mHealth Revolutionizing Public Health: An Economic Study

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ABSTRACT

The existing disease surveillance and notification system in India and Sri Lanka were introduced a century back but revised, over time, with the emergence of epidemics such as yellow fever, SARS, H1NI. The two countries' emphasis is on monitoring around 25 reportable infectious diseases. This legal requirement is a slow and labor intensive process that takes several weeks before epidemiologist receive aggregates of these handful of diseases for any kind of analysis (Prashant and Waidyanatha, 2010). The limitations have lead to human and economic losses: Leptospriosis outbreak in Sri Lanka (Argampodi et al, 2008), Chikungunya in Tamil Nadu (Ganesan et al, 2009). An unusual number of patients presenting with similar symptoms concentrated in a particular geographic areas could have signaled the epidemiologists of an abnormal event and may have effectively mitigated their consequences. In addition, life-style or non-infectious diseases like diabetes, hypertension, asthma, and arthritis are affecting the national health budgets. The Real-Time Biosurveillance Program (RTBP) pilot, stemming from the realization of the system's weaknesses, introduced modern information communication technology to health departments in India and Sri Lanka to overcome the latencies and monitor all diseases, reportable and non reportable ones, to monitor the health status of the country. The processes involved digitizing all patient clinical health records with a mobile phone application, analyzing them in near real-time with an event detection software, and disseminating those adverse events, once again with mobile phones, to health workers for prompt response. Relative to the existing system, the RTBP can reduce expenses, introduce benefits, and improve the efficiencies in disease surveillance and mitigation. This paper discusses those economic benefits and the policy reforms required before the RTBP can take full effect.

Key words - Applications, Innovation, Public Goods, Productivity, Policy

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* The paper discusses cost analysis data gathered through literary surveys and interviews with health officials in India and Sri Lanka. The pilot was carried out in Sivagangai District, Tamil Nadu, India and Kurunegala District, Sri Lanka. The Authors wish to acknowledge the project partners – Ministry of Health and Nutrition – Sri Lanka, Department of Health and Family Welfare, Tamil Nadu – India, LIRNEasia, IITM's Rural Technology and Business Incubator, Lanka Jathika Sarvodaya Shramadana Sangamaya, Carnegie Mellon University's Auton Lab, National Center for Biological Sciences, University of Alberta, and Respere Lanka.

mHealth Revolutionizing Public Health: An Economic Analysis

INTRODUCTION

Under the current systems in Sri Lanka and India the epidemiological departments monitor a subset of around 25 infectious diseases, termed as Notifiable diseases. When a patient is diagnosed with a Notifiable disease, at the point of care, the medical officer notifies regional health administrations or local authorities, using a paper-based reporting methods, followed by a phone call in certain critical instances. Health Inspectors would, then, make house calls to investigate the individual cases and, if necessary, execute preventive procedures.

The limited epidemiological statistics from the hospitals, health clinics, and healthcare centers are gathered using paper-based forms and procedures. These forms are then sent to regional health officials where data is consolidated by qualified staff. Some trend analysis is done by regional and national epidemiological centers to identify long term effects for resource allocation.

In certain instances of the process computers are used merely for the production of printed reports but not necessarily a proper computerization of the current system. The Indian National Informatics Center (NIC) hosted Directorate of Public Health and Preventive Medicine (DPH&PM) web based portal is a tool for entering manually aggregated data for generating electronic reports (i.e. replacing the previous postal delivery with Internet). The Sri Lankan Epidemiology Unit manually enters aggregated data received from the health departments in to spreadsheets, once again to generate the Weekly Epidemiological Return (WER) electronic report. Under the present system it can take up to 15-30 days for information to move through these various steps, leading to delays in both outbreak detection and notification.

The present systems' ability to detect rapid onset outbreaks or emerging diseases is questionable. Observations and interviews with health officials made the RTBP researchers realize that only 20% of the patients' diagnosis are confirmed in the outpatient departments or clinics, while the remaining 80% are regarded as probable or suspected cases. This is mainly because hospitals and clinics in rural India and Sri Lanka are predominantly regarded as “clearing houses” where medical officer examine hundred or more patients each day, which limits their patient service rates to less than 2 minutes per patient. Given that most deadly diseases present similar symptoms, with only 20% cases being confirmed, it is possible for an influenza like outbreak that presents fever-like symptoms to go unnoticed.

Leading experts in the field of Biosurveillance and health informatics have argued that improvements in disease detection and notification can be achieved by introducing more efficient means of gathering, analyzing, and reporting on data from multiple locations (Wagner, 2006). The introduction of new information and communication technologies are central means to achieve these efficiency gains. The primary research objective of the multi-partner research initiative: The RTBP was to examine these claims more closely by producing evidence to indicate in what ways and to what applications available for mobile phone-based (Vital Wave Consulting, 2009) extent the introduction of new ICTs might achieve efficiency gains when integrated with existing disease surveillance and detection systems.

Gow et al (2010) and Kannan et al (2010) discussed the robustness of the mHealthSurvey when used by healthcare workers with a medical background and data-entry assistants without medical training, in India and Sri Lanka. Ganesan et al (2010) focused on the data digitizing field experience in Tamil Nadu, India. Dubrawski et al (2009) described the utility, acceptability, and acceptance of the T-Cube Web Interface (TCWI) analyses tool for rapid detection of outbreaks in large multivariate datasets. Sampath et al (2010) discussed the usability, comprehensibility, benefits, and performance of the Sahana Alerting Broker (SABRO) messaging in RTBP for public health alerting and situational-awareness.

