Published in final edited form as:
Med Decis Making. 2012 January ; 32(1): 105–117. doi:10.1177/0272989X10391808.

Decision making for HIV prevention and treatment scale up: Bridging the gap between theory and practice

Sabina S. Alistar, M.S.[*] and **Margaret L. Brandeau, Ph.D.**
Department of Management Science and Engineering Stanford University, Stanford, CA 94305-4026

Abstract

Background—Effectively controlling the HIV epidemic will require efficient use of limited resources. Despite ambitious global goals for HIV prevention and treatment scale up, few comprehensive practical tools exist to inform such decisions.

Methods—We briefly summarize modeling approaches for resource allocation for epidemic control, and discuss the practical limitations of these models. We describe typical challenges of HIV resource allocation in practice and some of the tools used by decision makers. We identify the characteristics needed in a model that can effectively support planners in decision making about HIV prevention and treatment scale up.

Results—An effective model to support HIV scale-up decisions will be flexible, with capability for parameter customization and incorporation of uncertainty. Such a model needs certain key technical features: it must capture epidemic effects; account for how intervention effectiveness depends on the target population and the level of scale up; capture benefit and cost differentials for packages of interventions versus single interventions, including both treatment and prevention interventions; incorporate key constraints on potential funding allocations; identify optimal or near-optimal solutions; and estimate the impact of HIV interventions on the health care system and the resulting resource needs. Additionally, an effective model needs a user-friendly design and structure, ease of calibration and validation, and accessibility to decision makers in all settings.

Conclusions—Resource allocation theory can make a significant contribution to decision making about HIV prevention and treatment scale up. What remains now is to develop models that can bridge the gap between theory and practice.

1. Introduction

Affecting more than 30 million people and killing 2 million annually,[1] HIV destabilizes economies, compromises development, and disproportionately incapacitates young, productive adults.[2] Combating and controlling the global HIV/AIDS epidemic is one of the seven United Nations Millennium Development Goals and a top priority for governments worldwide.[3, 4] Specifically, the sixth Millennium Development Goal is to achieve universal

[*]Corresponding author: Department of Management Science and Engineering, Huang Engineering Center, Stanford University, Stanford, CA 94305, ssabina@stanford.edu, 650-521-1202.

access to HIV treatment (widely defined as access for at least 80% of eligible patients[5]) by 2010 and to halt the spread of HIV by 2015.

The HIV epidemic is highly heterogeneous across countries and settings in terms of prevalence, incidence and transmission patterns. Currently, 95% of infections occur in developing countries,[2] which face additional hurdles in epidemic management due to lack of resources, poorly developed infrastructure, and sometimes unstable governance. Sub-Saharan Africa accounts for 67% of people living with HIV and 75% of AIDS-related deaths.[1] The highest HIV prevalence in the world is registered in countries such as Swaziland (26% of adults), Botswana (24.1% of adults), and South Africa (18.8% of adults).[1, 6] However, HIV incidence is highest in Eastern Europe and Central Asia (Russian Federation, Ukraine), and some Asian countries (Indonesia, Vietnam).[1] Additionally, transmission patterns vary widely: in sub-Saharan Africa, HIV transmission occurs mainly among heterosexual couples and from mothers to their newborns; elsewhere the epidemic is primarily driven by injection drug use (IDU), commercial sex workers (CSWs), and men who have sex with men (MSM).[1]

Despite years of concerted efforts and investment, an estimated 2.7 million people became newly infected with HIV in 2007.[1, 7] Although significant decreases in HIV incidence have been achieved in some countries (e.g., Zimbabwe, Botswana, Thailand), incidence has increased in other areas of the world (e.g., Eastern Europe, Central Asia).[1, 7]

Recently, considerable progress has been achieved in expanding access to treatment and increasing funding for HIV/AIDS programs.[8] A six-fold increase in financing for HIV treatment in low- and middle-income countries in the past six years has led to a ten-fold increase in the number of people receiving antiretroviral drugs, with almost 3 million people in treatment by the end of 2007.[1] However, in 2007 in low- and middle-income countries an estimated 70% of eligible individuals still did not receive treatment.[1, 9]

Prevention efforts have lagged behind treatment efforts in many parts of the world, even though prevention is considered essential for reversing the epidemic.[1, 10] A recent estimate suggests that for every two patients who initiated antiretroviral therapy in 2007, five more acquired HIV infection.[11] In addition, it has been estimated that fewer than 10% of individuals at risk in 2007 were reached by key prevention interventions.[2, 11] Many potentially effective prevention programs (e.g., condom promotion, harm reduction, education) have not been targeted or scaled up sufficiently to reach the desired number of individuals.[12, 13] In some cases, funds have been allocated to largely ineffective approaches such as ABC programs (Abstinence, Be faithful, Condom use).[12, 14, 15]

Additionally, prevention and treatment efforts need to be sustained by appropriate investments in health care infrastructure, development of human resources, multisectoral programs addressing education and stigma, and management structures that will support the HIV programs in the long term.[5]

