSS-06-15, 14 Nanyang Drive, 637332 Singapore*
[c] *School of Physical and Mathematical Sciences, Nanyang Technological University, SPMS-PA-04-03, 21 Nanyang Link, 637371 Singapore*
[d] *Center of Social Media Innovations for Communities (COSMIC), Nanyang Technological University, HSS-06-16E, 14 Nanyang Drive, 637332 Singapore*
[e] *Department of Electrical Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India*

## Abstract

This paper describes a social media system to prevent dengue in Sri Lanka and potentially in the rest of the South and Southeast Asia regions. The system integrates three concepts of public health prevention that have thus far been implemented only in silos. First, the predictive surveillance component uses a computer simulation to forewarn health authorities and the general public about impending disease outbreaks. The citizen engagement component allows the general public to use social media tools to interact and engage with health authorities by aiding them in surveillance efforts by reporting symptoms, mosquito bites and breeding sites using smartphone technologies. The health communication component utilizes citizen data gathered from the first two components to disseminate customized health awareness messages to enhance knowledge and increase preventive behaviors among citizens. The system, known as "Mo-Buzz," will be made available on a host of digital platforms like simple mobile phones, smart phones and a website. We present challenges and lessons learnt including content validation, stakeholder collaborations and applied trans-disciplinary research.

**Corresponding Author Contact Information:**

Telephone: (+65) 81838657; Fax: (+65) 6592 3258; Email: santoshv@ntu.edu.sg

**1.0 Introduction**

Sri Lanka has borne the brunt of dengue with over 70,000 cases in 2009-10 (Bhattacharya et al., 2013), and nearly 44,000 in 2012 (Ministry of Health, 2013b). The first nine months of 2013 accounted for nearly 23,000 cases (Ministry of Health, 2013a) with a majority (57%) emerging from the capital city of Colombo (Ministry of Defense, 2013), that is increasingly being characterized as the nerve center of dengue in the country. Epidemiologists report that the threat of dengue continues to grow in Sri Lanka with new clades continuing to emerge from the four dengue serotypes that have been co-circulating for more than 30 years (Kanakaratne et al., 2009).

The narrative in the mainstream Sri Lanka media highlights how the Sri Lankan public health workforce is straddled by various factors that impede their functioning. For one, their ability to execute daily epidemiological tasks (that includes disease reporting which informs dengue mapping) is stymied by limited staff and a workload that has increased from one public health inspector (PHI) per 10,000 people to one per 40,000 (Peiris, 2009). Proactive surveillance measures (such as identifying and treating breeding sites in advance) are inadequate, as a result of which preventive actions implemented after an outbreak accrue limited benefits (Fazlulhaq, 2012). In addition to these structural issues, public attitudes toward maintaining hygienic surroundings and performing health behaviors that will prevent them from dengue, remain far from desirable (Hettiarachchi et al., 2013).

Public health prevention and management of dengue is challenged by three main limitations: 1) use of traditional epidemiological methods leading to reactive, as opposed to proactive, disease monitoring & surveillance (Hsieh and Ma, 2009), 2) lack of citizen engagement in public health programs leading to low exertions among individuals regarding their own health and that of the public health ecosystem (Gubler and Clark, 1996) and 3) lack of effective, interactive health education for citizens leaving awareness untranslated into action (Parks and Lloyd, 2004).

However, the country faced with a grave dengue situation also boasts of a technological opportunity to help itself. According to the International Telecommunications Union (ITU) (2013), mobile cellular signals cover almost all (98%) of the Sri Lankan population, with prices of cellular services being among the lowest in the world. In the past decade, information and communication technologies (ICTs) – especially mobile phones – have provided the global health community with some of the most innovative and cost-effective strategies to address similar challenges in dengue and other health areas (Ekeland et al., 2010).

Given the lack of an integrated mobile health system that addresses limitations in dengue prevention by optimizing social media, scientists at Singapore's Center of Social Media Innovations for Communities (COSMIC) have developed a prototype of an integrated social media-based system called Mo-Buzz. The purpose of this paper is to provide a detailed description of the functionalities of Mo-Buzz after discussing existing evidence on ICT-based

approaches to address the aforementioned limitations. The paper culminates with a discussion of challenges encountered in terms of validating content, collaborating with institutional stakeholders and functioning as a trans-disciplinary team. We present lessons which will be relevant and valuable to public health researchers and practitioners engaged in similar initiatives or interventions.

## 2.0 Related Literature

On the *predictive surveillance* front, various efforts to develop early warning systems for dengue (Lowe et al., 2011; Racloz et al., 2012) and malaria (Hay et al., 2001; Thomson et al., 2006; Thomson et al., 2005) have been reported. The mandate of these initiatives is to develop robust associations between environmental and vector variables that can help to predict malaria in advance so as to inform in advance the efforts of public health and vector control personnel (Ebi, 2009). The Malaria Atlas Project (MAP) is one of the foremost exemplars that attempts to make malaria early warning systems accessible to the general public through an interactive website (http://www.map.ox.ac.uk/). Predictive modeling efforts for infectious diseases such as dengue and West Nile virus have been extensively chronicled in public health literature (Degallier et al., 2010; Estallo et al., 2008; Rochlin et al., 2011) but efforts to make these early warning devices available to the general public remain scant.