This paper specifically discusses the investment and operational costs, problems associated with daily operational costs, the aspects of costs in relation to institutionalizing the RTBP and measuring the tangible and intangible benefits and efficiencies in monitory terms. The basis for calculation and comparison of the RTBP with the existing system was the *total cost of ownership*.

RESEARCH DESIGN

In the last decade or so, there has been a lot of talk and praises heaped on the potentials benefits and value of using Information and Communications Technologies (ICTs) for health. This new paradigm, called e-health, is being adopted widely, from primary to tertiary health care, in many countries, especially developed ones. Further to this, leveraging emerging mobile technologies in e-Health, termed as "mobile health" (m-Health), is one that is gaining much interest; especially in developing markets.

Technology

The project developed a mobile phone application, namely the *mHealthSurvey*, for digitizing patient disease and demographic information. It is a data entry software that works on any standard Java-enabled mobile phone. A typical record contains the patient visitation date, location, gender, age, disease, symptoms, and signs. Data is transmitted over General Packet Radio Service (GPRS) cellular networks (Figure 1). The Application presents the healthcare worker with a series of fields and menus that are completed using the standard keypad on the phone (Gow et al, 2010).

The large volume of data is analyzed by trained staff at the health departments with the help of the TCWI statistical analyses tool. It is a generic tool designed to efficiently visualize and manipulate large scale multivariate temporal and spatio-temporal datasets commonly encountered in public health applications. TCWI's automated algorithms are in place to pre-screen the data that would present a daily ranked set of possible disease outbreaks. These computer generated possible outbreak alarms are presented to the epidemiologist to further filter and determine those ones that are of significant interest. The interface allows the user to execute complex ad-hoc queries quickly and to run various types of statistical tests on the loaded data. Upon uploading the working dataset, the user can manipulate and visualize data through the Time Series, Map, and Pivot Table panels (Ray et al, 2008).

Targeted groups of medical officers, health inspectors, nurses, and other health officials would receive the confirmed adverse event via SMS, Email, and the Web; once again using mobile phones and GSM cellular networks. A condensed version of the alert is pushed through SMS to get immediate attention of the recipients and a more descriptive message emailed and published on the web. SABRO allows for the dissemination of localized and standardized interoperable messages. A single-entry of the standardized message can be issued through multiple channels on to various terminal devices (Gow and Waidyanatha, 2010).

Figure 1 shows the three step information flow of submitting digitized data for epidemiologists to analyze and then share those events of interest with targeted healthcare workers.

Figure 1: data collection, event detection, and alerting processes

Process

First step of the process involves digitizing the health records. A group of healthcare workers, 28 in India and 15 in Sri Lanka, were supplied with mobile phones and the mHealthSurvey application in order to digitize patient records and enter data into the real-time biosurveillance system. For the purpose of the pilot, data in India came from four Primary Health Centers (PHCs) and 24 Health Sub centers (HSCs) located in the state of Tamil Nadu; similarly, data was collected from twelve hospitals and clinics located in Kurunegala District, Sri Lanka. The data was typically extracted from paper registers and chits for digitizing. However, with the acceptance of the RTBP by the government health departments and necessary framework for replacing the present legal paper documents, the handwritten records can be obsolete with records being directly digitized.

For the purpose of the project the data centers for the respective countries were located at the premises of the project Principal Investigators: Indian Institute of Technology – Madras's Rural Technology and Business Incubator and Lanka Jathika Sarvodaya Shramadana Sangamaya. RTBP in an actual implementation would require the data centers to be located with the government health department.

TCWI trained staff in India belonging to the District's Integrated Disease Surveillance Program (IDSP) of the Deputy Director of Health Services (DDHS) and PHCs as well as trained staff belonging to the Sri Lankan Regional Epidemiology (RE) Unit and Medical Officer of Health (MOH) departments analyze the epidemiological data. Typically, the trained staff would investigate the pre-screening lists produced daily by TCWI of fever-like diseases, reportable set of communicable diseases, and other communicable diseases. Any alarming events are shared with the in-house epidemiologists or other designated decision-makers before confirming the event as an outbreaks of interest.

The same trained staff from the IDSP, PHC, RE, and MOH would transform the confirmed outbreak in to a SABRO message to be disseminated to the respective medical officers, nurses, and health inspectors in the targeted geographic areas. There are two types of messages: action alerts and situational-awareness. Action oriented alerts (or action alerts) require the recipients of the message to execute their established response plans such as investigating the patients at their homes, educating the communities of preventive measures. Inaction oriented situational-awareness messages would not require immediate action but would inform the healthcare workers to be vigilant of the potential outbreak in a neighboring area, and be ready to respond, in the event the disease were to spread in to their areas.

Implementation

The project began in July 2008. During the first year of the project, the researchers studied the existing polices and procedures in each country. Thereafter, applied an iterative top-down bottom-up approach to develop and customize the mHealthSurvey, TCWI, and SABRO technologies. Project produced standard operating procedures and training material were used to introduce the new technologies and processes to the users. The users were given 4-6 weeks to get familiar with the technologies and processes. Thereafter, the project initiated the evaluation cycle, which began in July 2009 and ended in August 2010.

EVALUATION FRAMEWORK

The importance of field testing cannot be exaggerated: “Many important characteristics of biosurveillance systems can only be determined once they are deployed, at least partially, in the field” (Wagner, 2008, p. 507). Field testing can be intended as formative or summative in approach, with formative studies aimed at producing insight as to the effectiveness of a component or subsystem and identifying potential improvements to that component, which was the essence of the RTBP pilot. A summative study would evaluate the outcomes of the RTBP, which would essentially be subsequent.

