Conference Paper

A SYSTEM DYNAMICS APPROACH TO MONITORING AND EVALUATION AT THE COUNTRY LEVEL:

An Application to the Evaluation of Malaria-Control Programs in Bolivia

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INTRODUCTION

This paper considers the monitoring of progress in achieving targets, within a results-based management framework. We argue that progress is more likely to be rapid if an underlying structural model that explicitly links policy actions to results is developed and if the planning, monitoring and evaluation activities are integrated. In developing such structural models, we find that a system dynamics (SD) approach is useful, since rarely is a result due to a single action.[1] Even in simple cases, results depend on a multitude of policy actions – each with its own dynamic path – that affect outcomes within that system. Modeling tools developed within the SD approach can be useful in developing the underlying structural models linking policy actions to results. This is demonstrated using an example of malaria control in Bolivia.

A results-based management framework (RBM) has been promoted by Canada, the UK, the US and the Netherlands over the past five years. According to the Canadian International Development Agency, RBM can be understood to mean a process by which realistic, expected results are defined and progress towards these results is monitored with the use of appropriate indicators. In fact, a “results framework” is now widely used by USAID as a planning and evaluation tool that sets in motion a process for the identification of strategic objectives with corresponding results arranged around these in a descending hierarchy (see Bertrand et al, 1999).

The RBM approach has also been incorporated into broader international initiatives. The International Conference on Financing for Development in Monterrey, for example, resulted in a broad consensus around the Millennium Development Goals (MDGs) as a framework for working towards specific targets and results. This can be seen as a broad, universal application of the RBM approach. Increasingly since Monterrey, the focus on results has been adopted by more bilateral and multilateral agencies and developing country governments – although not always in the context of the MDGs.

But the RBM agenda emphasizes the need to clarify the underlying cause and effect relations between actions and results. What the SD approach described in this paper does is provide a way of developing rather complex, graphic, structural models of these dynamic relations in a given system easily and intuitively. The approach also allows for the representation of the dynamic aspects of feedback effects and time lags in a system and helps avoid the difficulty of keeping more than one dynamic relation in your head. This SD approach also offers important benefits to both planning, and monitoring and evaluation activities.

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[1] Hummelbrunner (2000) also takes a system dynamics approach to evaluation, but with a different emphasis than the approach taken in this paper. Senge (1990) and Sterman (2000) provide useful descriptions of System Dynamics

SYSTEM DYNAMICS IN EVALUATION

Today, virtually all strategic planning involves the identification of indicators that will be used to monitor progress and often the setting of quantitative targets. As part of a results-based management approach, some reward or penalty can be attached to achieving the targets. However, rarely is there an attempt to link explicitly the policy actions with the results, tracing through exactly how a given set of policy actions is expected to lead to the final outcome. The ideas regarding what needs to be done and how to proceed are usually implicit – buried within the minds of policy-makers.

Developing explicit links between policy actions and results is akin to developing a structural model and can be contrasted with those monitoring approaches that, in essence, take a reduced-form approach. In a reduced-form approach, one applies a program designed to generate a particular outcome or result and then tries to either (a) obtain point estimates of the total expected impact; or (b) define a performance standard – subsequently determining whether that performance standard has been met or not (Manski et al, 2002). If the relation between a set of policy actions and the results are well-known, then working with the reduced form may be sufficient. However, if the causal relations are not well known, it may be possible to reach the proposed targets faster by specifying an initial structural model – and then updating it over time as new information becomes available.

The lack of an underlying structural model can become a problem if one wants to go beyond the task of simply analyzing whether progress has been achieved and, instead, wishes to assess rewards or penalties on the basis of the outcomes. If targets are achieved, there is less of a problem (although one could wonder whether the targets were sufficiently ambitious). The problem is more serious if targets are not met and one has to consider imposing a penalty. If no explicit structural model had been developed, it is difficult to know whether the targets set were, in fact, achievable.

Should one choose to waive the penalty? If so, this could cause those involved in carrying out the program not to take the focus on results seriously. Should one impose the penalty despite the possibility that the target may not have been achievable? This could create resentment among the staff for being held accountable for something that was not achievable and could lead to lower productivity or to staff leaving the program. Should one try to understand what led to the outcome before applying penalties? If so, then one must squarely face the problem of having to specify a structural model linking policy actions to results.

