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SUSTAINABLE WATER AND SANITATION SERVICES
FOR ALL IN A FAST CHANGING WORLD

Modelling pump functionality with a Markov process: insights and implications from Malawi

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This paper uses recent data on water point functionality from Salima District, Malawi, to predict the expected pump functionality rates using a model known as a Markov process. If the model fits, as the findings suggest, the implication for infrastructure sustainability is that long-term pump functionality rates will only improve if there is an increase in the probability that pumps will be repaired. Examples from Malawi, notably from Nkhotakota District, suggest possible methods for improving this probability of pump repairs through strengthening local stakeholder relationships, which may hold greater potential for improving infrastructure sustainability than the temporary benefits typified by direct project interventions.

Using a Markov process

The Markov process is used to model scenarios with a defined number of states and a probability that an object will shift from one state to another. (Britannica, 2013) Originally developed by Andrey Markov, the model has been widely applied to help understand fields such as communication systems, population, epidemiology, resource management and financial engineering. (Ward, 2009)

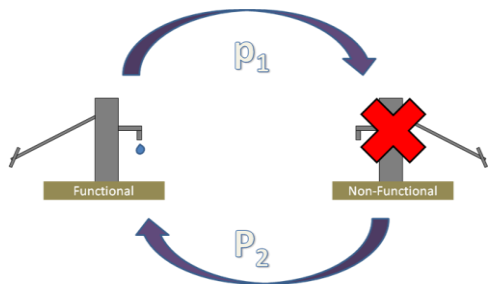

Figure 1. Pump Markov process

Pump functionality as a Markov process

This paper tests the application of this model to rural water pump functionality using data from Salima District, Malawi, and explores possible implications if the model provides a good fit for the actual pump functionality rates. In the case of pump functionality, there can be assumed to be two states: functional and non-functional. There are therefore two main probabilities for switching between these two states: the probability that a broken pump will be fixed; and the probability that a working pump will break.

A true Markov process will eventually produce an equilibrium (Page, 2012). If pump functionality rates match a Markov process, eventually a certain unchanging percentage of pumps would be functional and a certain percentage would be non-functional, regardless of the initial number of functional and non-functional pumps. While individual pumps will change states – some broken ones will be fixed and some functional ones will break – the overall percentages of functional and non-functional pumps would remain constant. By using real data from Salima District we can investigate if an equilibrium predicted by a Markov process can accurately predict the percentage of functional pumps, and identify possible implications of this for the sustainability of rural water supply infrastructure.

Conditions of a Markov process

There are three main conditions for a Markov process. The conditions are (Page, 2012):

- A finite number of states (i.e. functional and non-functional)
- An object in the system must be able to get from one state to any other (i.e. switch from functional to non-functional and back)
- The probabilities of switching between states must be fixed (i.e. constant likelihood that a functional pump will break).

If the model predicts an equilibrium that approximates the real world data then these three conditions are implied to be true. The first and second conditions are met when considering pump functionality; pumps can be defined as either functional or not, and any given pump can move from one state to the other. Fixed probabilities, however, is a more interesting condition that has important implications for work on infrastructure sustainability.

Assumptions for modeling pumps

Modeling pump functionality poses the additional challenge of determining the number of possible pump states to include in the model. Depending on the enumeration conventions used, pumps can be categorized in a number of ways to represent varying degrees of functionality. In data used for this analysis, enumerators only assessed pumps as either functional or non-functional, simplifying the numerical analysis, but limiting the accuracy of the model.

Two distinct types of errors may be created by this simplified categorization. Firstly, abandoned pumps that will never be repaired may be counted as non-functional. Doing so would artificially reduce the probability of broken pumps being repaired because this would combine the probability of repair with the probability of rehabilitation – the latter being something directly controlled by the government and NGOs instead of a community of private sector behavior. Secondly, subjective interpretation by enumerators may cause one assessment to classify a pump with low flow as non-functional, while another might later classify the same pump as functional. This subjectivity caused through imperfectly understood standards might present a pump as having been repaired when it has, in fact, not changed state.

Without the availability of further data to compliment these assumptions, the model incorporated the data as provided by district government with only functional and non-functional states.

