WaSH Policy Research Digest

ISSUE #8, MAY 2018: REMOTE MONITORING OF HANDPUMP FUNCTIONALITY

Detailed Review of a Recent Publication: Remote sensors may hold promise for new maintenance models

Nagel, C., Beach, J., Iribagiza, C., Thomas, E.A., 2015. Evaluating Cellular Instrumentation on Rural Handpumps to Improve Service Delivery—A Longitudinal Study in Rural Rwanda. Environmental Science and Technology 49(24), pp 14292–14300. doi: 10.1021/acs.est.5b04077

In their 2015 paper, Nagel et al. describe a study undertaken in rural Rwanda in 2014. The objective of this study was to examine whether remote sensors installed in handpumps could enable increased pump functionality by comparing three models of breakdown reporting and maintenance. The authors also set out to determine which of the three models studied was most cost-effective. The study ran for approximately seven months, half in the rainy season and half in the dry season, in 181 rural communities in three provinces with a user base of about 45,000 people.

In the area of Rwanda studied, the district government is responsible for water and sanitation infrastructure, including operation and maintenance of water sources. Small piped systems are usually managed through public-private partnerships, but in the case of handpumps, the communities they serve are responsible for arranging operation and maintenance. In some cases nongovernmental organizations both install handpumps and provide maintenance services. In this study, Living Water International Rwanda (LWIR), an NGO supported by an international organization headquartered in the US, provided these services in the study area.

The sensors were installed inside Afridev and India Mark II handpumps and included a cellular radio chip, an accelerometer, and a differential water pressure transducer. The sensors recorded whether there was water in the overflow basin of the pump, and also whether the pump was being operated. The sensor included a fully integrated cellular connectivity system, and the sensors reported data over cellular networks directly to an online platform, creating a "dashboard" of data.

Key Policy and Programmatic Takeaways

- Data from remote sensors on handpump uptime and failures can increase operational performance, but only when combined with a highly responsive maintenance service.
- Advanced data analytics open up the possibility of predicting faults and undertaking pre-emptive repairs, potentially reducing downtime to zero, but this must be weighed against the cost of sensors.
- Data from remote sensors could contribute to regulatory and contractual oversight, supporting the creation of rural water utilities and effective performance contracts.

The study compared three different types of operation and maintenance models, only one of which used the data recorded by the sensors:

1. Ambulance Model - in this model an operations and maintenance manager with LWIR, based in Kigali, the capital city, used the dashboard data created by the sensors to identify water pumps that were presumed to have failed and to dispatch a dedicated ambulance operations and maintenance team, made up of two technicians in a pickup truck.

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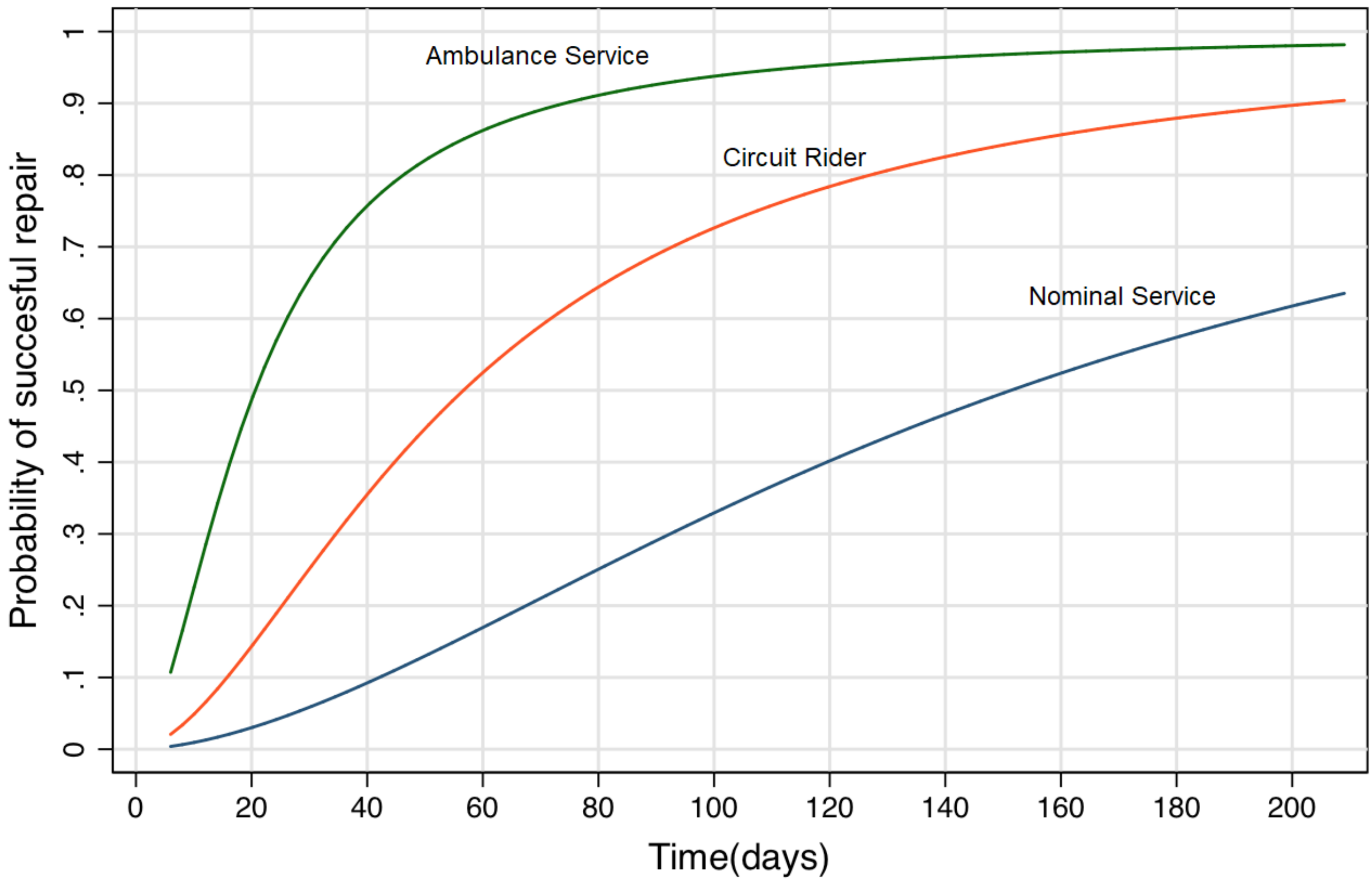