However, it would be better to define these aspects at the outset and have the actors involved in producing the results identify what it is that needs to be done. This is particularly important if a results agreement is viewed as a form of a contract. Using this analogy, it is best to define the terms of the contract upfront. If there is substantial uncertainty among policy-makers as to how to reach desired targets and if an agreement is made without explicit hypotheses about what determines the results, then unrealistic expectations may be imposed on both the program and program staff. The SD approach forces policy-makers to acknowledge upfront if there is uncertainty and to identify where this uncertainty lies. This acknowledgment may make it easier to get people to buy-in to the more systematic approach to results that is considered in this paper.

Finally, it is important to note that the SD approach to monitoring and evaluation does not only consist of the modeling of a complex problem. Rather, it should be conceived more as a *process* in which various things occur. First, at the policy-making level, one must specify how a particular target will be reached. That is, one specifies a structural model underlying the achievement of the target. System dynamics tools can help develop such structural models. Second, one must identify exactly what information is needed to ensure that one is on track to achieve the desired results. Third, there should be an on-going review of a program's outcomes, comparing expected outcomes to actual outcomes and, if actual outcomes fell short of expected outcomes, why this occurred. The expected outcomes may not have been achieved because the planned policy actions were not carried out. Or it may be the case that the actions were carried out, but certain key parameter values were misestimated. If the actions were carried out and the key parameter values were, indeed, correct, it may be that the underlying structural model was incorrect and needs be reconsidered. With the SD approach, the model is constantly being reconsidered and appropriate modifications and adjustments are expected in the course of one's work.

As one can imagine, taking a more structural approach through systems thinking is much more intensive in the use of information and requires more work than with a reduced-form approach. Although collecting information and allocating the necessary human resources all involve significant burdens, there are certainly ways of reducing these information costs. For example, by identifying the key drivers of desired outcomes within a given system, one can focus efforts on generating the necessary data only for those particular areas. This also helps to reduce the financial costs of collecting information which can be considerable. In doing this, one can thus develop a work program which concentrates work efforts only in certain areas.

Our hypothesis is that, in many cases, the benefits of the SD approach outweigh the costs. However, to give a clearer idea of what is involved, it is useful to consider a particular example and we turn to that below.

BOLIVIA'S MALARIA-CONTROL PROGRAM

Overview

We will describe the use of the SD approach in the case of a malaria-control program in Bolivia. Malaria was chosen as an example for several reasons. First, the underlying link between the proposed policy actions to control malaria and their expected results are relatively well-known. Second, there has been a dramatic decrease in malaria prevalence in Bolivia over the past five years, suggesting that we do in fact know which particular policy actions lead to the desired outcomes. There are, however, some problems that could be attributed to deficiencies in the monitoring and evaluation of these activities. In the past, the principal problem was that despite a decrease in malaria prevalence, it re-emerged later as a health problem. Currently, even with the strong improvement in the situation, the latest data suggest that now after the problem has been solved, it no longer receives adequate attention by the relevant authorities. This lack of attention might allow the problem to re-emerge once again. Third, there is global interest in making advances in malaria, exemplified by the Roll Back Malaria program. There has been considerable effort extended in developing a monitoring and evaluation system for the Roll Back Malaria effort, yet the monitoring and evaluation system appears to have some deficiencies.[2]

By applying the SD approach to make explicit the links between the policy actions pursued and the results obtained, the fact that the behavior of malaria prevalence is largely predictable over time – and a direct consequence of action (or inaction) – could be highlighted for everyone. A strong monitoring and evaluation system could bring the right information to the attention of the proper authorities – particularly the Minister of Health and the Minister of Finance – in time for them to allocate the resources necessary to keep the problem under control permanently and not wait until there has been a resurgence of the problem. An SD approach can facilitate this kind of work.

The Malaria Problem

After a decade of registering a modest upward trend, the incidence of malaria in Bolivia increased dramatically in the early and mid-1990s, rising from 19,031 in 1991 to 74,350 in 1998. As a result, the country was considered at high risk of malaria transmission. The increasing malaria incidence can be traced back to the low-level of political and financial commitments to the anti-malaria program (i.e. financing to the program dropped off from US$ 257,936 in 1996 to just US$ 57,471 the next year despite the increase in incidence) and the inappropriateness of the interventions – an excessive dependence on vector-control by massive insecticide spraying.