Functionality rates in Salima District, Malawi

Real data were needed to see if a Markov process could accurately model pump functionality rates. Ongoing Monitoring and Evaluation efforts by the Government of Malawi have provided village-level pump functionality data, collected by government extension workers in Salima District at three points in time– July 2012, December 2012, and July 2013 – which are used in this analysis (Salima District Council, 2012 and 2013). By identifying villages with only one pump and tracking them over these periods we can estimate the probabilities of pump breakdown and repairs. A total of 121 unique pumps met these criteria, and their data were used to observe breakdowns, repairs, and then calculate the likelihood of either happening. Calculated results are summarized in Table 1 to show probabilities of breakdowns and repairs for the two different periods.

Table 1. Probabilities of pump breakdown and repair in Salima District

Probability of:	July 2012 – Dec 2012	Dec 2012 – July 2013
A functional (F) pump breaking down (p_1)	1.98%	0.95%
A non-functional (NF) pump being repaired (p_2)	5.26%	18.75%

These probabilities can then be used to calculate the long-term equilibrium of pump functionality, regardless of the initial functionality rate. Table 2 shows how the calculations for a subsequent period are made from the current period. For example, to find the percentage of pumps that are functional at time $t=1$ that change to non-functional at time $t=2$, we multiply the percentage of functional pumps by the probability of a functional pump becoming non-functional (p_1). To find the total percentage of non-functional pumps at time $t=2$ we also need to add the number of non-functional pumps that remained non-functional. Since p_2 is the

probability that a non-functional pump will become functional, 1- p_2 is the probability that a non-functional pump will remain non-functional (since the probabilities must sum to 1). Therefore, the percentage of non-functional pumps multiplied by (1- p_2) gives the percentage of non-functional pumps that remain non-functional at time *t=2.*

Adding together the percentage of functional pumps that have become non-functional to the percentage of non-functional pumps that have remained non-functional gives the total percentage of non-functional pumps at time *t=2.*

Table 2. Calculating functionality rates

	F (t =1)	NF (t =1)	Sum (t =2)
F (t =2)	%F x (1- p_1)	%NF x (p_2)	*Sum of F (t =2)*
NF (t =2)	%F x (p_1)	%NF x (1- p_2)	*Sum of NF (t =2)*

Table 3. Example calculation

	F (t =1) = 100%	NF (t =1)= 0%	Sum (t =2)
F (t =2)	100 x (1- 0.0198) = 98.02%	0% x (0.0526) = 0%	98.02% + 0% = **98.02%**
NF (t =2)	100% x (.0198) = 1.98%	0% x (1- 0.0526) = 0%	1.98% + 0% = **1.98%**

Table 4. Sample calculations Dec 2012

t =	F	NF
1	100%	0%
2	98.02%	1.98%
3	96.18%	3.82%
....	....	....
39	74.12%	25.88%
40	74.01%	25.99%
....	....	....
100	72.67%	27.32%

As an example, we can assume that pumps are 100% functional to begin with and use the probabilities from July 2012 – December 2012 of $p_1 = 0.0198$ and $p_2 = 0.0526$. Inserting these values into the same formulas from Table 2 produces the worked example in Table 3.

The same series of calculations is carried out for each period until equilibrium. Continuing with the figures from the example calculation through subsequent periods in Table 4, the value for functionality changes little after forty periods and from there incrementally approaches equilibrium.

These calculations were made with the probabilities from Table 1 to estimate current pump functionality rates in Salima. The equilibriums estimated using Markov processes were then compared to actual functionality rates in Salima to assess the accuracy of the Markov model predictions. Table 5 presents a summary of the findings, and the calculated differences between the predicted and actual values. The results demonstrate that the average of the two predicted equilibrium functionality rates approximates the actual functionality rates for these pumps in Salima District.

Table 5. Actual versus predicted functionality rates

	Jul '12 – Dec '12	Dec '12 – Jul '13	Average for the year
Predicted functionality rate	72.66%	95.20%	**83.93%**
Actual functionality rate	84.54%	83.96%	**84.25%**
Difference between predicted and actual	**-11.88%**	**11.24%**	**-0.32%**