ICT-based *civic engagement* in public health has been driven mainly on the premise of a virgin concept called participatory epidemiology (PE). PE denotes the use of local, on-ground intelligence to gather information and track the spread, causes, and effects of diseases. The PE concept was popularized by Catley and Mariner's work in East Africa where qualitative community-based approaches were deployed to derive animal health status from local farmers (Catley, 2006). However, the rapid proliferation of the Internet and mobile phones has transformed the PE landscape in recent years. As shown by initiatives such as FrontlineSMS and Ushahidi (Freifeld et al., 2010), disease surveillance, health monitoring, and information sharing can now be digitally integrated and used to link disparate stakeholders such as health authorities, health providers and the general public. Chunara *et al*. (2012) tested an online initiative where respondents reported their experiences with malaria, and concluded that "micro-monitoring and online reporting are a rapid way to solicit malaria, and potentially other public health, information". The Program for Monitoring Emerging Diseases (http://www.promedmail.org) provides an online reporting system and rapid information dissemination related to infectious disease outbreaks. In this sense, participatory epidemiology also denotes employing participatory methods – those nestled in, and involving communities – to collect epidemiological data. The other key principle includes the use of participatory mapping techniques in order to inform prevention activities.

In terms of shaping healthy behaviors through *communication*, mobile phone-based short messaging service (SMS) has been used to promote smoking cessation behaviors (Rodgers et al., 2005), create awareness about sexually transmitted diseases (Lim et al., 2008) and encourage adherence to antiretroviral treatment (Lester et al., 2010) in both developed and developing countries. At the health systems level, mobile phones have empowered community health workers in developing countries through cost-effective and time-effective techniques that facilitate data collection, surveillance and mobile-based telemedicine (Chib et al., 2008; Mechael, 2009). The advantage of such technologies to the general public is that they bring accessible and affordable healthcare to the remotest and impoverished of communities. The use of information and communication technologies (ICTs) in public health has thus rapidly proliferated over the last two decades given the deep penetration of the Internet and mobile phones in both developed and developing countries. While many developing countries in Asia and Africa are developing robust mechanisms for integrating mobile phones into their health systems framework, Sri Lanka has yet to make a concerted effort in this area.

The above literature review underlines the emerging criticality of ICTs in addressing global health challenges including dengue. However, it also highlights the fact that existing initiatives address the three core needs – predictive surveillance, civic engagement, and health communication – in silos. As a result, the benefits of each of these components on the other is largely missed, leading to a disparate contingent of tools that the health workforce and the general public must use. An issue like dengue commands the necessity to integrate these components on a common platform and offer it to these two key stakeholders on easily accessible mobile devices. In addition, we argue that the capabilities of social media that allow users to participate and share information have thus far been underutilized in the global health space. There is a need to optimize social media affordances with an eye on the future, given that smartphones are becoming an increasingly ubiquitous commodity in developing countries because of decreasing costs and increasing availability.

## 3.0 Mo-Buzz for Participatory Epidemiology & Health Communication

Mo-Buzz is an integrated mobile and desktop-based dengue communication system that is built upon PE principles. Mo-Buzz extends its reach to provide an interface between citizens and health authorities, and sends customized health messages to enhance preventive behaviors and health awareness.
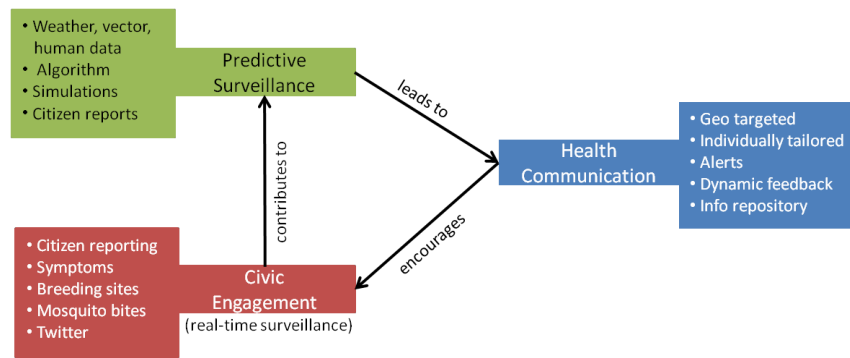
**Figure 1: Integration of three dengue prevention components in Mo-Buzz**

As shown in Figure 1, Mo-Buzz comprises three main components: (1) predictive surveillance; (2) civic engagement and (3) health communication. Broadly speaking, the predictive surveillance component uses a predictive algorithm and computer simulations (based on weather, vector and human data) to predict dengue outbreaks and disseminate such information in the form of hotspot maps to health officials and the general public. The civic engagement component enables citizens to use their smartphones in order to inform health authorities about breeding sites, symptoms and mosquito bites using interactive forms and social media such as Twitter. The crowdsourced information is also reflected on the hotspot maps. Using the predictive hotspots and the crowdsourced information, the intelligent system disseminates health alerts and tailored messages to individuals or communities living in respective geographic zones. The system is designed to enable sharing of health information with an individual's social network using social media tools. In this way, Mo-Buzz integrates the capabilities of predictive surveillance, civic engagement and tailored health communication to offer a holistic dengue prevention social media suite. This suite is intended to help health authorities manage resources more efficiently and effectively, and encourage preventive behaviors among the general public by forewarning them of dengue outbreaks. Mo-Buzz is made available on a host of handheld devices including mobiles phones and tablets. Heretofore, the term "mobile phone" is used to represent all such handheld devices. We now present detailed descriptions of each of the three components below.

