MANAGEMENT FRAMEWORK FOR SUSTAINABLE RURAL E-HEALTHCARE PROVISION

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ABSTRACT

E-Healthcare provision in rural areas has been defined as a promising tool to monitor, control and improve health services, especially in developing regions with scarce qualified staff and limited resources for adequate diagnosis and treatment. However, there exist particular challenges for sustainable e-Healthcare provision in such contexts that lead to low success rates. Here, economical, financial, institutional, technological, educational, and social and cultural aspects must be considered. This work presents a management framework for the technological factors influencing sustainable e-Healthcare provision with a focus on operation and maintenance requirements. The particular case of EHAS-Napo project has been analyzed considering relevant technology-based sustainability indicators, specific user needs and budget restrictions given by end-user Public Health Institutions. This work suggests a set of procedures for e-Healthcare maintenance linked to action research, also with optimized assignment of human resources and logistic and organizational considerations. The management framework is part of a broader research so-called Sustainability Action Plan that embraces a set of strategies facing all cited factors affecting sustainable use of rural e-Healthcare in developing countries.

KEYWORDS

e-healthcare, rural connectivity, network management, maintenance, organizational aspects, sustainability.

1. INTRODUCTION

Half of the world's population lives in rural areas of developing countries. The penetration of the Information Society in those regions is extremely low. Main difficulties arise from isolation (insufficient roads, electricity and communication infrastructure) and unavailability of resources (scarcity of qualified technical staff and scattered low-income population). This makes it difficult both to launch and to maintain Information and Communication Technologies (ICTs) over time. In rural environments ICTs are proposed as a cross-cutting and multi-sectoral approach to promote social priorities for achieving the Millennium Development Goals (MDGs). Several initiatives born within civil organizations, universities and research institutes have developed specific low-cost computers, wireless communication infrastructures and open-source software to be used in such environments. However, ICT initiatives in developing countries have shown low success ratios in terms of sustainability (Heeks, 2002).

Here sustainability refers to Information Systems that maintain and extend their benefits over the medium to long term (Batchelor, 2009). The main challenge in achieving sustainability comes from the complexity of development interventions and the consideration of the several factors involved: economical, financial, institutional, technological, educational, and social and cultural aspects (Pade, 2006). Since 2003, various authors have proposed theoretical frameworks for the study of those factors and compiled good and bad practices from case studies review (Batchelor, 2003; Braa, 2004; Krishna, 2005; Sunden, 2006). However, how to fit sustainability of ongoing ICT initiatives, evaluate risks and implement action plans for sustainability assessment all remain open issues (Bebea, 2010).

The use of ICTs is proposed to help healthcare sectors in developing countries to plan, monitor, control and improve health services as well as to communicate more effectively across organizational hierarchies. This implies to facilitate organizational change of Health Institutions (Heeks, 2006), as well as to involve health and maintenance personnel for self-sustainability (Kimaro, 2006). Rural e-Healthcare strategies first need to assure connectivity among rural health facilities and hospitals, and secondly confront the scarcity of qualified staff, improve ICT literacy in rural areas and adapt to the continuing decentralization of Public Healthcare. ICTs appear to be a tool to improve e-Healthcare strategies but there are also challenges implementing ICTs (Herbert, 2008; Kimaro, 2004; Mosse, 2005; Piotti, 2006).

Both the technological design of ICT infrastructure and the sourrounding community infrastructure (electrical, roads, etc.) impacts projects sustainability. Solutions must be robust, low-maintenance and low-cost. But maintenance is also highly dependent on spare equipment availability and road infrastructure. Achieving high availability rates for e-Healthcare services depends on early-detection of system failures, accurate diagnosis of faults and fast recovery response. All cited maintenance requirements are particularly hard in rural wireless deployments for various reasons (Surana, 2007; Bebea, 2009):

- Rural technical staff tend to start with limited knowledge of computer administration and wireless networking, so ICT education is primarily provided by the project team. This leads to lack of awareness of service degradation, incomplete diagnosis of faults and misconfiguration in the first stages of the project. Rural staff need to contact experts for troubleshooting and decision making processes.
- Locations of wireless sites are quite remote. So it becomes important to avoid unnecessary visits to remote sites, which consume inordinate amounts of time and money. Failures might be prevented by routine maintenance.
- The topology of a wireless network providing a unique medium for connectivity means a failure in a single link might make parts of the network unreachable. This makes it hard for remote experts to diagnose the problem and implies increasing autonomy of rural technical staff for troubleshooting.
- The absence of power also contributes to communications failures. Unstable power supply, lightening-damaged voltage regulators or destroyed multimedia devices connected to non-protected batteries are some examples.
- Spare equipment supply usually is often delayed because of non provisioned budget expenditures or limited stock availability at suppliers.