The technology design of the RTBP was an integral of data collection, event detection, and alerting subsystems. The evaluation framework for field testing of biosurveillance systems examined the attributes of the system or system components that were further divided into four general categories: institutional challenges (e.g. healthcare workers,health officials, epidemiologists), content standards (e.g., ontologies, semantics, syntax, vocabulary), computing resources (e.g., mobile applications, detection analytics software, databases), and communications Networks (e.g., mobile devices, computer, wireless links, internet connections, GSM technology).

The overall vision and strategies for evaluating the RTBP was adopted from the literature by Ammenwerth et al (2004). General methods for subjective and objective quantitative and qualitative evaluation of bioinformatics systems were introduced by Friedman and Wyatt (2006). More specific to

RTBP, Lewis (2003) and Wagner (2008) have proposed biosurveillance system and public health informatics evaluation methods with a broad set of evaluation criteria on the usability of the technology, affect on structural or process quality and social consequences of introducing the technology. Anderson and Aydin (2005) describe methods and key aspects of qualitatively evaluating the organizational impact of introducing ICTs in Healthcare.

To perform the cost analyses of the existing paper-based system and the RTBP introduced technology system, the researchers calculated the investments and expenses as whole, in terms of Cost Benefits, Economic Efficiencies, and Cost Sensitivity.

cost analysis framework

Total Cost of Ownership (TCO) for the three subsystems: data collection, event detection, and alerting were calculated taking both operational and capital expenses in to consideration. The tangible goods such as mobile handheld devices, computing equipment, and furniture were depreciated over a life span specific to each tangible good from which a monthly cost was calculated. The common denominator of unit for all cost elements was established as the monthly district cost.

Each macro-cost element would contribute a certain proportion towards each of the three subsystems. For example, the health department decision-makers salary would contribute equal proportions towards the event detection and alerting subsystems but zero contributions for the data collection subsystem (i.e. a ratio of 0 : 0.5 : 0.5 for data collection, event detection, and alerting, respectively). In general, the i^{th} cost element: $X_i = a_iX_i + b_iX_i + c_iX_i$; where $a_i + b_i + c_i = 1$ and a_i , b_i , c_i are the contributing proportionality factors for data collection, event detection, and alerting, respectively. The overall cost for the data collection subsystem would be the sum of all contributions: $a_1X_1 + a_2X_2 +...+ a_nX_n$. Similarly, aggregating the b_i and c_i components of all cost elements would give the cost for event detection and alerting.

Efficiency Gains are not about cutting expenses, but raising productivity and enhancing value for money. Efficiency gains accrue when projects: reduce inputs for the same outputs, reduce prices for the same outputs, get greater outputs or improved quality for the same inputs, and get more outputs or improved quality in return for an increase in resources that is proportionately less than the increase in output or quality. The inputs would be the disease information and the outputs would be epidemiological indicators.

Cost Benefits - Friedman and Wyatt (2006) recommend investigating the cost benefits in terms of direct costs (or TCO), time costs, indirect costs, and intangible costs. The analysis in this paper will be mainly on direct and some time costs. Although it is far more acceptable by decision-makers to see the economic aspects in terms of suffering prevented, loss of house hold productivity, Quality Adjusted Life Years (QALY), or lives saved (Lee et al, 2006), the project has not been in effect long enough to study these impact measures. In terms of benefits, this analysis will predominantly address the aspect of “money saved” and 'productivity increased”.

Lee et al (2006) recommend that organizations, when acquiring or planning Biosurveillance systems should take in to account the considerable financial resources required to develop, use, and maintain the system as well as the feasibility and costs of recruiting and training capable personnel. In this regard, the mechanics of the cost determination was a micro-costing method which were aggregated to distinct level macro-costs categorized as system delivery, system administration/support, data center, health facilities, health departments, and healthcare workers. Table 1 explains the macro-cost elements used in the calculation of the expenses for each of the country programs: present IDSP in India (IN), present Disease Surveillance and Notification System (DSNS) in Sri Lanka (LK), and the project introduced RTBP.

Table 1: Elements of the macro-costs used in calculating the existing and RTBP expenses

Macro-cost	***Existing (IN) - IDSP***	***Existing (LK) DSNS***	***Introduced RTBP***
System delivery	Develop and implement the IDSP and the NIC hosted	Develop and implement DSNS, software and	Develop and implement technology: mHealthSurvey,

(*design, develop, and deploy the program*)	DPH&PM web application for collecting and reporting aggregated statics	hardware for consolidating and generating the WER reports	TCWI, SABRO; produce training material and standard operating procedures
System administration/ support (*resource person for upkeep of system and assist clients*)	Maintain computers at DDHS and PHCs; maintain the DPH&PM system hardware and software	Maintain the computers at Regional Epidemiology Unit and National Epidemiology Unit; maintain the software and data of the WER	Upkeep of the database, servers, and networks; provide support to the users on the mHealthSurvey, TCWI, and SMAM
Data Center (servers and network)	Physical space of the NIC DPH&PM servers with network and environment control	Office space for the data entry and WER report generating computers at RE and National Epidemiology Unit	Physical location of RTBP server with network, back-up power, and environmental control with redundancy
Health Facilities (Data collection and submission)	Training, printing/storage of paper forms/registers, salaries, report delivery (transport/post)	Training, printing/storage of forms/registers, salaries, report delivery (transport/post)	Mobile phones, connectivity, and staff salaries
Health Departments (Event detection and Alerting)	computer, network, office space, salaries, forms/registry, archiving and other expenses	computers, office space, salaries, forms/registry archiving and other expenses	computer, network, office space, and salaries
healthcare workers (Alerting and Response)	Salaries, communications, transport	Salaries, communications, transport	Salaries and communications, salaries

Incremental Cost-Effectiveness Ratio (ICER) compares the RTBP cost-effectiveness with that of the present day IDSP and DSNS in India and Sri Lanka, respectively. ICER represents the net costs that will be expended by implementing the RTBP divided by the net benefits (Friedman and Wyatt, 2006); i.e. the net cost of moving from present system to the introduced system divided by the benefits of moving from collecting patient data related to 25 diseases to all diseases. Given that the goals of any disease surveillance and mitigation system is to address all potential disease related health threats, we establish the benefits to be the number of disease related statistics that are collected, analyzed, and reported.