## 3.1 Predictive Surveillance

The purpose of this component is to forewarn public health authorities and the general public about impending dengue outbreaks by disseminating predictive hotspot maps generated by a computer simulation. We start by building a spatio-temporal susceptible-exposed-latent-infected-recovered (SELIR) model consisting of the 47 wards of Colombo. Because *Aedes aegypti*, the primary vector for dengue transmission in Colombo, bites mostly at dawn and at dusk (Jones, 1981), we also discretize time in our model, so that each time step is one day. The model equations are

where     is the susceptible human subpopulation,     the asymptomatic human subpopulation,     the infected human subpopulation,     the susceptible mosquito subpopulation, and     the infected mosquito subpopulation of ward    on day  . In this prototype model, we do not explicitly simulate the recovered human subpopulation    , as it has no interesting dynamics of its own. We also do not simulate the exposed human subpopulation     and the exposed mosquito subpopulation    , and model their impact by introducing delays into the respective infected subpopulations. For simplicity, we assume that the total human population     in each ward does not change with time.

In this model, susceptible humans become exposed humans after being infected by infected mosquitoes at a rate of    per human per mosquito per day. We assume that exposed humans remain symptom-free and un-infective for    days. Thereafter, a fraction    becomes infected, i.e. infective and showing symptoms (perhaps due to secondary infections), while the remaining      becomes asymptomatic, i.e. infective but shows no symptoms (perhaps due to primary infections). We then assume both infected and asymptomatic human subpopulations recover at a rate of    per human per day. At the same time, susceptible mosquitoes become exposed mosquitoes after biting infected or asymptomatic humans at a rate of    per mosquito per human per day. These exposed mosquitoes take    days to become infected mosquitoes.

We assume that infected mosquitoes never recover. New susceptible mosquitoes appear at a rate of    per mosquito per day from all mosquito subpopulations, assuming there is no vertical transmission of the dengue virus from one generation of mosquitoes to the next generation. To keep the overall mosquito population constant, we also make all mosquito subpopulations die at a rate of    per mosquito per day. Finally, in contrast to static humans, mosquitoes can move from ward    to ward    at a rate of    per mosquito per day. This diffusion of mosquitoes is simulated explicitly for the susceptible and infected mosquito subpopulations. For the exposed mosquito subpopulation, we introduce an attenuation factor    that integrate mosquito diffusion as well as death of exposed mosquitoes over the time delay   .

For the SELIR model to generate meaningful predictions, it must be calibrated against the real world. Some model parameters, such as the *intrinsic incubation period* (IIP), *extrinsic incubation period* (EIP), and average infectious period can be fixed to their published values of

days (Chan and Johansson, 2012; Nishiura and Halstead, 2007; Salazar et al., 2007) respectively. Other model parameters, like the proportion of asymptomatic cases (Favier et al., 2005), have large uncertainties and we choose tentative values to start the simulations (for example,          ), but are open to adjusting them to get better fits to data. Finally, there are model parameters where no reliable values are reported in the literature. For example, the infectivities    and    are strongly influenced by human behavioral patterns. Therefore, we leave these parameters free in the model, to be determined by fitting model simulations to real-world incidences. While the diffusivities      should fundamentally be proportional to the length of the boundary shared by ward    and ward  , they should also incorporate penalty factors that reduce the mosquito exchange rate between wards separated by roads or rivers. The overall proportionality constant for these will also be determined by fitting model simulations to real-world incidences.

Once the model is calibrated, we can utilize it for two purposes. The first is to use the present distribution of dengue cases as initial conditions, and run simulations that look one week to several weeks ahead of time. These simulations allow us to predict where and when an epidemic will likely emerge, as well as how ongoing or future infections will progress in space and in time. These predictions can help healthcare workers better allocate limited resources (for example, getting isolation wards ahead of time to meet the demands from the epidemic peak), and also design intervention measures to respond to the epidemic. The second is to perform scenario analysis. For example, if the City of Colombo has a fixed amount of funds that they can use to perform citywide low-intensity, low-frequency chemical fogging all year round, or to perform targeted high-intensity, high-frequency chemical fogging at the ward level during a dengue outbreak, the natural question would be which would be more effective in the short term and which would be more effective in the long term. As we understand how interventions like those described above impact the spatio-temporal SELIR model, we can run these scenario simulations, and compare their outcomes against the benchmark intervention-free simulation.

This combined forecasting and scenario testing capability represents the greatest advantage of our dynamic SELIR model have over static risk factor models (no forecasting, but possible scenario testing. See for example Koopman et al. (1991).) and time series models trained on historical data (possible forecasting, but no scenario testing. See for example, (Luz et al., 2008) and (Althouse et al., 2011)). More importantly, the spatio-temporal transmission patterns predicted by our model can help health authorities prioritize mitigation and intervention efforts, to achieve epidemic management in the most cost-effective way. Besides catering to healthcare policymakers, the SELIR model is also an important component in the crowd sensing part of the Mo-Buzz project (Kamel Boulos et al., 2011). To encourage participatory data collection by Colombo citizens (described in detail in the next sub-section), low-resolution forecasts on the progression of the dengue epidemic will be fed back to Mo-Buzz users. These crowd users might also report or collect data (like mild symptoms, the time and place of

mosquito bites, potential breeding spots, etc.) that are difficult or not collected by authorities. While these are generally much less reliable than official data, it is still possible to incorporate them into the model calibration and validation processes after assigning smaller weights. Finally, we aim for latent education of the masses. By sending small snippets of dengue-related information to users after they submitted a report, in particular evaluation ratings from the model on how useful the data they submitted is, we expect Mo-Buzz users to become more knowledgeable with time, and submit more and more useful data.

*3.2 Civic Engagement*

The fundamental purpose of this component is to strengthen the surveillance efforts of public health authorities with real-time information about risk-related incidents occurring among the general public. We crowdsource this task of data collection by enabling the general public to send information using their mobile phones, as health authorities might find such information difficult to detect or trace. Specifically, the public will be empowered to report three kinds of information to health authorities using the "Report" option on Mo-Buzz's mobile app and website: symptoms, mosquito bites and breeding sites.