[2] Macintyre et al (2002) state, "..the conceptual framework spells out the major elements of a malaria control program. However, it does not further clarify the processes, outputs and outcomes within each element. Such definitions are critical in helping to develop national-level monitoring and evaluation plans, particularly in the selection of indicators and the timing of data collection."

It was in the late 1990s when authorities took the first steps to reverse these poor malaria-related outcomes by establishing the National Program of Malaria Control which was strongly supported by the Government and the donor community. As in many other countries, the approach to tackling the problem changed with a comprehensive set of strategies directed not only at vector-control but, also, the diagnosis and treatment of those infected, the strengthening of research capacities (in order to provide feedback to better direct the activities under the program) and an initiative aimed at involving the community in the control of the disease by informing, communicating and educating populations in endemic areas about the risk of communicable diseases.

The program has been successful in the struggle against malaria by *plasmodium falciparum*, the lethal type of the disease. The number of cases caused by *plasmodium falciparum* dropped from 11,414 in 1998 to 251 in 2002; in relation to the total number of malaria cases, the proportion dropped from 15.4% to 5.1% between 1998 and 2001 revealing a change in the epidemiological distribution of malaria in Bolivia and a relative reduction regarding the seriousness of the situation. As for malaria by *plasmodium vivax*, the other type of malaria that prevails in Bolivia, its incidence has also decreased. When compared to the Annual Blood Test Index (ABTI), it can be clearly seen that the number of positive cases due to *plasmodium vivax* is decreasing.

Despite the remarkable efforts in reducing malaria, the potential risk of transmission still affects 136 out of Bolivia's 314 municipalities. By 2001, it was estimated that 37.7% of the population lived in malaria-endemic areas, covering 75% of the country's area. Moreover, despite the overall reduction of the API, highly risky endemic areas still exist. For instance, 27 out of 1,000 inhabitants living in the Amazonian region were infected in 2001, accounting for more than 50% of the total amount of malaria cases in the country. Eco-epidemiological and geographic conditions make it costly to keep reducing its incidence. But unless the disease is controlled in the region, malaria will remain a primary health concern because of seasonal migration to the Amazonian region during Brazil nut harvest time.

THE APPLICATION OF SYSTEM DYNAMICS TOOLS

The World Bank has started using a commercial software package[3] – *iThink* – to carry out the modelling of the complex and dynamic system represented by the malaria problem in conjunction with Bolivia's Ministry of Health and PROCOSI, the major NGO network in health.[4] The software has allowed authorities to take into account the explicit links between the different sub-processes that make up the malaria problem in Bolivia. Through its intuitive, dynamic, graphical modelling capabilities, the software has provided users with a useful organizational framework for integrating a range of sub-models and sub-processes in the context of the problem of malaria. This range of sub-

[3] There are various software tools, each with different strengths and weaknesses. More information on the I-Think package can be found on their web site, www.hps-inc.com.

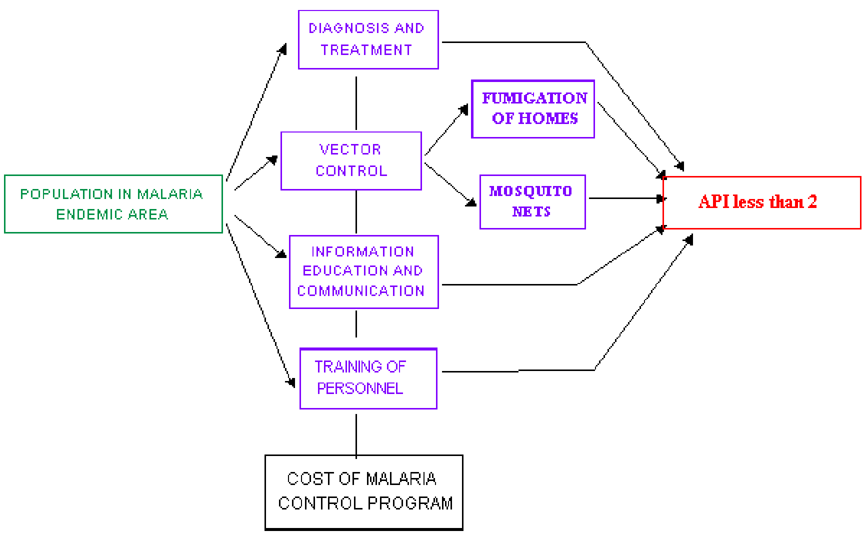
[4] Guido Monasterios, Rene Mollinedo and Tatiana Ruiloba were the people most involved in this activity within the Ministry of Health, Ramiro Bernal, a consultant for PROCOSI, also worked on the models.