Due to determinants listed above, there is usually a lack of accurate information about devices status and performance. This makes it difficult to anticipate faults. For these reasons, we provide a framework for managing operation and maintenance of e-Healthcare in rural areas in developing countries, that considers the following: activity planning, human resources management, logistic issues and necessary budget. The aim of this work is both to identify risks related to sustainability in terms of technology and relevant criteria in the design of an action plan (Operational Maintenance Plan) that improves the present situation with a view to definitive ICT project ownership by Public Healthcare Institutions.

2. CONTEXT: EHAS-NAPO CASE STUDY

In this work, we present an action plan that addresses technological factors affecting sustainability for a particular case study: EHAS-Napo project. This initiative started in 2007 and serves a broadband wireless network for e-Healthcare provision to rural facilities of the National Health System (see Figure 1). Napo is located in the Amazonic region of Loreto, Peru, and therefore counts with extreme isolation conditions (Martinez, 2004). Table 1 illustrates access time in available transportation along Napo river.

Table 1. Transport time (hours) between remote sites in Napo case. Leyend: 1-Lima (*2 hours for a passenger flight), 2-Iquitos (Regional Hospital), 3- Iquitos (Petro Peru), 4- Mazan (Amazon side), 5- Mazan (Napo side), 6- Huaman Urco, 7-Tuta Pishco, 8- Negro Urco, 9-Tacsha Curaray, 10- Santa Clotilde, 11- Copal Urco, 12- San Rafael, 13- Rumi Tuni, 14-Campo Serio, 15- Angoteros, 16- Tupac amaru, 17- Tempestad, 18- Torres Causana, 19- Cabo Pantoja

Transport	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19
Ship	15 days		20		4	4	4	4	7	3	9	12	6	4	6	4	6	6
Fast boat			2		1	1	1	1	1.5	0.5	1.5	2	1.5	1	1.5	1	1	1
Road		0.5		0.5														
Airplane	4 days*																	

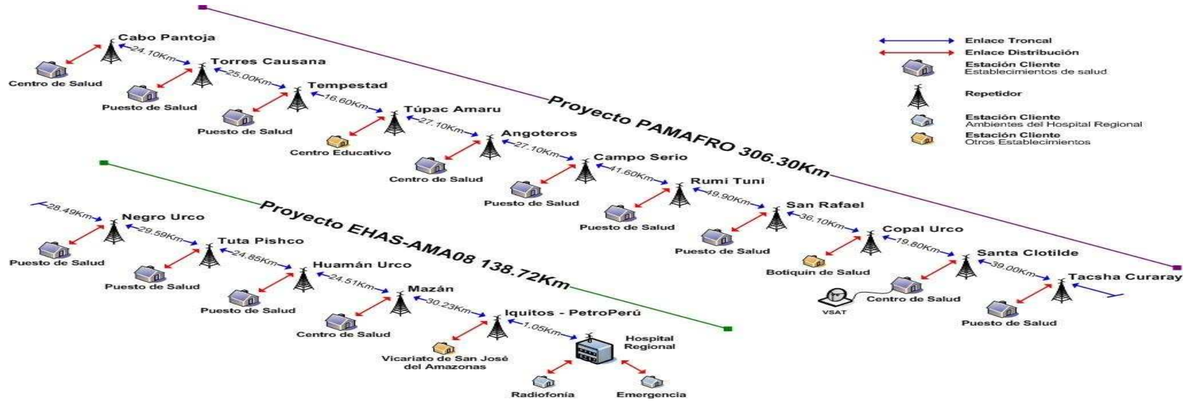

Figure 1. Wireless telemedicine network in EHAS-Napo project connects rural health facilities with city reference hospital.