When the net cost is plotted (Y-axis) against the net benefits (X-axis) in a Cartesian plane, if the result is negative along the Y-axis and positive along the X-axis; i.e. bottom right quadrant of the Cartesian plane, then no further analysis is required because the project is relatively effective and relatively cheaper than the existing system. If the result falls in the top left quadrant (Y positive and X negative), then the introduced project is expensive and less effective. If the result falls in to any of the other quadrants: top right or bottom left, then further analysis of CEA is required to justify its worth (Friedman and Wyatt, 2006).

One-way Sensitivity Analysis is the method used in this project. Although the best-case/worst-case method provides an estimate of the spread of possible results, given the scope of the project, which was mainly proving the technology concept, calculating the confidence limit was not a priority. The economic analysis of the research was more interested in the estimate of the effect of individual variables on the ICER (Friedman and Wyatt, 2006).

RESULTS

Total Cost of Ownership

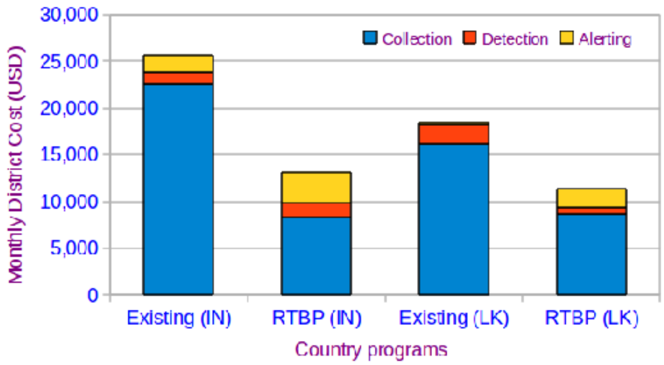

Figure 2: cost comparison of data collection, event detection, and alerting subsystems for existing paper-based and introduced RTBP

Table 2: Subsystem cost (USD) in Figure 2

	Collect	Detect	Alert
Exist (IN)	22,614	1,294	1,752
RTBP (IN)	8,353	1,436	3,390
Exist (LK)	16,181	1,997	328
RTBP (LK)	8,647	736	1,979

The stacked chart in Figure 2 shows a comparison of the subsystem TCO costs and the overall costs for the existing paper-based programs: Existing (IN) and Existing (LK) and the introduced technology based programs: RTBP (IN) and RTBP(LK). Costs reduced between existing and RTBP systems in India and Sri Lanka are 48.6% and 38.6%, respectively.

From the set of macro-costs mentioned in Table 1, Figure 3 shows those macro-costs for health facilities, health departments, and healthcare workers, required to operationalize both the present paper-based Existing (IN), RTBP (IN), Existing (LK), and RTBP (LK)[1]. Figure 3 does not show the macro-costs for system delivery, system administration/support, and data center because these three macro-costs are near negligible (less than 8% of overall cost) relative to the health facility, health department, and health worker costs (Table 3).

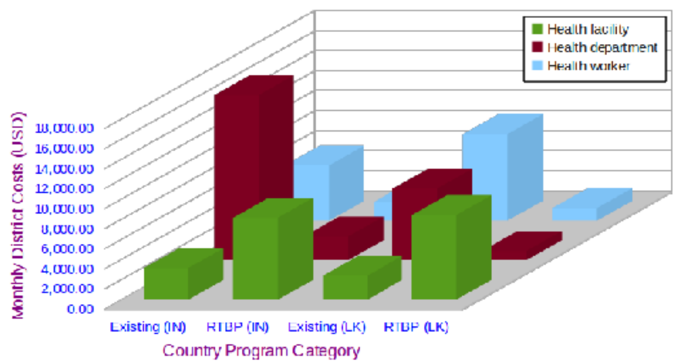

Figure 3: District monthly costs comparison of health facility, department, and health worker for existing paper-based and introduced RTBP

Table 3: Monthly district macro-costs and percentages for existing paper-based and introduced RTBP

Macro-cost	***Existing (IN)***		***RTBP (IN)***		***(IN)***	***Existing (LK)***		***RTBP (LK)***		***(LK)***
	Cost USD	% of total	Cost USD	% of total	Diff %[2]	Cost USD	% of total	Cost USD	% of total	Diff %
System delivery	5.00	0.02	66.00	0.50	92.42	40.00	0.22	79.00	0.70	49.37
System Admin/support	400.00	1.50	470.00	3.57	14.89	60.00	0.32	525.00	4.62	88.57
Data center	130.00	0.49	236.00	1.79	44.92	283.00	1.53	189.00	1.66	-49.74
Health facility	3,158.00	11.82	8,168.00	61.98	61.34	2,370.00	12.81	8,433.00	74.23	71.90
Health department	16,652.00	62.31	2,359.00	17.90	-605.89	7,120.00	38.47	893.00	7.86	-697.31
Health worker	6,378.00	23.87	1,880.00	14.27	-239.26	8,633.00	46.65	1,242.00	10.93	-595.09

1 *Definition of the labels used in Figures 2 – 5*: Existing (IN) = present system in India (Integrated Disease Surveillance Program); Existing (LK) = present system in Sri Lanka (Disease Surveillance and Notification Program); RTBP (IN), RTBP (LK) = Real-Time Biosurveillance Program in India and Sri Lanka, respectively.