Reporting symptoms involves selecting one or more among a list presented to the user on the symptoms page. The list includes fever, body aches, nausea, vomiting, fever with sore throat, joint pains, loss of appetite, development of skin rash and an option called "others", where users can type in any other symptom they might be experiencing. The individual can report his/her temperature and also report whether he has been diagnosed for dengue. Clicking on the "submit" button sends the citizen's symptom report to the system.

While reporting mosquito bites, the user may specify whether he experienced the bite indoor or outdoor. He may report visible changes in skin and select one or more of "bumps" and "rashes", or report any other kind of visible change by simply typing into the text box. The user may then report the mosquito density visible to him by answering a simple question "How many mosquitoes can you see?" and choose between "few" and "many". It is unrealistic to expect the user to report the exact number of mosquitoes and so, this data point is solely intended to offer the health authorities an approximate idea of a possible threat. Lastly, citizens can report breeding sites that they might come across, so health authorities can plan the required preventive actions. While reporting breeding sites, citizens choose between an "indoor" or "outdoor" site. Then, they choose from a list of possible locations which includes industrial areas, residential areas, construction sites, office premises and others. Here too, users can report mosquito density visible to the naked eye as described earlier.

Common to all the three reporting forms is a GPS-based location sensor that automatically captures the geographical coordinates of the user. The system also automatically

captures date and time of the day as the latter is especially critical to dengue diagnosis. Each of the three reporting components – symptoms, mosquito bites, and breeding sites – is denoted with a unique icon. As soon as a user submits the report, it gets stored in a data repository after the necessary checks of authentication and validation are carried out by the server. Subsequently, the server is engaged in constant communication with the front-end-client (the mobile application) so that any new data input in the server is automatically depicted in a graphical format on the application's live map. Thus, the icons respective to each of the reports appear on the Mo-Buzz map and the map is made visible to health authorities and registered users. Users can choose if they wish to view any one specific type of reports based upon their selection.
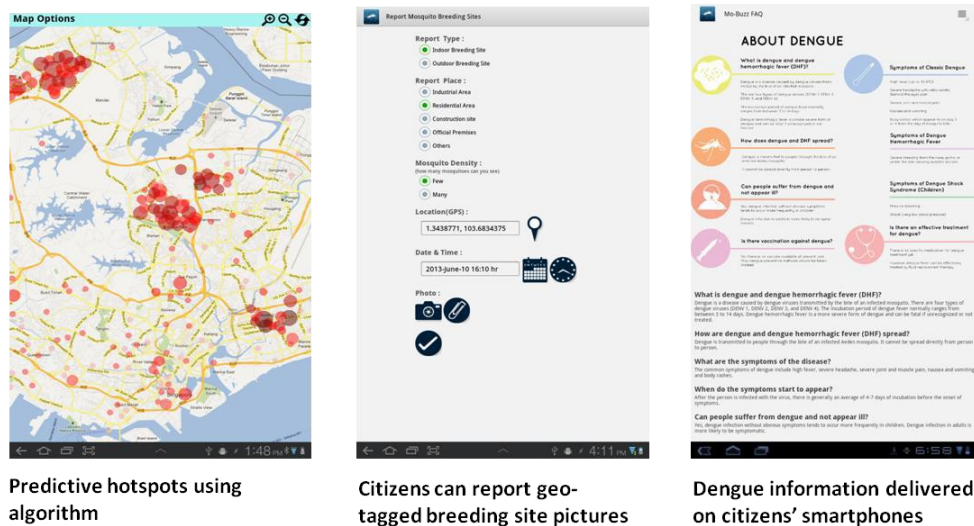


Predictive hotspots using algorithm

Citizens can report geo-tagged breeding site pictures

Dengue information delivered on citizens' smartphones

**Figure 2: Screenshots of the Mo-Buzz mobile application (dummy data used)**

*3.3 Health Communication*

Health messages can be alerts, reminders, or any useful information generated by the system or authorized users depending on the prediction generated by the system. The proposed system tries to avoid message broadcasting. Instead, personalized messaging is used to disseminate messages to end users based on their location, message priority and other settings of messages and users (such as chosen frequency, message type, etc.). Also, the client application can pull the messages according to its options and user settings. These messages can be sent to email inboxes, to devices through the Google cloud or as SMSs.

The health communication component consists of three sub-components each serving a different function. The first pertains to "health alerts" where the system, based on the data from the surveillance component which predicts hotspots, sends a dengue alert to the user based on his geographical location. Along with the alert, the system also prompts the user to access information on the steps needed to protect oneself from dengue. The second sub-component pertains to tailored health communication. Based on the submitted report, the system

automatically prompts the user to access relevant information. For instance, a user who reports dengue-related symptoms will be prompted for symptom-related information; in contrast, a user who reports the picture of a breeding site will be prompted for information on strategies to keep his surroundings clean and free of mosquitoes.

The third sub-component refers to an information repository which both registered and non-registered users can access. This informational module is divided into various sections such as dengue serotypes, risk factors, symptoms, statistics and preventive steps. The interface is designed in such a way that a user initially gets a brief snippet of information from the section he clicks on, but can access detailed information on that topic by simply clicking on a link. The user is also able to share the dengue information with those in his social network by choosing them from his phone's contact list, Facebook, Twitter or through simple SMS.