The initiative provides broadband connectivity to 18 isolated health facilities along Napo river (covering a distance larger than 500 km) from Iquitos Regional Hospital to Cabo Pantoja in the frontier to Ecuador (see Figure 1). Connectivity is achieved using WiLD (WiFi IEEE 802.11 modified for Long Distance) technologies (Reigadas, 2008), and also some services are provided on top of the network, such as VoIP telephony, videoconferencing, reporting, image diagnosis and real-time stethoscopy, chat and Internet access for various purposes related to e-Healthcare: tele-consultation, tele-diagnosis, tele-treatment, health information management, emergency coordination, drugs dispatch and logistics. In 2009, Napo project seemed prepared for transfer process to public institutions, as the initiative counted with strong support and motivation from rural health staff and municipalities. However, low availability of e-Health services and local technicians dependence on EHAS engineers, pointed to a maintenance weakness.

For the Napo case, we encountered a main risk for sustainable e-Healthcare provision in the low availability of ICT services, which could be mostly solved by improving technical aspects related to e-Healthcare performance. Availability had dropped to 70% in connectivity and therefore to 60% in telephony and telemedicine services. Interviews to users and staff in charge of maintenance, together with operational data collected pointed to a principal cause: high time to recover from failures. Main reported failures for the period 2009-2010 are:

- Connectivity interruptions in main stream are due to lightening which damaged up to 5 sites. Burned term-magnetic interruptors and voltage regulators blocked energy supply to wireless routers. Recovery time for those faults vary from two weeks to 3 months due to non-assigned transport resources for maintenance in remote sites.
- Battery charge overflow blocked voltage inverters, thus limiting availability of client devices. Inadequate use of batteries for other multimedia devices or exceeding PC up-time restrictions, throw batteries into deep discharge cycles thus reducing their life time. Sometimes batteries are maintained using rain water instead of still water due to supply delays.
- IP Telephony short interruptions and degradation was caused by version conflicts on PBX software that took up to four months to be solved by an expert, due to incomplete information about the problem causes.

3. MATERIALS AND METHODS

In order to identify and analyze problems related to maintenance of e-Healthcare infrastructure and services, we conducted a case study qualitative research methodology that included the following: a revision of maintenance documentation materials (technical and audit reports, technical manuals), statistics of IT services availability and use; participant observation in Napo network; in-depth interviews to engineers, physicians responsible for rural health networks, physicians at reference hospital, and local and regional authorities assistants; and inquiries to rural health and maintenance staff .

For the analytic study of compiled information, detected variables have been classified following the Sustainable ICT Framework (Sunden, 2006). Logical Framework Approach (LFA) has been used to analyze trees of partial problems and solutions in the design of the Operative Maintenance Plan (OMP): objectives, expected results, activities and stakeholders involved. This framework is part of a broader action research plan denominated Sustainability Action Plan (SAP) (Bebea, 2010) that proposes strategies to face institutional and financial challenges of rural e-Healthcare provision (Institutional and Financial Plan) and ICT literacy and expertise of e-Healthcare users and maintenance technicians (Continuous Learning Plan). As shown in Figure 2, SAP considers all factors affecting sustainability.

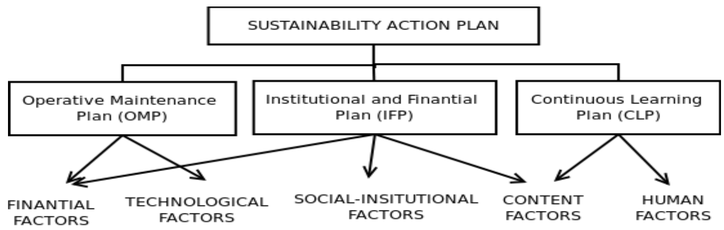

Figure 2. A Sustainability Action Plan improving sustainability at each category

Considering the analysis of needs related to e-Healthcare maintenance in Napo described above, together with health staff actions for which communication is critical, the design of this Management Framework is shown in the Figure below.