2 Diff % = (RTBP – Existing)/Existing given as a percentage of the difference

Incremental Cost-Effectiveness Ratio

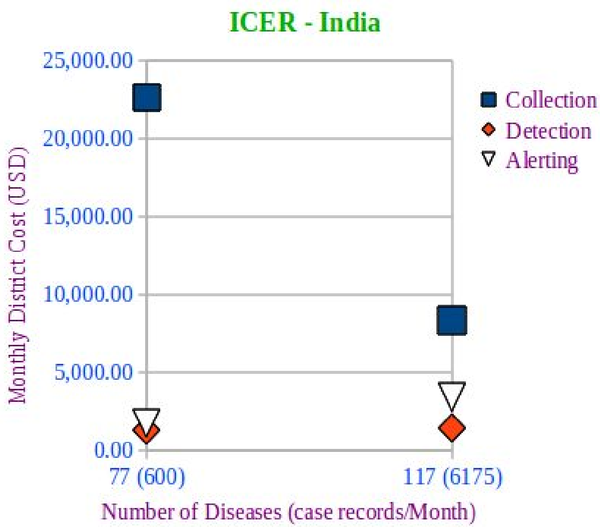

Figure 4: Incremental cost to move from existing to RTBP system in India

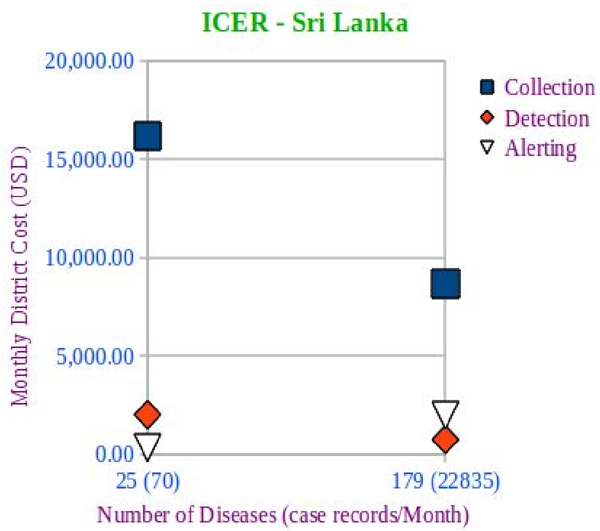

Figure 5: Incremental cost to move from existing to RTBP system in Sri Lanka

Figure 4 (India) shows that the collection: USD -356.53 to be in the bottom right quadrant of the CE plane but the detection: USD 3.55 and alerting: US$ 40.94 in the top right quadrant of the CE plane. Therefore, the detection and alerting component requires further analysis to justify the new investments. Figure 5 (Sri Lanka) shows that the ICER with the collection: USD -48.92 and detection: USD -8.19 being in the bottom right quadrant of the CE plane but the alerting: US$ 10.72 in the top right quadrant of the CE plane. Therefore, the alerting component requires further analysis to justify.

One-way cost sensitivity

Table 4: Description and typical values of the parameters used in OpEx and CapEx calculations

Parameter:			**Typical value**	
Number	***Name***	***Description***	***Tamil Nadu***	***Sri Lanka***
I	Health District	Number of districts in a State or Province; Sivagangai district, Tamil Nadu state, India and Kurunegala district in Western province, Sri Lanka	32	24
II	Health Facilities	Average number of hospitals/clinics and primary health center in a district of India and Sri Lanka, respectively	47	44
III	Health Departments	Regional Epidemiology Unit and Medical Officer of Health division in Sri Lanka and a Deputy Director of Health Services, and Administrative section of a Primary Health Center in India	48	18
IV	Healthcare workers	Medical officer, nurse, and health inspector in India and medical officer, nurses and pubic health inspector in Sri Lanka; they all respond to epidemiological events for preventive and curative actions.	10	12
V	Exchange rate	Currency exchange rate relative to the United States Dollar	45.00	110.00

The cost mentioned in Figure 6 is the amount by which the overall monthly costs would fluctuate if the respective parameter was to be changed by one unit. We applied a local method by examining the simple derivative. The cost calculations were linear with respect to the parameters and does not carry non linear components. Therefore, all the derivatives were monotonically increasing, which was also verified through an iterative process by obtaining outputs for a series of inputs of the parameters I – V described in Table 2.

Sensitivity was applied to parameters II, III, and IV that affect individual cost element X_i . We excluded parameters I and V that are a global proportionality factors (homogeneous) that influence the total expenses uniformly. Symbolically, if Pj is the parameter $j = I,II,III,IV,V$ and x_i, y_i, z_i were the unit costs for health facility, health department, and health worker; then the i^{th} cost element X_i :