Funds for HIV prevention and treatment fall far short of estimated need,[16] even in developed countries.[17, 18] In developing countries, the bulk of funding for HIV prevention and treatment has come from international donations and sponsor contributions — funding sources that may be jeopardized by the current economic downturn.[5, 7] It is estimated that treatment programs will be impacted by changes in available funding in 33% of countries, affecting 61% of people on treatment.[19] With scarce funding, and much progress remaining to be achieved in both treatment and prevention, efficient resource use is critical. No country has found an ideal solution yet, but relative successes in countries such as Thailand and Uganda have demonstrated that a consistent effort that includes a variety of interventions and sustained funding can achieve significant results.[20]

In addition to the goal of improving health, many political and social considerations affect decisions about investment in HIV prevention and treatment.[13, 21] Without adequate scientific data to support their adoption, some effective interventions, particularly those targeting most-at-risk populations (IDUs, CSWs, MSM), may be difficult to include in the HIV agenda, even if they are highly cost-effective or even cost saving. For example, longstanding debates have occurred over the acceptability of opiate substitution therapy and needle exchange for IDUs,[22, 23] as well as condom promotion programs,[24–26] despite their proven effectiveness in reducing risky behavior. Ethical, cultural, and equity concerns are also important. For example, while the most effective use of funds may direct resources toward a single population group, in practice it may not be acceptable to neglect the rest of the population, due to ethical and equity concerns.

Significant scale up of global HIV prevention and treatment efforts is needed if the sixth Millennium Development Goal is to be achieved. However, determining the optimal investment in HIV prevention and treatment programs for any particular region is challenging. The heterogeneity of the epidemic across different regions means that different intervention packages with varying levels of investment will be most effective in different settings.[13, 14, 27, 28] Moreover, different regions have different sets of accepted and available interventions and different levels of HIV funding; the effectiveness of interventions in any given setting may be uncertain; and the HIV epidemic is dynamic and nonlinear. How, then, can decision makers determine the best allocation of scarce HIV prevention and treatment resources for their setting?

Despite the broad body of research estimating the cost-effectiveness of various single HIV/AIDS interventions, decision makers often have little guidance as to which interventions or sets of interventions will yield optimal results in their particular settings. Since resources are limited and cannot be expanded indefinitely, it is essential to use them in a way that maximizes health outcomes (in measures of epidemic control such as HIV infections averted, quality-adjusted life years (QALYs) saved, etc.). Research allocation theory – defined as the methodology for allocating resources to optimize a goal (in this case, health benefits), subject to budgetary and other types of constraints[29] – effectively addresses this question. Much work has been done on the theoretical problem of resource allocation for controlling HIV, but little work has been done to translate the results of such work into practical tools for decision makers. Lasry and others[30, 31] describe a number of difficulties encountered in implementing academic models of HIV resource allocation for practical purposes, including model complexity and data requirements; the presence of multiple stakeholders; political, social, and ethical considerations; and funding limitations and historical funding patterns.

In this paper, we describe what is needed to bridge the gap between HIV resource allocation theory and practice, and thus support efficient and effective scale up of HIV prevention and treatment efforts. We do not comment on the normative implications of the diversity of practices across the world, but acknowledge it as requirement for a practical model design. Section 2 provides a brief overview of modeling approaches in the resource allocation literature, and Section 3 discusses the limitations of these models. Section 4 describes HIV resource allocation in practice. Section 5 addresses the gap between theory and practice: we describe characteristics needed in a model that can effectively support planners in decision making about HIV prevention and treatment scale up. We conclude in Section 6.

2. Resource allocation literature

Allocating resources for epidemic control has been a topic of interest in academic studies since the 1920's.[32, 33] A variety of modeling approaches have been developed, ranging from simple linear projections,[34] to dynamic compartmental models based on systems of differential equations,[35, 36] to complex optimal control models[37–40] solved via simulation[41] and numerical techniques.[42] Such models have been applied to a variety of epidemics, including tuberculosis,[43] influenza,[44] and gonorrhea[45] and, more recently, to HIV/AIDS.

In this section we describe key modeling approaches that have been used to address the HIV resource allocation problem, ranging from simple, deterministic linear projections to highly complex stochastic simulation models. Our goal is not to provide an exhaustive review of the literature; rather, we describe three broad categories of models (linear, dynamic, and simulation models) and present illustrative examples of each (Table 1). Comprehensive reviews of resource allocation models for epidemic control can be found elsewhere.[46, 47]

Existing resource allocation models vary in their approach to incorporating the evolution of the epidemic, with some models assuming linear growth and others including nonlinear epidemic effects. Some models allow for a nonlinear relationship between funds invested in a program and its direct effects (e.g., the relationship between intensity of an educational program and the resulting level of change in risky behavior). For many programs, this relationship may not be linear.[34, 48–52] Some models incorporate stochastic effects (e.g., variability in individual response to treatment) whereas others use only deterministic values (e.g., average rates of disease progression). Advantages and disadvantages of different types of models of infectious disease evolution and control are described elsewhere.[46, 47, 53, 54]

2.1 Linear models

A simple approach to the resource allocation problem uses linear modeling. As part of an Institute of Medicine report addressing HIV prevention in the United States,[55] Kaplan and others developed a linear resource allocation model that aims to maximize the number of infections averted by distributing resources between interventions directed to high-risk populations in proportion to HIV incidence in the target group and cost-effectiveness of the intervention. This simple model assumes linear evolution of the epidemic (i.e., a time horizon short enough so that an assumption of linear epidemic growth is approximately correct) and linear scale up of intervention costs and effects.