models is, in turn, linked to a high-level map that allows the user to zoom up (or down) between different levels of detail.

The model developed in Bolivia analyzes the relations between health sector policies and underlying epidemiological risks that together determine the level of malaria prevalence in the country. The model takes into account the feedback between infected individuals and the rate of transmission of the disease, as well as the actions undertaken and the Government's planned 2001-05 strategic sector plan, and also tracks the costs and financing needs contemplated by the plan.

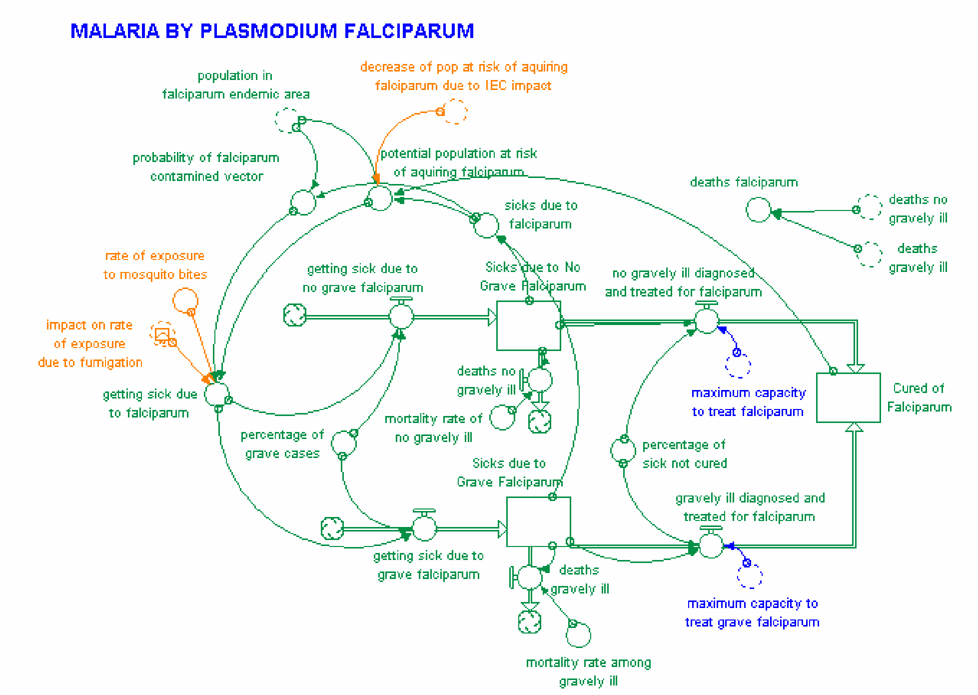
A high-level map of the principal variables (or sub-models) that make up this health system is presented below (see Figure 1):

Figure 1.



In this high-level map, each of the variables (such as Diagnosis and Treatment or Fumigation of Homes) is a sub-model by itself. For example, if one were to click on the variable "Diagnosis and Treatment," one would be taken to the structure of that particular sub-model which is a visual description of the structure determining the transmission of the disease and the manner in which the interventions of diagnosis and treatment reduce the likelihood of transmission (see Figure 2).

Figure 2.



The sub-model in Figure 2 is created using icons representing stocks and flows, the basic language of the SD approach. In the figure, squares represent stocks, pipes represent flows, circles represent variables that can affect either stocks or flows, and arrows represent the connections between and among variables. The relationships between and among these different elements can be made as mathematically complex as one would like – which helps to better represent the actual system that one is modeling and facilitate the analysis of the stocks and flows therein.