$$X_i = P_I P_{II}(P_{III} x_i + P_{IV} y_i + P_V z_i)$$

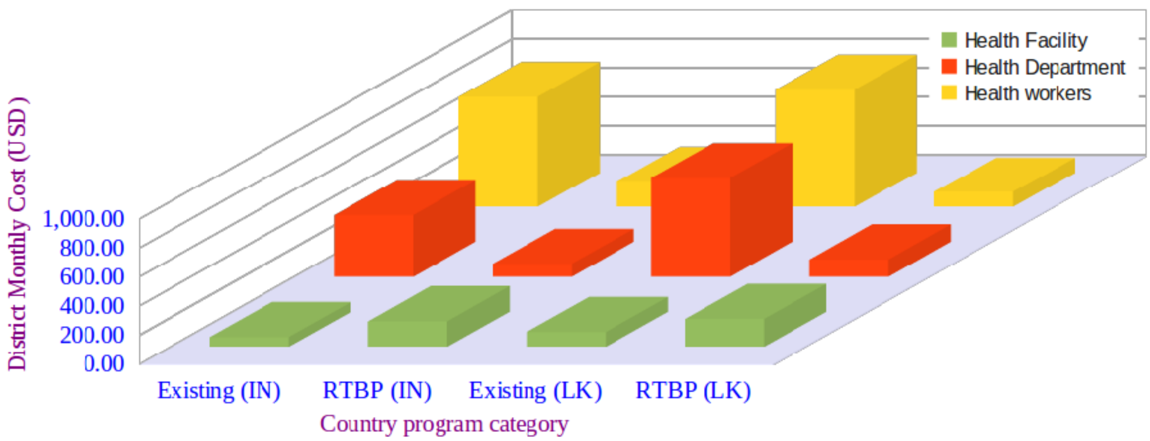

Figure 6: cost sensitivity and comparison between present and introduced systems

Table 5: cost sensitivity (marginal costs) for the 3 key parameters for India and Sri Lanka

	India (US$/Unit)		Sri Lanka (US$/Unit)	
Parameter	***Existing***	***RTBP***	***Existing***	***RTBP***
Health facility (P_{III})	67.00	176.00	102.00	192.00
Health Departments (P_{IV})	425.00	88.00	687.00	119.00
healthcare workers (P_V)	763.00	179.00	812.00	104.00

DISCUSSION

An important attribute of the economic study is the perspective of the epidemiologist. Their key interests are in the ability to detect communicable diseases and escalating common symptoms. Within this context, the discussion is on the comparative advantageous and disadvantageous of the RTBP, compared with that of the Indian and Sri Lankan present systems, in collecting, analyzing, and disseminating epidemiological information.

The researchers had difficulty in obtaining accurate costings for the system delivery (development and implementation) of the Indian IDSP, which would typically involve developing the web based NIC DPH&PM software, training the data entry operators and data managers in using the technology, and training the healthcare workers in reporting the statistics to be entered in the system. The Sri Lankan WER reporting system would also comprise developing the program and training the medical officers, public health inspectors, infectious disease control nurses, and data entry operators. The costing had to be estimated based on information gathered through face-to-face meetings with health officials. In some cases, the system delivery and implementation was funded through an international organization like the World Health Organization.

Efficiency gains

The present Indian and Sri Lankan paper-based disease surveillance programs invests resources predominantly in data collection (approximately 88% in both countries, Table 2), with very little or no emphasis on real-time event detection and alerting (figure 2). This is an indication of the passive nature of the present day disease surveillance and notification programs that is absent of a prognostic approach and is merely a reporting mechanism for counting the patients afflicted with those few, World Health Organization mandated, diseases.

Table 2 shows the overall investments for the existing Indian system to be twice (1.94) as mush as that of what the mHealth RTBP has to offer; whereas in Sri Lank it is slightly above one and half (1.64) times. Besides the technology based RTBP being overall cheaper, efficient, and comprehensive, it offers a more proactive approach with the introduction of an end-to-end rapid detection and efficient alerting (Figure 2). At present the RTBP databases have a non-exhaustive list of 179 and 117 disease for Sri Lanka and India, respectively. This list continues to grow as and when new diseases are reported by patients. The symptom and signs list are equally large and growing but only 50 high priority symptoms and signs (syndrome) are absorbed for RTBPs detection analyses. Moreover, the 3 – 7 day latency of the paper-based manual systems are reduced to less than one day for the data to be sent to the central database that is ready for any kind of analyses through the T-Cube statistical data mining tool.

Data sharing in Sri Lanka between the regional and national health departments for trend analysis is poor, with parallel data entry of the same information at each of the departments for their local analysis. This is apparent from the excessive expenditure for the detection subsystem illustrated in Figure 2, which amounts to 2.7 more than what the RTBP's TCWI would cost (i.e. RTBP can reduce cost by 63%). The RTBP detection subsystem cost increment in India is as little as 10% but the benefits and efficiency gains a much higher. With the RTBP, single entry of data at the health facilities is accessible by all authorized regional and national health departments for local and global analyses.

RTBP's TCWI detection subsystem offers more than just tabulating aggregates. It offers, massive screening of the data with all combinations of the attributes applying public health accepted statistical estimation methods to find anomalies in the data. The data subject to analyses in both spatial and temporal forms present the detected strange events in an easy to comprehend visual form with further drill down capabilities . Simple tabulation of aggregates filtering by thresholds cannot not present the same results and predictions. Performing the same TCWI offered statistical inferencing manually or through other ways is computationally costly. Decision makers would not be able to obtain the results in an interactive and fast responding manner, which TCWI is capable of producing with simple click of buttons. The automated algorithms in TCWI pre-screen the most current data to look for alarming patterns in fever-like, notifiable, other-communicable, and non-communicable disease that presents a ranked list based on the statistical significance of the most alarming events. This eliminates the routine tasks of a typical epidemiologist having to perform the same. Instead, they would go trough the daily list to determine those events that may pose a threat and perform further drill down analysis to verify the severity to decide on any response actions, if needed.