Figure 1. Time to Successful Repair (Nagel, 2015)

2. Circuit Rider Model – this approach involved one LWIR technician in each of two districts equipped with motorcycles who travelled on a "circuit" carrying out routine service visits of every pump regardless of its functionality status. When a pump repair or preventive maintenance was required the technicians performed the repair if they had the capability. When repairs required tools or materials they did not have, a separate repair team was requested and dispatched.
3. Nominal Model – this model was the regular operational maintenance model provided by the NGO before the study. Repair services were provided on request when communities or officials contacted LWIR. This model included two part-time staff and a pickup truck, but these technicians had other duties, including pump installation, so were not dedicated to maintenance tasks.

The need to geographically limit the technician routes meant that the ambulance and circuit rider models were only applied in two districts (Ruhango in Southern Province, and Karongi in Western Province). The nominal model was only applied in districts in Central Province. Of the total of 181 pumps in the study, the ambulance model covered 47, the circuit rider model 50, and the nominal model 84. The authors describe the selection of pumps for the study as "iterative and semi-random".

During the seven months of the study, 89 of the pumps experienced periods of non-functionality, and 78 repairs were carried out. The number of repairs on a single pump during the study ranged from 1 to 5, and multiple repairs were carried out on 11 of the pumps.

The data collected from the sensors during the study revealed substantial differences between the three service models. Pump functionality, estimated using a model that adjusted for pump age, type and cylinder depth, and expressed as percent of functional days per pump, was higher in the ambulance model (91%) than the circuit model (73%) or the nominal model (68%). The median time in days to attempted repair was also significantly lower in the ambulance group (20 days) than the circuit rider group (40 days) and much lower than the nominal group (143 days). The ambulance service model thus achieved an 86% reduction in the time to repair compared to the maintenance model used by LWIR before the study. The authors use their results to compare predictions for probability of a successful repair against time for the three service models, as shown in Figure 1.

The authors include in their paper an analysis of the total expense per functional pump, calculated as the pump capital expenses divided by mean functionality estimates. Their analysis shows that the three models cost almost the same amount.. This is because the significantly higher installation cost of the pumps with sensors is balanced by the higher proportion of functional time. The sensors are estimated to cost about $500 each and have a usable lifetime of two years, and added to this is added sensor servicing of $115 per pump per year. While sensors are predicted to come down in price over time, it should be noted that the study revealed higher levels of sensor maintenance than expected, and shorter battery life.