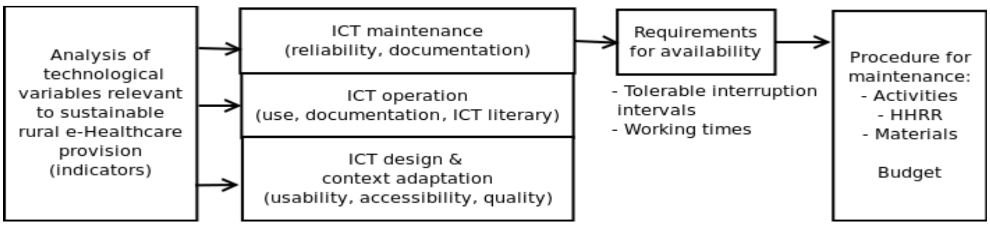

Figure 3. Design workflow of the Management Framework for operation and maintenance of e-Healthcare in rural areas of developing countries

4. DESCRIPTION OF THE MANAGEMENT FRAMEWORK

We now describe the indicators identified as part of technological factors influencing success and sustainability of rural e-Healthcare provision:

I1. Quality: considers whether implemented technologies are capable to fulfill knowledge, information and communication needs of rural health personnel. Includes variables such as end-to-end transmission rate, delay, jitter, packet loss, Internet access rate, busy external PBX lines, CPU consumption of switches and computers, electricity availability and autonomy ratio, electric protection failure rate and user perception.

I2. Reliability: refers to robust, secure and inter-operable e-Healthcare technologies. Reliability is closely related to availability and use of systems and services. Availability is understood as the percentage of time an ICT system performs normally and can be obtained considering the number, type, frequency and duration of incidents: i.e., for a connected health facility suffering an IP telephony service interruption every

3 months, which is repaired within 1 week, service availability would be 92.8%. This might be enough considering alternative HF radios located at health facilities or satellite phone in the village. Availability requirements for extreme conditions as those of rural areas of developing countries must be adjusted to user needs and low-income budget constraints. Thus increasing availability in such scenarios typically means building redundant links, back channels and/or assigning more and more qualified staff for rapid fault recovery.

I3. Appropriate maintenance: considers procedures for e-Healthcare systems monitoring, prevention and failure recovery. Maintenance takes into account quality and autonomy of basic maintenance realized by users and advanced maintenance executed by local technicians, together with their availability to travel to remote sites (days time), and also the existence and fulfillment of procedures for fault monitoring, incident management, logistics and spare purchase and stock.

I4. Usability: defined as ease and commodity of hardware and software use. Usability is part of technology solution design and might be affected by users ICT capabilities.

I5. Appropriate accessibility: refers to existing road infrastructure and additional communication media (fixed lines, satellite access points or radio communications) that facilitates users access to e-Healthcare and in-site maintenance requirements. This variable is endemically negative in Napo context, due to restricted high-cost river transportations of 9 hours of average duration and inexistent or deficient communication alternatives.

I6. Documentation that details systems design, use and maintenance.

I7. Operation and maintenance budget calculated according to described maintenance procedures for a certain availability assessment. However budget includes technical restrictions together with organizational aspects, it is part of financial factors that need institutional approval (Bebea, 2010) .

Through the definition of an efficient framework and layered maintenance team, we aim to improve e-Healthcare availability (to 90% in connectivity and 80% in telemedicine services), while assuring quality of services provided and minimizing operation and maintenance costs. The executive protocol proposed is shown in Figure 3, with a central core which is the 'Historical Knowledge of Network Status' (HKNS). This core is the basis for accurate, registered and up-to-date information that allows fast response, experience-based fault diagnosis and technology adaptation to dynamic user needs. The framework is illustrated in Figure 3.