Figure 3 shows that the present systems' heavy health department budgets, predominantly spent on record keeping (or aggregation and consolidation of data). This can be reduced by assigning the real-time digitizing of the front-line information by the health facilities. Since the data is immediately accessible, the health departments can concentrate on analyses and planning. The costing was done anticipating the introduction of a new resource person to carry out the health record digitization. The human resource costs are far greater than the technology expenses. Relatively, the incremental difference to introduce the RTBP digitization process to the health facilities are 61% and 72% in India and

Sri Lanka, respectively. However, this marginal increment is less than the relative decremental cost in the health departments, which are 86% (< 61%) and 87% (< 72%) in India and Sri Lanka, respectively.

Delivering the statistics up the chains is still primitive with the paper documents being hand delivered or sent by post. Typically, village healthcare workers would visit the divisional administrative department with their weekly statistics to consolidate their data. The divisional data would, once again, be hand carried or mailed to the district administrative office for further aggregation. Public Health Inspectors make several trips between their villages and the MOH to pickup the investigation information and delivering the completed investigation results. The direct costs associated with delivery and data aggregation can be drastically reduced with the use of mobile phones. These savings can be diverted for salary increments or investments in health programs (Figure 2). Moreover, the 3 – 7 day latency of the health facility data through the paper-based systems can be reduced to less than 12 hours for the same data to be present and accessible through a central database. This near-real-time data is ready for any kind of analyses through the T-Cube statistical data mining tool.

The Indian NIC had given computers with an Internet connection and a web application to the divisional administrators at the PHCs intended for electronically submitting their weekly and monthly statistical aggregates. Most of the computers and Internet connections were dysfunctional forcing the system to revert to the old ways of hand delivery. There was no technical support to revive the ill-fated computers in those remote areas. The lack of support is evident from Table 3 that shows no budgets allocated for system administration and support services. On the contrary, both in India and Sri Lanka, when a mobile phone was dysfunctional, the healthcare workers and data-entry assistants took it upon themselves to have it repaired at the local mobile phone shop or purchase a new phone with their own money. The mobile phone, besides its utility in the RTBP and other official work, it is also used for their personal communication.

Incremental Cost-Effectiveness

Ideally the system should be proactive in identifying any outbreak in advance when a few geographically spread cases are presented in order to mitigate the problem before escalating to epidemic states. This would require an nondiscriminatory approach of collecting information on both disease and syndrome, which is what the RTBP mobile health introduced. The IDSP *Possible and Suspected list* (or PS-list report) data collection process and the *infectious disease notification* process (or H-544 paper form) are confined to, approximately, 25 diseases that provide counts of average 600 and 70 cases per month for the project's pilot districts of Sivagangai (IN) and Kurunegala (LK), respectively.

The RTBP's mHealthSurvey provides a much richer dataset with a high resolution of attributes: disease, symptom, signs, gender, age group, location, and status. The RTBP comprehensive data collection system accumulates an average 22,800 (from 12 pilot hospitals) and 6,175 (from 4 PHCs) in Sri Lanka and India, respectively. The comprehensive data set contains patient health records pertaining to communicable and non communicable disease. Besides monitoring deadly infectious disease (i.e. notifiable communicable diseases), the comprehensive dataset provides the opportunity to carry out analyses on other-communicable and life-style (or non communicable) disease.

Unlike the fixed 25 notifiable infectious diseases monitored in India and Sri Lanka, the type of disease or syndrome information collected, analyzed, and alerted for response through RTBP is non-exhaustive. Figure 4 and 5 show that the TCO to adopt the RTBP, except for the alerting sub system, is either far cheaper for data collection and almost in par or cheaper for event detection. Since the concept of alerting, especially, the concept of situational-awareness is new, the cost of the RTBP is relatively higher. However, the benefits of informing the healthcare workers and health officials of ongoing events, either within their jurisdiction or neighboring areas, would increase their responsiveness. Being vigilant of similar emerging cases, over the effective period, would allow them to better prepare and ready resources. Thus reducing the mitigation expenses, which otherwise may lead to greater costly consequences. Besides it would give the health workers a greater incentive to digitize the health records knowing they intern benefit from that process by receiving alerts.

In addition to the situational-awareness alerting there is also the action oriented alerting, where by public health officials intervene with preventive actions. With the paper based system, when a suspected infectious disease case was identified at a hospital and was notified to the area health department, the public health officials would investigate the particular case. At present the public health inspector would come to know of the incident only when they visit the health department to receive the stack of notified cases. PHIs in Sri Lanka, at one time, were given a travel allowance that was recently revoked. Now that the PHIs have to spend for the travel out of their own salary, they chose to come once a week or less frequently than before when they had the travel allowance. In some cases they would use their personal phones to communicate with the MOH office to gather information to conduct their field activities. The introduction of the mHealth alerting component can reduce these travel times and personal expenses with a simple issuing of a SMS that carries the required information. Since the introduction of the RTBP alerting sub system the health departments have improvised it for this very purpose of sending investigation information via SMS to the PHIs. As a result reducing the back and forth travel time and giving more time for the PHIs to work in the field.

Having access to a comprehensive set of patient disease and syndrome information is one that a public health systems can capitalize on. Medical officers in India and Sri Lanka that cope with 100 patients a day and are unable to confirm the diagnosis of all patients right away. Collecting real-time disease and syndrome data on all diagnosed and undiagnosed cases would allow epidemiologist to perform syndromic surveillance. Thereby, be able to identifying similar clusters of patterns that may lead towards detecting an outbreak well in advance. Waiting for the cases to be confirmed either by laboratory testing or house visits that usually takes several days may be too late because by then the outbreak may alleviate to epidemic states. This was the case with the Leptospirosis outbreak in Sri Lanka, where flu like systems went unnoticed and the incubation period of the disease being as long as 10 days, suddenly escalated with many cases that lead to several deaths (Agampodi et al, 2008). The TCWI software is capable of performing syndromic surveillance for detection of unusual patterns. This is an important component that is missing in the present day paper-based systems. Figure 4 and Figure 5 show that the incremental cost to accommodate comprehensive disease and syndromic surveillance is either less or the increment is minuscule, while the effectiveness and efficiencies are improved by several folds.