Based on the results of this study, the authors suggest that the considerable investment in sensors would result in significant increases in pump functionality, and lower down times. However an important limitation of this study is that it did not compare "like to like". Only the ambulance model had a dedicated repair team that responded to all breakdowns. The nominal model relied on both efficiency of reporting and availability of a maintenance team. This raises the question whether, if both of these were improved, the results could be similar to those achieved with the ambulance model using the sensors. The article does not discuss how sensors compare to other systems of reporting, for instance through SMS messages, it also does not examine whether downtimes would have been lowered with a dedicated maintenance team available for the nominal model. The authors also do not examine the additional logistical and administrative burden of keeping the sensors running in terms of spare parts supply chains and repair skills.

The authors suggest that in the future downtime may be reduced to zero through "predictive algorithms for pump failure". That is, it may be possible for the sensors to apply "machine learning" (which allows computers to progressively improve performance on a specific task, without being specifically programmed) to analyse pump performance and predict if a breakdown was imminent. This is certainly an attractive possibility, but, again, requires a highly-responsive and well-equipped maintenance team to pre-emptively service failing pumps.

The authors of this paper present the interesting vision of a performance-based model of rural water supply, with a "pay for performance" approach to incentivize quality in handpump maintenance. In this model, water service delivery metrics would be supplied by sensors. However, rural water supply providers considering investing in sensors must consider all the logistics, and costs, associated with making such a model work.

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Literature Review: Remote Monitoring of Rural Water Supplies

The use of remote monitoring of rural water supply systems, handpumps in particular, is on the increase, driven by a convergence of factors:

1. The expansion of mobile phone networks into rural areas currently unserved by piped water and many other forms of infrastructure.
2. Advances in the Internet of Things leading to both faster and cheaper data, and new ways of thinking.
3. The general reduction in the cost of electronics—enabling the development of low-cost devices—and improvements in performance, especially with respect to power consumption.

A number of different technological approaches have been taken to sense pump usage and water abstracted; traditional flowmeters that aim to directly measure water flow have been attached to the pump spigot (Welldone 2014; Susteq 2016); sensing water in the body of the pump (charitywater 2015; Nagel et al. 2015) using capacitive and pressure sensors respectively; and measuring the movement of the handle (Thomson et al. 2012a; Swan et al. 2017). Although the nature of the raw data generated varies with the sensor technology used, all systems process the raw data and transmit it over the mobile phone network to a database. A linked dashboard presents the data to users, with the primary goal of monitoring pump use and functionality. These systems generate near real-time data on the status of pumps and present them in a structured and objective way.

Trials in Kenya and Rwanda linked remote monitoring data to professionalised maintenance services. A study conducted by Oxford University (2014) in Kenya showed a reduction in mean days-to-repair from 27 days pre-trial to just under four days for pumps for which faults were called in manually, but only two days for pumps transmitting automated data. In their Rwanda study, Nagel et al. (2015) (reviewed in detail in this Digest) reported a greater reduction in repair time to for pumps using automated data to trigger repairs compared to pumps with manual reporting. However, both studies had methodologoical limitations: Nagel et al. (2015) ran two different types of maintenance schemes; Oxford University (2014) did not have a random split between their two treatment arms. As such, it is difficult to disaggregate the benefits of the monitoring from those of a well-run maintenance service. It is also difficult to justify the significant installation and maintenance costs of sensors based on the evidence so far.

As Thomson and Koehler (2016, p.91) note, "automated monitoring is not a panacea and non-automated systems also offer the possibility of generating performance improvements when a properly resourced maintenance service is in place".

Research is ongoing as to how use analysis of the raw sensor data to predict handpump failures rather than identifying and reacting to them after the fact (Colchester et al. 2017; Wilson et al. 2017). Operational implementation of this would combine the strengths of preventative maintenance ("circuit rider") and reactive models, and open up the possibility of zero downtime.

Overall, the evidence base related to the performance of remote monitoring systems is currently limited: it seems unlikely to generate substantial benefits if used within existing poorly performing systems of maintenance provision, but may contribute to improved performance as part of a professionalized rural water services model. The technology is still maturing and as it develops costs will inevitably fall, with performance and reliability improving.

Thomson et al. (2012b) suggest that the truly transformative value of automated data is the move to a "surveillance-response" paradigm, proposing that performance measured by automated data can allow a contracting body to provide contractual incentives for high performance to a service provider, and penalties for poor performance. Viewing handpumps as a rural water supply network instead of a collection of individual point sources can lead to economies of scale and reductions in the financial risk that individual water users and communities are exposed to when faced with a pump breakdown (Hope et al. 2012). It also may open up new opportunities for bringing finance into the sector by making multi-handpump "utilities" financially viable and credit-worthy. The real contribution of remote monitoring systems may thus be as a tool that helps change thinking in terms of the way rural water services are delivered.

Literature review prepared by Patrick Thomson, Researcher, School of Geography and the Environment, University of Oxford

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