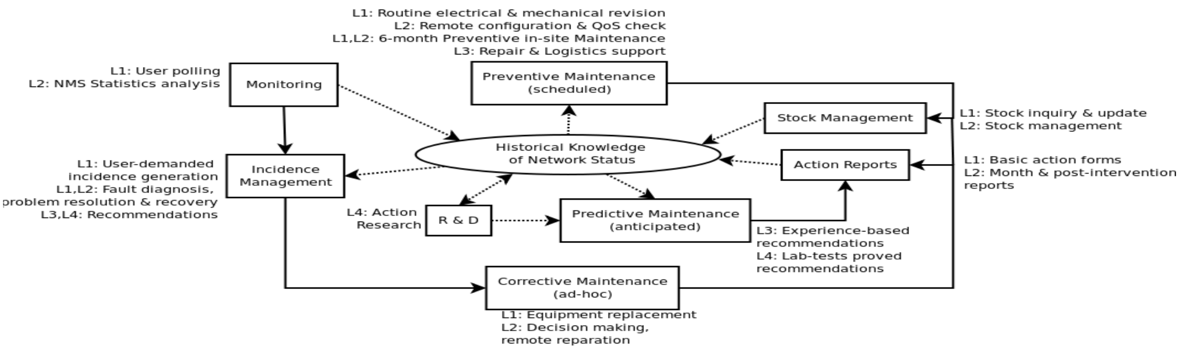

Figure 4. Management Framework for operation & maintenance of rural e-Healthcare, including human resources assignment.

4.1 Layered Team

Due to high cost of maintenance caused by great distances between remote sites, this framework relies on competent local technicians, as well as on engineers at a Network Operation Center (NOC) in the city town (nearby Internet & PSTN access, and reference hospital). Four maintenance levels are defined for technical staff according to their ICT education and expertise and to their proximity to network nodes (see Table 1). L1 technicians are non ICT professionals but general maintenance staff working at certain rural health facilities. L1 are assigned a coverage area around their working health facility, so L1 dedication to maintenance is about 0.35 MM (Man-Month), thus adding tasks to human resources that must be considered in organizational aspects (IFP). L0 will dedicate 0.5 MM to basic everyday maintenance of their systems. Maximum responsibility is given to L2 (1MM), a group constituted by ICT engineers staffed by political or healthcare authorities at NOC. As soon as EHAS is an NGO oriented to R & D, it becomes of mutual interest to keep in touch with running systems and dynamic user needs over time, as well as to record experiences for other ICT interventions.

Table 2. Layered team proposed for Operative Maintenance.

Level	L1	L2	L3	L4
Technical Expertise	*	**	****	***
Scientific Knowledge	*	**	***	****
Accessibility to sites	****	***	**	*
Responsibility	***	****	**	*

4.2 Block Detail

Monitoring collects accurate information from network devices and services running via an open-source Network Management System (NMS) and contextual information from user polling, thus checking non-managed service performance and human perception about system performance. NMS measures parameters such as connectivity status, received signal level at wireless routers, network traffic, delay and data rate, CPU consumption at every device, etc. NMS proposed here is open-source Nagios, added Centreon GUI, for remote node management through Simple Network Management Protocol (SNMP) notifications.

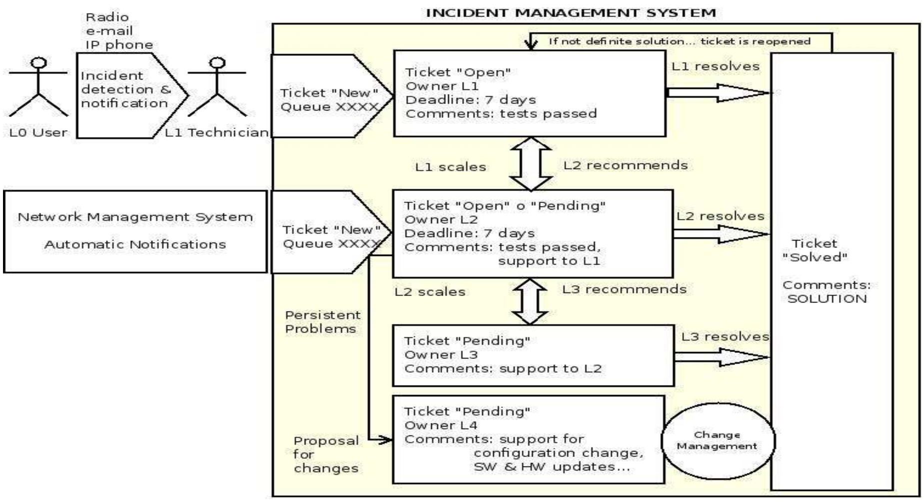

Figure 5. Workflow for incident escalation in Management Framework.