Similar to data collection the economic gains in the introduction of T-Cube Web Interface and associated processes decreases the costs of at the health-departments and increases efficiencies in near-real-time outbreak detection. T-Cube allows the data to be investigated in the form of time series analysis, spatial analysis, and pivot tables, which neither of the present systems provide. If at all the present systems provide aggregated weekly, monthly, or annual counts of limited set if notifiable infectious diseases grouped by locations (district, division, or province). Given that T-Cube is a web based tool, there is no incremental cost to the health departments besides a computer terminal with Internet connection, which they already have. The health department expenditure for the RTBP is the same compared to the present system because they already have this infrastructure in place. Although the sophisticated TCWI software may seem expensive as a whole, when the cost is shared among all districts and all health departments it is affordable.

Alerting for situational-awareness is not a function that exists within the Indian and Sri Lankan disease surveillance and notification programs. Voice phone calls or fax is used in very rare occasions of adverse events that require rapid response. There are some downstream paper-based reports that are shared with healthcare workers and health departments. However, these reports are mostly for performance evaluations and long term planning. Whereas, the mHealth RTBP introduced alerting would empower the healthcare workers with more frequent real-time information that can be used for mitigating disease outbreaks before they escalate into measurable economic and human loses. Moreover, the healthcare workers are better informed of the real health situations in their localities. The SABRO system can be extended for community-based organizations to receive situational-awareness messages. They can display these messages on community bulletin boards informing the public to be hygienic and for parents to avoid exposing infants to public places or public transport when Respiratory Tract Infection is escalating.

The RTBP intervention's pure technology components comprising development and operationalizing the software, hardware, training material, standard operating procedures, and capacity building is approximately 40% for both countries. The existing Indian IDSP, which utilizes computers, printers, and internet to some extent but under utilized, allocates 32% of the TCO for the technology. In Sri Lanka the existing system's technology TCO component is very little, only 9%.

One-way cost sensitivity

Relative to the present system, the sensitivity analysis in Figure 6 show the RTBP to be higher in adding a health facility to the RTBP but less in adding a health department or a health worker. This was mainly due to the assumption that the mobile health technology would be bundled with a new human resource (i.e. a data entry assistants). Digitizing the data at the point of care would elementary intermediary steps aggregation and consolidation that is being done by health department staff (Table 4). Thus reducing the cost of adding a health department to the RTBP, when compared with the existing program.

Nurses in Sri Lanka, expressed reluctance to digitize clinical data through RTBP's mobile health, claiming that they were already overwhelmed with work. As a result, data-entry assistants from the community were recruited to digitize the data at the hospitals. Similarly, nurses from two of the four PHCs in India said that they had no time to spare for digitizing patient clinical records. Later, nurses from the remaining two PHCs, who had been digitizing the data themselves, refused to continue when they realized that there were no incentives in aiding with the extra project related work. If the paper work is relaxed and would allow the healthcare workers to directly submit data through the mHealthSurvey, then it is possible that existing nurses be given the responsibility and the additional resource person becomes redundant.

The patient clinical data that is available in a centralized repository in the finest granular form can be analyzed in any form by any authorized person. Although the cost of enabling a health facility with the mHealthSurvey seems relatively higher, this investment helps in reducing expenses elsewhere, such as drastically reducing the expenses and workload bestowed on health departments at present.

Introducing a new health department to the existing systems is relatively expensive compared with that of the RTBP. The major portion of the expenses are in managing the paper work, office space, storage of paper records, which is not required when all that can be confined to a simple personal computer.

Policy implications

Although the inefficiencies and TCO can be reduced with the mobile health technology, it is not possible to replace the paper-based forms and registries immediately as they are considered legal government documents. Once the policies are in place, the costs associated with archiving the physical documents that requires floor space and cupboards can be reduced down to a server.

Electronically storing patient health records must be secure and the privacy must be protected. Electronic health data is quite valuable, especially to pharmaceutical and insurance companies. Although it was not a priority of the RTBP pilot to address the security and privacy issues, it was important that the consequences are understood and addressed to evaluate the necessary solutions to overcome the vulnerabilities.

There is also a cost associated with false alarms generated by Biosurveillance systems that can be extremely expensive if it leads to unexpected consequences (Lee et al, 2006). Policy makers would be quite concerned with this aspect. Once again, to examine such costs the system must be fully functional for an extensive period of time; where by a Receiver Operating Characteristics like analysis along with the consequential loses or gains can be studied to set the alarm thresholds to minimize the losses.

The economic impact of the RTBP intervention is important to determine the long term consequences. For that policy or decisions makers would be interested in economic indicators of QALY, lives saved, or house hold productivity improved.

CONCLUSION

Within the context of proving that technology can aid in reducing the efficiencies and expenses as well as offer greater benefits in the national efforts of disease surveillance and notification, the RTBP has proven its worth. There may be uncertainties that the project may have overseen when it comes to scaling the project nation wide from the few hospitals and clinics. Nevertheless, the Government of Sri Lanka is keen in taking keen interest in the project; while the Indian Government workers are resting change. Given the interest built within the region in adopting the RTBP and the economic gains of the system proven through the pilot, we are in the process of scaling the RTBP in the region.

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