Figure 2 also illustrates a classic feedback loop within a systems model. Specifically, one can see the re-enforcing dynamic of the malaria epidemic by *plasmodium falciparum*: the greater the number of people sick due to the *falciparum*, the greater the probability of a *falciparum*-contaminated vector (mosquito). This, together with the rate of exposure to mosquito bites, determines the overall number of people infected with malaria.

In fact, with additional information and values that can be input for each of the different variables, a simulation of the entire model (comprising all of the various submodels) of the system can be run. If particular values are not known, the user can specify ranges – and determine sensitivity – to different values. This can then be used to develop a work program for identifying information needs and for proposing ways of collecting and gathering the data.

One final point worth mentioning is that after the modeling, the software itself writes a system of non-linear difference equations based on the system of stocks and flows modeled graphically. Modeling these complex relationships within the system mathematically and without the software would otherwise be very difficult and time-consuming.

Data Sources

As mentioned before, the application of this approach is intensive in its use of data and information. For the development and functioning of the malaria model, for example, several different sets of data were required:

> *Data from Information Systems.* This is data regarding population, birth and mortality rates, population living in endemic areas, number of health facilities in endemic areas.
>
> *Productivity Measures.* This includes treatment effectiveness,[5] useful life of laboratory equipment (typically 5 years), liters of insecticide needed per fumigated house (0.25, based on entomological studies), and productivity by technician in fumigation (1,303 houses per year).
> *Impact Parameters.* This refers to the IEC impact on the population at risk of acquiring malaria,[6] the impact on the rate of exposure due to fumigation, and the impact on the rate of exposure due to mosquito nets (assumption, also a graphical function).
>
> *Cost Parameters.* These include the cost per microscope, the unit cost per *vivax* treatment, the unit cost per *falciparum* treatment, fumigation equipment cost, the unit cost of impregnated mosquito bed nets, training costs for laboratory and fumigation technicians, and annual salaries for personnel.

SOME INITIAL FINDINGS

Although international health organizations provide general guidelines for the control and treatment of communicable diseases such as malaria, effective treatment of these diseases at the country level relies on the development of strategies adjusted to meet local conditions. For example, vector-control activities in Bolivia should be designed based on local entomological studies. In the same way, the treatment of those infected should be the result of evidence regarding the effectiveness of drugs and possible drug-resistance in specific endemic areas of the country. But control and treatment of malaria can also benefit from incorporating findings from the results of the modeling and simulation of the malaria problem using *iThink* (see Figure 3 for an example of the simulation screen).

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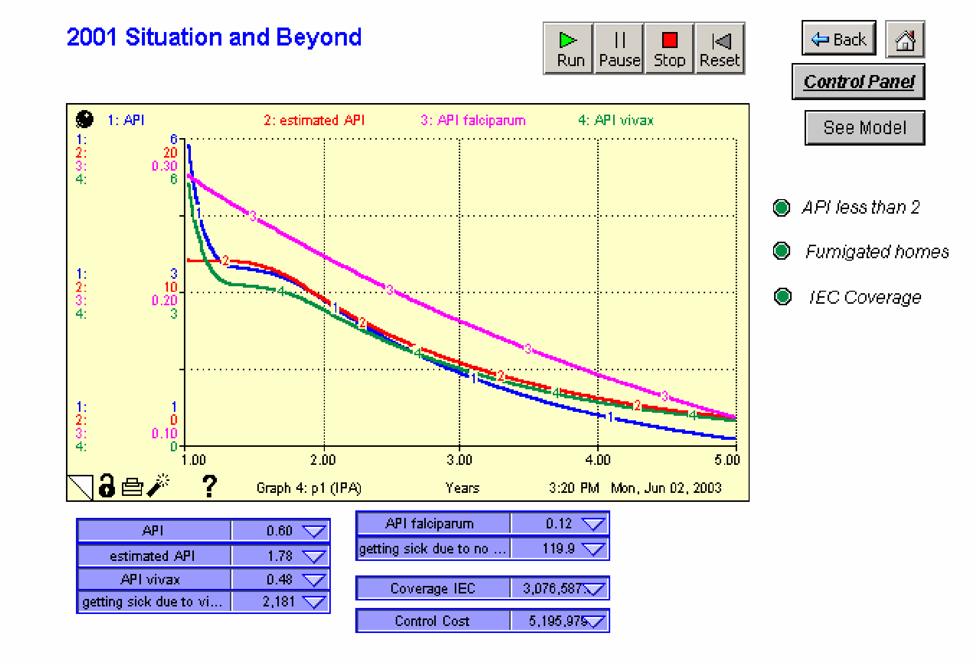
[5] The number of pills an infected person has to take is determined by malaria protocols, these are designed taking into account general guidelines provided by international health organizations, but are adapted – based on local research – to meet local conditions (i.e. one infected with *vivax* has to take 10 cloroquine pills and 14 primaquine pills).
[6] There have been some pilot experiences, but uncertainty remains. In our model, IEC impact is a range between 10% and 20%.