## 4.0 Current Status

In collaboration with the Colombo Municipal Council (CMC) and the University of Colombo, the Mo-Buzz system was deployed in July 2013 for the entire cadre of public health inspectors (PHIs) in Colombo, Sri Lanka. This represents the first phase of deployment for beta-testing by a chosen group of five PHIs, engineering modifications to the system based on their feedback and conducting training of trainers (TOT) sessions before final roll-out.

Adapting the system for use by the PHIs involves three primary areas of change as they require a different set of functionalities as opposed to the general public. First, we utilize historical dengue-related data from the Colombo Municipal Council to build maps specific to this region using the model (described in section 3.1).  Second, we integrate the paper-based Dengue Investigation Form (currently used for dengue reporting in Colombo) into a tablet interface for use by the PHIs. This is being done to reduce the current lag time between collection and reporting of dengue and preventive action taken (7-10 days) as PHIs can instantly submit the investigation form as soon as it is completed. Getting rapid access to such data will help health authorities to execute preventive steps in a quicker, more efficient manner. Third, we digitize existing paper-based dengue educational materials (used by the Colombo Municipal Council), so they can be embedded in the mobile application and used as necessary. From an evaluation standpoint, the Sri Lanka roll-out will comprise a mixed-method longitudinal study that will examine the drivers of technological adoption among the entire cadre of PHIs using the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003). The UTAUT attempts to explain technology-related intention to use and usage behavior using four main constructs: performance expectancy, effort expectancy, social influence and facilitating conditions.

**5.0 Discussion**

While the conceptual thinking and design of Mo-Buzz offers a novel, holistic approach to dengue prevention and management in the future, the technology development process faced several challenges at different levels. Here, we chronicle three main challenges – content validation and verification, inter-organizational integration and trans-disciplinary research – and present strategies used to address each of them.

One of the major challenges of a technology-driven participatory health system enterprise is validating the quality of informational inputs from citizens. Previous studies pointed to the dangers of misinformation spreading swiftly through social media (Scanfeld et al., 2010). There are three main challenges in terms of content validation: 1) quality of the image in terms of clarity, 2) identifying the content of the image and ensuring its topical relevance to the system and 3) identifying and filtering exact or near-same duplicates. We examine these challenges closely and present our plans for addressing them.

Clarity of the image is important to enable public health authorities to identify the specific features of the image report and react accordingly. From a technical standpoint, image clarity becomes necessary for the system to be able to detect and extract content features and cross-validate for duplicates. Validating the image content and ensuring it's propriety to the system is important in order to protect the system from the burden of irrelevant and inaccurate information, especially critical in the context of public health. Identifying duplicates is critical to ensure that the burden of dengue-related risk incidents is accurately communicated to health authorities and the general public in a visible form. To illustrate this problem, let us take an example of a breeding site with a certain mosquito density. It is possible that 10 citizens take photos of the same breeding site from either the same, or slightly different geographical coordinates. In such a case, there is a risk of the visual interface depicting 10 breeding sites when, in fact, there is only one.

Our strategy to address these problems is based on subjecting the content through two stages: filtering and verification. Filtering can be achieved using image processing and machine leaning techniques. The images will be uploaded to a database on the server where they would be classified using image processing and machine learning algorithms into two classes namely 'breeding site' and 'irrelevant'. The breeding site class may have further subclasses such as 'water body', 'tyres', 'construction site' and 'bushes' as possible sites where mosquito breeding normally takes place. For this purpose, a large corpus of images will be collected as the training data and they will be appropriately annotated for machine learning purposes. The 'irrelevant' category of images will be removed from the server. Relevant images will be categorized with a "high confidence" or "low confidence" score based on the output of the machine learning algorithm. The high confidence sites will be given first priority of action by the health authorities concerned

for mosquito control followed by manual inspection of images labeled as low confidence sites. In the future, a program will be developed in Java (Android) on the client side to reject the images that are of very low confidence from getting uploaded on the server with suggestions prompting the user to submit more appropriate and clear images. Over reporting of cases from the same geographical location can be addressed by performing a clustering of images within a geographically bounded area so that these images can be treated as a group for a more accurate verification and validation process to be carried out. Once verified, one representative location can be used to mark the breeding site.

The validation process is consistent in keeping with the core idea of using participatory media and crowdsourcing technologies. In that, we engage people (individuals and health systems personnel) as validation experts for secondary validation. If users are self-disciplined to provide only related information, then the system can avoid this and there will be no delay or effort needed to verify the information.

The process of conceptualizing, designing and deploying the Mo-Buzz system demanded concerted exertions to integrate with a range of stakeholders at different levels of the public health ecosystem: civic agencies, research institutions, telecommunications companies and policymakers. Our effort was guided by Axelsson and Axelsson's (2006) framework with an emphasis on two forms of inter-organizational integration in public health programs: 1) Cooperation, described as being "based on hierarchical management, but combined with voluntary agreements and mutual adjustments between the organizations involved" (Mintzberg, 1993); and 2) Collaboration, described as being "based on a willingness to work together and…implemented through intensive contacts and communications between the different organizations" (Alter and Hage, 1993).