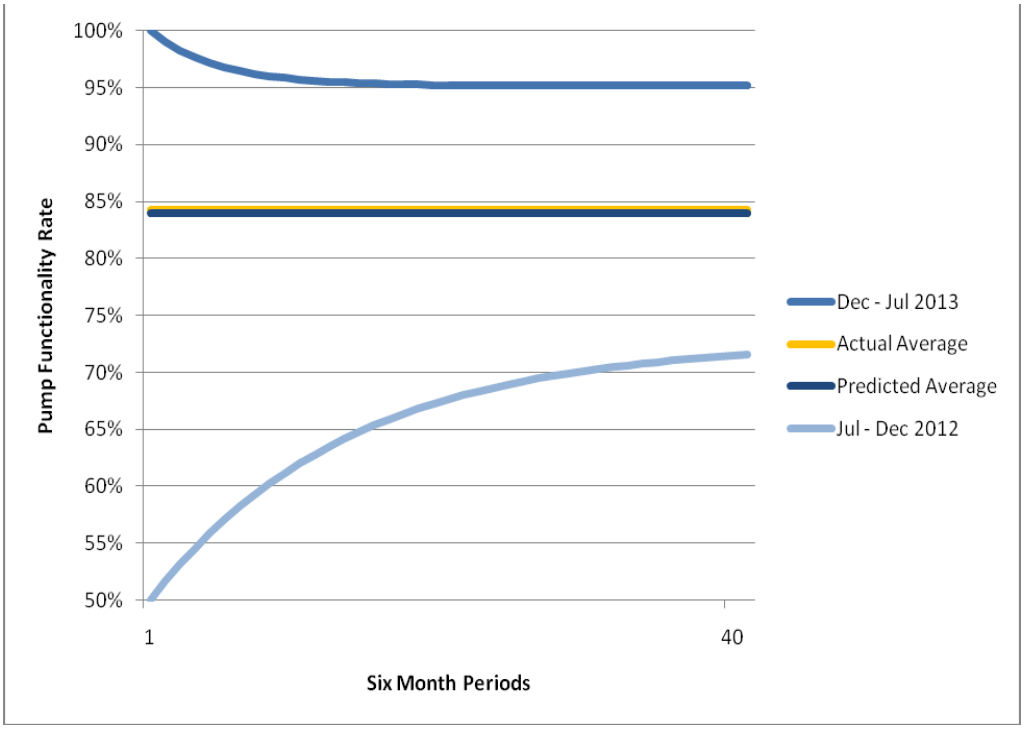

Figure 1. Predicted versus actual functionality rates

Source: Data from Salima District Council, July 2012 – July 2013

Figure 2 displays predicted functionality rate calculations (as demonstrated in Tables 3 and 4) as they converge on their equilibriums in comparison to the actual average functionality rate and the average of the two predicted equilibriums. This figure graphically illustrates how the Markov calculations converge on their respective equilibriums when using the arbitrary starting points of 100% functional and 0% functional.

Implications of the Markov process

Although more data and analyses are required to determine if a true Markov process is at play, the possibility that pump functionality in Salima represents a Markov process implies important potential implications for infrastructure sustainability. Perhaps the most important implication of a Markov process is that the same equilibrium will be reached regardless of the initial values. This means that simply installing new infrastructure, repairing broken pumps, or training pump repair mechanics may have no long-term effect on pump functionality rates if these interventions fail to impact the long-term probabilities of pump repairs or breakdowns. Salima District, the source of the data in this paper, has benefitted from sustained investment in infrastructure from major organizations such as WaterAid over the past decade (Shaw and Manda, 2013) that have improved water coverage rates with only minimal impact on infrastructure sustainability. Practitioners should therefore reflect on the intentions behind interventions to critically assess the likelihood of influencing these long-term probabilities for infrastructure repair. For example, although

short-term gains from pump repairs do have immediate benefits, they may not be sufficient to trigger a longer-term and potentially more profound impact on sustainability.

Based on this condition, practitioners need to focus on influencing the probability of pump repair through methods that can continue well beyond the length of a project intervention. Projects, by definition, are temporary measures because they have both an inception and a phase out. Shifting attention to focus on long-term probabilities of repairs implies focusing on permanent institutions and stakeholders providing ongoing services that can change this likelihood in the day-to-day. This also requires working within existing local resource constraints rather than relying on projects to provide temporary means for action.

Improving on Markov modeling for pump functionality

Further improvements in data collection could significantly improve modeling ability. For the purposes of this analysis, existing data from district government were used and, despite the aforementioned limitations, the analysis was found to be worthwhile.