Figure 3.



The main findings of the SD modeling and simulation process for malaria in Bolivia indicate that it would cost roughly US$7.5 million and roughly 3.3 years to bring the key malaria index (the Annual Parasitic Index or API) below the target of 2. It would also cost roughly US$580,000 per year to maintain this index below 2 once it has been reached, a difficulty for a country with limited financial resources.

Unfortunately, donor financing declined dramatically in 2002 as previous programs came to an end. Actual expenditure fell substantially below the US$580,000 that was estimated to maintain the levels. As a result, the number of cases in the first three years of 2003 jumped up to 3,700 (74% of the number of cases registered in all of 2002). This increase in the number of cases was predictable, given the shortfall in the financing provided.

The simulations suggest that some improvements could be made in malaria prevalence if there were a reallocation away from vector control towards diagnosis and treatment, but this improvement is not dramatic. The simulation also indicates what should not be done. For example, re-allocating funds away from diagnosis and treatment towards greater vector control would significantly raise the costs of reaching the target to US$9.3 million.

But the findings of the simulation process also suggest that important and significant results could also be achieved if resources were to be allocated to strengthening the capacity of epidemiological surveillance systems which help to measure the number of deaths due to malaria, as well as the number of asymptomatic people, migration rates to malaria-endemic areas, and the rate of exposure to mosquito bites. Additionally, resources allocated to scientific research on mosquito infestation rates and drug-resistance, for example, could produce some positive and encouraging results.

Finally, the modeling of the malaria problem at the national level can also be extended to different municipalities. The application of the model to localities is important as each of the country's 324 municipalities face different decisions than those faced at the national level. Attempting to understand why some municipalities have better results than others given their characteristics is important both for improvements in the design and implementation of malaria-control program at the municipal level as well as for an analysis of extreme cases at the municipal level.

Additional Considerations

Achievements in controlling malaria in Bolivia have been impressive and can be seen as a great success story in improving health outcomes. To a large extent, the advances can be attributed to the implementation of a comprehensive strategy to address the problem and a clear focus on results coupled with the knowledge of the link between proposed policy actions and their expected results. But with the use and application of SD tools to the problem, much more can be achieved in the near-future – especially by re-focusing Government efforts on the monitoring and evaluation of malaria-control efforts.

Within the context of development programs, *iThink* takes the spirit of the traditional LogFrame and extends it by using graphical tools which allow the user to build up a system of different elements and components, allowing one to make explicit the links between a proposed action, its expected result and its cost. Once data and other information are introduced for the different variables, one can simulate what would happen to the final outcomes over time if one or more actions were to take place. Users can modify assumptions and simulate impacts of policies in real-time and generates visual projections of the impact of proposed actions on a given set of indicators. It even allows one to perform a sensitivity analysis to identify the most important knowledge gaps that need to be filled.

A well-designed model, then, can generate graphical projections of the impact of proposed policy actions on key indicators and target results, permit an estimate of financing requirements in order to achieve those results, and serve as a useful tool for a constructive dialogue on prioritizing policy interventions. By enforcing this kind of systematic approach to the analysis of the problem of malaria in Bolivia, it is hoped that more rapid progress might be made in reaching targets than if the current, rather *ad hoc*, approach were to continue to be followed.

Despite the positive aspects of the SD approach that we have highlighted, there are some caveats:

First, it is important to recognize that there are always multiple ways of reaching a goal and achieving a particular target. This leads to the question: why model anything at all? In the example used to illustrate the SD approach in this paper, the point is that we are looking at the particular path chosen by decision-makers and policy-makers for tackling a social sector problem. There may be many possible paths, but with a public policy focus, what is important is modeling and analyzing the path chosen by public agencies and authorities.