Our process of cooperation and collaboration was characterized by a range of facilitators and barriers. First and foremost, we learnt that civic agencies and public health authorities might be understandably cautious about sharing dengue-related data required for building the predictive algorithm. However, the level of data confidentiality and the type of agencies facilitating data sharing vary widely between contexts, as does their willingness to consider and buy-in to a new public health innovation. Obtaining such data requires consistent and transparent negotiations with the relevant stakeholders. The key ingredients that catalyzed our success with our Sri Lankan collaborators were a) a detailed communication about our system's capabilities and benefits, and b) a strong assurance about our technological ability to ensure the confidentiality of the data. Researchers involved in similar innovations in the mobile health (Mhealth) space might also encounter a resistance to change if their innovations require a shift in the daily routine tasks of the health systems personnel. In order to address this challenge, an appreciation of the  practical micro and macro level challenges that health workers and health authorities encounter  on a day-to-day basis needs to be complemented by a readiness to incorporate the new system in  a stage-wise or staggered manner. The main facilitating factors that furthered our efforts were

not only the enormity of the dengue problem but the enthusiasm, curiosity and urgency to consider mobile phone-based innovations.  The potential of mobile phones in transforming the global health landscape has been extensively chronicled by scholars (Boulos et al., 2011; Curioso and Mechael, 2010; Gurman et al., 2012; Kay, 2011; Mechael, 2009). As a result, health system stakeholders seem readier than ever to consider innovations that they feel might positively influence public health outcomes; equally so, corporate entities seem willing to partake in such initiatives as involvement in public-private partnerships furthers their corporate social responsibility initiatives.

The inherent trans-disciplinary nature of research inquiries in health communication has been previously elucidated (Kreps and Maibach, 2008) as the field draws upon theoretical ideas from social psychology, communication, public health and others. The nature of designing Mhealth interventions such as Mo-Buzz however propels the intent of the term "trans-disciplinary" in public health research to new levels. For instance, our team comprises experts from social communication, behavioral science, human computer interaction for novel interfaces, mathematics, software engineering, information sciences and psychology. In the absence of a formalized template to synergize the intellectual energies of these varied specialists, our collaboration is shaped organically but efficiently. The collaborative process was highlighted by a process of joint exploration into a new concept, identifying how and where each member could contribute in the development and research process and an implicit understanding of each other's capabilities. From a logistical standpoint the challenge, at times, lay in organizing various tasks requiring different skill sets towards achieving a common objective. The more enriching challenge, however, lay in communicating terminologies and concepts to each other, and we found, over time, that we could use the power of metaphors to accomplish the same. The other organizational implication from our experience in trans-disciplinary research may be construed either positively or negatively. At many stages during our system development, we observed that many processes (that could have been arduous) were easily facilitated as the team members trusted the respective expertise of the other, thereby not overstepping boundaries. While this worked in our favor, it might also be important to recognize that such a tendency, if pushed further, could result in an expert's ideas or inputs being left unchallenged and not critically evaluated. As Mhealth interventions expand across geographic frontiers in the future, it is incumbent upon health systems scientists to inquire about and inform the practice of trans-disciplinary research teams.

## 6.0 Future Work

Based on the data gathered and feedback from the first phase of deployment in Sri Lanka, Mo-Buzz will be refined in terms of its user interface, predictive ability and educational  modules. The second phase of deployment includes the launch of the mobile application for the  general public in Colombo. This application will comprise all the three components described in

the paper leading to the establishment of a dynamic communication channel between the general public and health authorities. The foremost limitation we foresee is the restricted reach of our application as the current version is only available on Android smartphones, unaffordable to many in a country like Sri Lanka. However, emerging reports (Daily FT, 2013; The Sunday Times, 2011)that suggest a sharp rise in smartphone penetration in Sri Lanka provide encouragement about the application's potential in the future.

A successful deployment of the system in Sri Lanka will provide a natural progression for the system to be contextualized and used in other countries facing similar threats of vector-borne infectious diseases (including malaria) such as India and Singapore. For instance,  dengue has been increasing every year in India with nearly 50,000 cases reported in 2012 (Chaudhuri, 2013). Singapore – among the most developed countries in the region – is experiencing its worst dengue outbreak this year with more than 15,000 cases reported as of September 2013 (http://dengue.gov.sg). This spell arrived after two previous epidemics in 2005 and 2007 that affected more than14,000 and 8,000 people respectively (Lee et al., 2010; Ler et al., 2011). The unprecedented surge of smartphones in both these countries is an encouraging sign for our concept. For instance, Singapore boasts more than universal penetration of mobile phones with 80% users adopting smartphones and 150% overall mobile penetration (Blackbox Research, 2012). India is arguably among the world's largest mobile phone markets with nearly 770 million mobile connections (Gartner, 2013) among its billion-over population.

As the major components of the Mo-Buzz system architecture are generic in terms of its functionality, it provides an opportunity to adapt and apply the system to other health areas. In this regard, the team is collaborating with Singapore-based clinical and non-clinical organizations to adapt and apply our concept to influenza and cardio-respiratory illnesses. In the context of influenza, the intention is to empower three main at-risk groups – school children, health workers and the elderly – with the application. The purpose is to enable them to report vaccine uptake behavior, measure vaccine effectiveness and disseminate dynamic health education. For cardio-respiratory illnesses, Mo-Buzz can be adapted to create a mobile-based social network of citizens with cardio pulmonary resuscitation (CPR) skills, and use GIS-mapping to create a mobile-based alert and communication system where caretakers can access the nearest defibrillators in case an individual experiences myocardial infarction.

**7.0 Conclusion**

Infectious diseases such as dengue pose a formidable challenge to public health authorities and the general public in tropical countries and especially so in South and Southeast Asia. We optimized the deep penetration of mobile phones in this region to develop a system that establishes a chain of communication between health authorities and the public, potentially enhances trust between these two stakeholders, and engenders a proactive give-and-take of

health information. While each of the three components of our system has been previously conceptualized in silos (Dengue Torpedo, 2013; Malaria Atlas Project, 2013), Mo-Buzz is among the first to demonstrate an innovative integration of the three. From an applied standpoint, our effort seeks to enhance the epidemiological capabilities of health authorities and empowers citizens to dynamically report to them. From an academic standpoint, our effort initiates a scientific conversation about how mobile phones might potentially transform the fields of epidemiology and health communication from being complementary to synergistic entities.