Incident Management records incidents occurred during ICTs operation, including detection (user case or automatic alerts), diagnosis and maintenance actions furthered. ISO defines incident as 'any event which is not part of the standard operation of a service and which causes or may cause an interruption to, or a reduction in, the quality of that service'. IM is crucial to control detection, maintenance response and recovery timings, and contributes to local technicians capacity building via proposed feedback escalation scheme. This framework has been tested using an open-source Ticketing System for this purpose (Request Tracker) due to its easy connection to NMS through a simple mailgate. Figure 5 illustrates incident notifications through NMS and incident escalation for suggested maintenance team.

Predictive Maintenance studies the evolution of quantitative (relevant statistical parameters) and qualitative (users and maintenance team perception) data regarding the aforementioned indicators over time. The aim of this analysis is to anticipate faults, preventing from service degradation or interruptions.

Simultaneously, action researches keep surveillance of technological improvements and innovations proposed by the academia, also considering their appropriateness and adaptation to this particular context.

Preventive Maintenance plans scheduled maintenance actions for general ICT infrastructure, hardware and software check. The aim of this action is to correct minor faults and prevent from service interruptions. Preventive activities are scheduled all over the year including basic in-site check, remote software configuration and update and 6-month general maintenance (ca. 1.5 days per site, travel included).

Corrective Maintenance consists of ad hoc remote or in-site reparations once faults occur. As biggest maintenance costs come from transportation to remote nodes, corrective interventions are highly undesirable, especially those that exceed L1 resolution capacity and need L2 to intervene in site. Then, depending on site distance to NOC and reparation complexity, a corrective intervention last 6 to 48 hours. Decisions for failure recovery must be made in a participatory environment including L2 and health staff and authorities. Corrective maintenance cost is hard to estimate, specially without an HKNS and incident temporal series. An approximation is described in the formula below, where *N* is the average number of incidents for the whole network within a year; η is the percentage of incidents that requires L1 in-site maintenance and γ the percentage that requires also L2 intervention; *TA* is travel allowance for L1 team (boat pilot, tower worker and L1) and for extra L2 respectively; *S* is referred to spare equipment replaced in corrective maintenance actions.

$$Cost_{Corrective\ Maintenance}=N\left[\eta\ \square TA_{L1}\square D_{L1}\ \boxplus\gamma\ \square TA_{L1+L2}\square D_{L2}\ \boxplus S\right]$$

Stock Management controls spare equipment and the toolbox, that must be ready for use in maintenance, in order to reduce time to response. This implies stock input-output recording, and purchase and shipment of equipment. Scheduled actions can minimize costs by using public transportation but strictly considering time restrictions shown in Table 1.

Reports of all cited actions contribute to HKNS, and therefore reporting must be considered a additional activity by resources management.

4.3 Other Considerations

Also social and organizational aspects have been considered in the design of the Management Framework that are cross-cutting to all defined activities: human resources management (management team salary and travel allowance, personnel rotation and capacity building), logistics (equipment purchase, stock, staff transportation and items shipment) and budget guaranteed for operation and maintenance of the network. Considering activities described in above framework, annual operation and maintenance of Napo e-Healthcare cost is estimated in 7% of the initial investment in project implementation. These issues are closely related to the essence and structure of Public Health Institutions, as they require the definition of new roles or the extension of existing roles now responsible of operating and maintaining e-Healthcare provision. Therefore the strategy for organizational change assessment and annual budget approval are described in a parallel framework defined as the Institutional and Financial Plan, which is also part of SAP (Bebea, 2010).

5. CONCLUSIONS AND FURTHER WORK

The Management Framework presented here is hard to extrapolate even to similar initiatives due to the idiosyncrasy of e-healthcare provision in rural areas of developing countries. However, the methodology proposed for this case could be adapted to address other e-Healthcare initiatives. Benefits of this plan are the optimization of costly reparation travels and the acceleration of failure response, while optimizing technical and health staff available in rural areas. This work could be completed with statistical data of number and type of incidences over years and recordings of spare equipment necessary per year, in order to obtain a more accurate estimation of cost and time dedicated for maintenance. Such data could be compiled after a couple of years monitoring and contributing to the Historical Knowledge of this e-Healthcare network, as proposed here.

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