Second, the simulations that can be run based on the model developed are only valid for analyzing small changes around a local optimum. If there are major changes – for example, the identification of a completely different path to achieving the outcome – the simulation may not capture them. Changes like this might have to be reflected in a completely different model. The example of the changes suggested by the malaria model and its simulation was simply a marginal shift of money from one activity to another but did not represent a radical change in approach.

Finally, there are also some additional thoughts regarding the use of the SD approach in general for the analysis, planning and evaluation of public policy programs that are worth mentioning here:

One has to be realistic about expectations. We are not saying that a single modeling process generates the results. Our hypothesis is that by following a SD approach, one may reach a target faster than one would if a more *ad hoc* approach were followed (maybe in 7 years rather than 12 years). However, in using such an approach, constant comparison of what one thinks is going to happen with what actually happened is required so that a constant modification of the approach is generated.

It is important to recognize that there are significant costs. One has to decide individually – and according to particular circumstances – whether pursuing the SD approach is worth the costs. It is, however, possible to test the hypothesis that the SD approach is worth the effort. One could, for example, conceivably design a random experiment over different municipalities where they are all given the same amount of financial resources; but in one case, there would be the added requirement that they must spend a small percentage on the SD approach. Then, after three years, one could see how much closer the "treatment" municipality is to the target compared to "control" municipalities. Municipalities would have to be randomly assigned to the different groups.

It may be difficult to model what policy actions lead to results. That may be true; but people still take decisions based on certain mental constructs. As one expert in SD has put it: "All models are wrong. But some models are useful." People must have a mental model of what they think is needed to achieve results before proceeding. All one is trying to do with systems thinking is force that model out in the open so it can be debated, discussed, analyzed. Just as the act of writing forces one to be clear about the thinking process, the use of systems thinking forces one to be explicit about the problem being considered. Especially for the purposes of achieving quantitative targets, modeling forces one to be clear about presumed relationships and hypotheses about cause and effect.

CONCLUSIONS

As indicated, the SD approach allows one to break systems down into their constituent parts and work with very complex systems in a manageable way, allowing users to think systematically of inputs, outputs and the relationships between them. In this paper, we have illustrated the application of the SD approach in the context of malaria-control efforts in Bolivia with the use of the *iThink* software for modeling and simulation.

The initial models completed for malaria have allowed for the identification of constituent parts of the problem and have shown considerable promise. There are also other important modeling efforts have also been undertaken in the country that are note-worthy.

For example, modeling has been completed in collaboration with public agencies of the health problems represented by tuberculosis and the *chagas* disease. The challenge faced now is how to turn the results generated by these models operational. As mentioned in the case of malaria, the tuberculosis and *chagas* models developed at the national level need to be re-adapted to reflect the way municipalities actually work as important links in the achieving results-chain.

A model has also been developed of the dynamic processes involved in reaching universal primary education in Bolivia. This model, developed in collaboration with the Ministry of Education, makes explicit the link between policy actions and results, generating graphical projections of the impact of proposed actions on key education indicators and provides estimates of financing requirements. The core sub-model is a cohort model of the flow of students through different primary school grades.

The more general point worth making based on the models described above is that whenever a target is specified for a public policy program, it may be useful both for public agencies and the international community providing the financing of such programs to consider making explicit the links between the specified target and the actions required to achieve it. Taking this kind of structural approach can be conceived more as an on-going process which not only helps specify how a particular target will be reached, but helps identify the kind of information that will be needed in order to track the achievement of desired results.

In the context of monitoring and evaluation activities, the SD approach helps provide an on-going review of a program's outcomes by helping the user in the comparison of a program's expected outcomes to the actual, observed outcomes. Thus, a given model can be re-evaluated and re-considered constantly in the course of a program's implementation with the necessary modifications and adjustments carried out as needed. The kind of understanding that the SD approach provides regarding a problem, the identification of a desired approach and the tracking of desired results is quite valuable in the context of the growing emphasis on results – and as an innovative approach to on-going monitoring and evaluation efforts in the field of development.

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