**References**:

Alter, C., Hage, J., 1993. Organizations Working Together. Sage, London.

Althouse, B.M., Ng, Y.Y., Cummings, D.A., 2011. Prediction of dengue incidence using search query surveillance. PLoS Negl Trop Dis 5, e1258.

Axelsson, R., Axelsson, S.B., 2006. Integration and collaboration in public health—a conceptual framework. The International Journal of Health Planning and Management 21, 75-88.

Bhattacharya, M., Maitra, S., Ganguly, A., Bhattacharya, A., Sinha, A., 2013. Dengue: A Growing Menace--A Snapshot of Recent Facts, Figures & Remedies. International journal of biomedical science: IJBS 9, 61.

Blackbox Research, 2012. Smartphones in Singapore: A Whitepaper Release Singapore.

Boulos, M.N.K., Resch, B., Crowley, D.N., Breslin, J.G., Sohn, G., Burtner, R., Pike, W.A., Jezierski, E., Chuang, K.-Y.S., 2011. Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples. Int J Health Geogr 10, 67.

Catley, A., 2006. Use of participatory epidemiology to compare the clinical veterinary knowledge of pastoralists and veterinarians in East Africa. Trop Anim Health Prod 38, 171-184.

Chan, M., Johansson, M.A., 2012. The incubation periods of dengue viruses. PLoS ONE 7, e50972.

Chaudhuri, M., 2013. What can India do about dengue fever? BMJ 346.

Chib, A., Lwin, M.O., Ang, J., Lin, H., Santoso, F., 2008. Midwives and mobiles: using ICTs to improve healthcare in Aceh Besar, Indonesia 1. Asian Journal of Communication 18, 348-364.

Chunara, R., Chhaya, V., Bane, S., Mekaru, S.R., Chan, E.H., Freifeld, C.C., Brownstein, J.S., 2012. Online reporting for malaria surveillance using micro-monetary incentives, in urban India 2010-2011. Malar J 11, 43.

Curioso, W.H., Mechael, P.N., 2010. Enhancing 'M-health' with south-to-south collaborations. Health Affairs 29, 264-267.

Daily FT, 2013. Smartphones: Future of communication.

Degallier, N., Favier, C., Menkes, C., Lengaigne, M., Ramalho, W.M., Souza, R., Servain, J., Boulanger, J.-P., 2010. Toward an early warning system for dengue prevention: modeling climate impact on dengue transmission. Climatic Change 98, 581-592.

Dengue Torpedo, 2013.

Ebi, K.L., 2009. Malaria early warning systems, Biometeorology for adaptation to climate variability and change. Springer, pp. 49-74.

Ekeland, A.G., Bowes, A., Flottorp, S., 2010. Effectiveness of telemedicine: A systematic review of reviews. International Journal of Medical Informatics 79, 736-771.

Estallo, E.L., Lamfri, M.A., Scavuzzo, C.M., Almeida, F.F.L., Introini, M.V., Zaidenberg, M., Almirón, W.R., 2008. Models for predicting Aedes aegypti larval indices based on satellite images and climatic variables. Journal of the American Mosquito Control Association 24, 368-376.

Favier, C., Schmit, D., Muller-Graf, C.D., Cazelles, B., Degallier, N., Mondet, B., Dubois, M.A., 2005. Influence of spatial heterogeneity on an emerging infectious disease: the case of dengue epidemics. Proc Biol Sci 272, 1171-1177.

Fazlulhaq, N., 2012. Dengue may reach epidemic proportions, health officials warn. The Sunday Times.

Freifeld, C.C., Chunara, R., Mekaru, S.R., Chan, E.H., Kass-Hout, T., Ayala Iacucci, A., Brownstein, J.S., 2010. Participatory Epidemiology: Use of Mobile Phones for Community-Based Health Reporting. PLoS Med 7, e1000376.

Gartner, 2013. Gartner Says Indias Mobile Services Market To Reach Rs.1.2 Trillion In 2013

Gubler, D.J., Clark, G.G., 1996. Community involvement in the control of Aedes aegypti. Acta Trop 61, 169-179.

Gurman, T.A., Rubin, S.E., Roess, A.A., 2012. Effectiveness of mHealth behavior change communication interventions in developing countries: a systematic review of the literature. Journal of health communication 17, 82-104.

Hay, S.I., Rogers, D.J., Shanks, G.D., Myers, M.F., Snow, R.W., 2001. Malaria early warning in Kenya. Trends in parasitology 17, 95-99.

Hettiarachchi, K., Jeewandara, S., Munasinghe, A., Perera, S., 2013. More dengue victims: Staff shortage, ignorance of people, poor garbage management to blame. The Sunday Times.

Hsieh, Y.H., Ma, S., 2009. Intervention measures, turning point, and reproduction number for dengue, Singapore, 2005. The American Journal of Tropical Medicine and Hygiene 80, 66-71.

http://www.promedmail.org.

International Telecommunications Union, 2013. ITU statistical market overview: Sri Lanka.

Jones, M.D.R., 1981. The programming of circadian flight-activity in relation to mating and the gonotrophic cycle in the mosquito, Aedes aegypti. Physiological Entomology 6, 307-313.

Kamel Boulos, M.N., Resch, B., Crowley, D.N., Breslin, J.G., Sohn, G., Burtner, R., Pike, W.A., Jezierski, E., Chuang, K.Y., 2011. Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples. Int J Health Geogr 10, 67.