Tracking individual pumps over long periods of time is perhaps the greatest opportunity for improving the analysis. In this instance, because data were reported as the total number of pumps in a village, only villages with one pump could be tracked over time, which may be incorporating unanticipated selection biases. Tracking individual pumps would help ensure accuracy in pump status over time and, cost permitting, could expand the number of pumps being used in the analysis. This, however, may have significant cost implications that were not encountered when accessing data freely available through a government system.

Furthermore, the classification of pumps could be expanded to additional categories including, for example, abandoned and partially functional (i.e. low flow) pumps. This would improve accuracy, and the additional states can easily be incorporated into a Markov model provided that sufficient data exists to calculate the probabilities of transitions between all states.

Strategies for influencing the probability of repair

Insights from analysis through a Markov process can inform interventions intending to create lasting changes in a system. In this instance, a permanent shift in the probability of repair of rural water points requires a permanent, consistent source of repair service provision. Alternatively, direct repairs from project interventions may increase functionality rates for a time before they return to the original equilibrium.

Working with District Water Development Offices (DWDOs) in Malawi, which are local government offices responsible for rural water development, has uncovered some interesting approaches for influencing the probability of repair of rural water points. As permanent government institutions, these offices are mandated to provide ongoing Operation and Maintenance (O&M) services to rural communities that are using communal water points. However, these offices are also severely understaffed and underfunded. Consequently, the approaches that have shown the most success in terms of sustainability have been those that focus on working within existing resource constraints.

In the resource-constrained environment experienced by these DWDOs, working within existing resource constraints means moving away from the traditional high-cost method of providing repairs directly to each water point in the area, and towards a more holistic view of O&M service provision that brings together both technical and community stakeholder support aspects of service provider responsibilities. In a typical district in Malawi, there can be upwards of one thousand rural water points spread over distances greater than 100 km from the service centre, with varying topography. At the same time, the DWDO responsible for the area may have between 1-5 field staff and a monthly operational budget somewhere in the range of $85-$270 USD (WESNET, 2012). With these constraints, to visit each and every water point directly on a regular basis becomes an impossibility.

Nkhotakota District: working with area development committees to engage communities

Before: The District Water Development Office (DWDO) had used nearly all funds available for fuel to travel to the field to conduct a handful of minor repairs that were within communities' abilities to perform. This happened because the DWDO did not have the staff or financial capacity to reach every water point, nor to identify where major repairs were needed in order to prioritise use of these limited resources.

After: Community-based groups of citizens called Area Development Committees (ADCs) are providing information to the DWDO about functionality of water points in the area and mediating community issues such as technical support for repair and connection to spare part suppliers. In just over eight months, one ADC had facilitated over 60 water point repairs, reactivated 25 water point committees, mobilized communities to collect over $500 USD for maintenance activities - all at a cost to the DWDO of less than $15 USD per month for communication costs and to provide the stationary needed for reports.

What changed:

- The ADC and DWDO worked on improving their relationship, finding common goals to work towards such as increasing water point functionality. As a result, the ADC formed a sub-committee specifically for water that makes monthly visits to each water point.
- The DWDO stays in regular contact with the water sub-committee, and attends an ADC meeting each month to collect information, as well as to provide stationary, technical assistance and advice.
- Through use of the sub-committee, the DWDO is able to leverage the existing meagre operational budget to coordinate service provision to approximately 5 times the number of communities.

The case study from Nkhotakota highlights a specific example of increasing the level of O&M service provision to communities by working through existing local committees. This is only one of many low-cost strategies that permanent institutions can leverage to influence the long-term probability of pump repairs.

Conclusions

Data collected by local government in Salima District, Malawi, shows that a Markov process can apply the probabilities of pump breakdown and repair to approximate, on average, the overall pump functionality rate for the District. The implication suggested by this model is that temporary repairs of pumps through direct intervention, as already occurs in Salima District, will not change the long-term functionality rates of pumps; functionality rates can only be changed through influencing the long-term probability of pump repair.

This finding has important implications for those interested in the sustainability of infrastructure. Instead of asking "how can we repair more pumps?" the finding urges us to ask "how can we influence the likelihood that pumps will be repaired?"

Strengthening linkages between stakeholders involved in pump repairs may hold a key towards improving long-term functionality rates. As seen in Nkhotakota District in Malawi, government service providers working with community level stakeholders can create opportunities for services to be sustainably improved without requiring an influx of resources. Working directly with government service providers to encourage innovation and improved management of existing resources might hold practical solutions for tackling critical issues of sustainability through improved systems for water point functionality.

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