Kanakaratne, N., Wahala, W.M., Messer, W.B., Tissera, H.A., Shahani, A., Abeysinghe, N., de Silva, A.M., Gunasekera, M., 2009. Severe dengue epidemics in Sri Lanka, 2003–2006. Emerg Infect Dis 15, 192.

Kay, M., 2011. mHealth: New horizons for health through mobile technologies. World Health Organization.

Koopman, J.S., Prevots, D.R., Vaca Marin, M.A., Gomez Dantes, H., Zarate Aquino, M.L., Longini, I.M., Jr., Sepulveda Amor, J., 1991. Determinants and predictors of dengue infection in Mexico. Am J Epidemiol 133, 1168-1178.

Kreps, G.L., Maibach, E.W., 2008. Transdisciplinary Science: The Nexus Between Communication and Public Health. Journal of Communication 58, 732-748.

Lee, K.-S., Lai, Y.-L., Lo, S., Barkham, T., Aw, P., Ooi, P.-L., Tai, J.-C., Hibberd, M., Johansson, P., Khoo, S.-P., 2010. Dengue virus surveillance for early warning, Singapore. Emerg Infect Dis 16, 847.

Ler, T.S., Ang, L.W., Yap, G.S.L., Ng, L.C., Tai, J.C., James, L., Goh, K.T., 2011. Epidemiological characteristics of the 2005 and 2007 dengue epidemics in Singapore–similarities and distinctions. Western Pacific Surveillance and Response Journal 2, 24-29.

Lester, R.T., Ritvo, P., Mills, E.J., Kariri, A., Karanja, S., Chung, M.H., Jack, W., Habyarimana, J., Sadatsafavi, M., Najafzadeh, M., 2010. Effects of a mobile phone short message service on antiretroviral treatment adherence in Kenya (WelTel Kenya1): a randomised trial. The Lancet 376, 1838-1845.

Lim, M.S., Hocking, J.S., Hellard, M.E., Aitken, C.K., 2008. SMS STI: a review of the uses of mobile phone text messaging in sexual health. International journal of STD & AIDS 19, 287-290.

Lowe, R., Bailey, T.C., Stephenson, D.B., Graham, R.J., Coelho, C.A.S., Sá Carvalho, M., Barcellos, C., 2011. Spatio-temporal modelling of climate-sensitive disease risk: Towards an early warning system for dengue in Brazil. Computers & Geosciences 37, 371-381.

Luz, P.M., Mendes, B.V., Codeco, C.T., Struchiner, C.J., Galvani, A.P., 2008. Time series analysis of dengue incidence in Rio de Janeiro, Brazil. The American Journal of Tropical Medicine and Hygiene 79, 933-939.

Malaria Atlas Project, 2013.

Mechael, P.N., 2009. The Case for mHealth in Developing Countries. Innovations: Technology, Governance, Globalization 4, 103-118.

Ministry of Defense, 2013. Troops to be deployed for dengue prevention.

Ministry of Health, 2013a. Dengue update.

Ministry of Health, 2013b. Disease surveillance trends.

Mintzberg, H., 1993. Structure in Fives: Designing Effective Organizations Prentice Hall, Englewood Cliffs NJ.

Nishiura, H., Halstead, S.B., 2007. Natural history of dengue virus (DENV)-1 and DENV-4 infections: reanalysis of classic studies. J Infect Dis 195, 1007-1013.

Parks, W., Lloyd, L., 2004. Planning social mobilization and communication for dengue fever prevention and control: A step-by-step guide. World Health Organization.

Peiris, V., 2009. Sri Lanka: Dengue epidemic claims scores of lives. World Socialist Web Site.

Racloz, V., Ramsey, R., Tong, S., Hu, W., 2012. Surveillance of dengue fever virus: a review of epidemiological models and early warning systems. PLoS Negl Trop Dis 6, e1648.

Rochlin, I., Turbow, D., Gomez, F., Ninivaggi, D.V., Campbell, S.R., 2011. Predictive mapping of human risk for West Nile virus (WNV) based on environmental and socioeconomic factors. PLoS ONE 6, e23280.

Rodgers, A., Corbett, T., Bramley, D., Riddell, T., Wills, M., Lin, R.-B., Jones, M., 2005. Do u smoke after txt? Results of a randomised trial of smoking cessation using mobile phone text messaging. Tobacco control 14, 255-261.

Salazar, M.I., Richardson, J.H., Sanchez-Vargas, I., Olson, K.E., Beaty, B.J., 2007. Dengue virus type 2: replication and tropisms in orally infected Aedes aegypti mosquitoes. BMC Microbiol 7, 9.

Scanfeld, D., Scanfeld, V., Larson, E.L., 2010. Dissemination of health information through social networks: Twitter and antibiotics. American Journal of Infection Control 38, 182-188.

The Sunday Times, 2011. Smart phone penetration in Sri Lanka better than other regional markets.

Thomson, M., Doblas-Reyes, F., Mason, S., Hagedorn, R., Connor, S., Phindela, T., Morse, A., Palmer, T., 2006. Malaria early warnings based on seasonal climate forecasts from multi-model ensembles. Nature 439, 576-579.

Thomson, M.C., Mason, S.J., Phindela, T., Connor, S.J., 2005. Use of rainfall and sea surface temperature monitoring for malaria early warning in Botswana. American Journal of Tropical Medicine and Hygiene 73, 214-221.

Venkatesh, V., Morris, M.G., Gordon, B.D., Davis, F.D., 2003. User Acceptance of Information Technology: Toward a Unified View. MIS Quarterly 27, 425-478.