To account for variations in intervention effectiveness as a function of level of funding, Kaplan[34] employed the concept of “production functions” that link level of investment to level of behavior change, and described how they could be used to determine the allocation of resources between multiple high-risk populations that maximizes the number of HIV infections averted. The resulting resource allocation model is equivalent to a knapsack problem (maximizing value obtained from investing in a set of programs, each of which has a cost and a value, while not exceeding a budget constraint) that can be solved via well-known techniques.[56] Kaplan and Pollack[57] determined the production functions implicit in typical resource allocation heuristics employed by local HIV Prevention Community Planning Groups in the U.S., and showed that the use of such heuristics does not maximize infections averted.

2.2 Dynamic epidemic models

A more sophisticated type of resource allocation model captures epidemic effects — specifically, nonlinearity of epidemic growth and changes in epidemic evolution caused by interventions.

Kahn[58] introduced a simple HIV epidemic model that projects the evolution of the disease in various independent populations. Susceptible individuals acquire HIV at rates proportional to their risk profile. The parameters are adjusted to match the evolution of HIV prevalence observed in real settings in each population. The model allows for variability in the effectiveness of prevention programs in the different populations. The analysis showed that the cost-effectiveness of prevention interventions depends on initial HIV prevalence and risk behavior in the target population. This analysis was one of the first to quantify the gains (HIV infections averted) caused by targeting HIV interventions to high-risk groups, and to mathematically justify such targeting.

Paltiel[59] analyzed the cost-effectiveness of various interventions initiated at different times in the epidemic life cycle using a dynamic compartmental model. The model considers a homogeneous population of susceptible and infected MSM who transmit HIV via sexual contact. The epidemic dynamics are controlled by differential equations modeling the rates of entry, exit, and infection acquisition, based on HIV prevalence and size of each population group. The model compares the effects of targeted (towards susceptible or infected individuals) or general HIV interventions, if initiated at various times in the epidemic cycle. The analysis showed that for early stage epidemics, the most cost-effective programs are those that focus on identifying the small number of highly infectious people. Conversely, for mature epidemics, efforts are most cost-effective if directed toward the small pool of remaining susceptible individuals.

Richter and others[42] used a more sophisticated dynamic epidemic model integrated with production functions that model the relationship between level of investment in an intervention and its effects on risky behavior. They considered susceptible and infected individuals in two independent (no cross-infections), homogeneous populations of IDUs and non-IDUs. The model quantified the effects of multiple interventions in terms of infections averted, as a function of investment, and accounted for variability of intervention effectiveness depending on HIV prevalence. The authors numerically determined the optimal investment in each population group and intervention over a five-year horizon, subject to a fixed budget.

Zaric and Brandeau[60] developed a resource allocation model based on a general compartmental epidemic model with a Susceptible Infected (SI) framework.[61] The model can include any number of populations based on risk levels, and HIV can be transmitted across the different populations and compartments. The model can be parameterized with data observed in practice. HIV interventions modify one or more of the parameters, thus curbing the evolution of the epidemic in the affected populations. The model includes production functions that relate investment in an intervention to changes in epidemic parameters (e.g., level of risky contacts or transition rates from high-risk to low-risk groups). Deriving an analytical solution to the model is difficult or impossible even for simple model assumptions, so the authors presented heuristics for solving the resource allocation problem. They verified the robustness of the proposed methodology with numerical examples.

2.3 Simulation models

More complex approaches involving simulation have been used to compare different sets of HIV interventions. For example, Bernstein and others[62] used a combination of deterministic and stochastic epidemic models to evaluate the effects of several HIV prevention programs in a severely affected East African city. The analysis showed which interventions were most effective in reducing the spread of HIV, and demonstrated that packages of interventions were more effective than single interventions.

Robinson and others[63] used a complex model including both deterministic and stochastic elements to analyze the impact of alternative HIV prevention strategies in rural Uganda. The model captured the transmission and progression of HIV and two other sexually transmitted diseases (STDs), demographic characteristics of the population (fertility, mortality, migration), and diverse sexual behaviors of individuals (one-time, short-term, and long-term partnerships).

Hogan and others[28] used a detailed epidemic model to simulate the effectiveness and cost-effectiveness of different combinations and levels of prevention and treatment programs in sub-Saharan Africa and Southeast Asia. Reflecting transmission patterns in these regions, the model considered interacting populations of CSWs and single and married men and women. To accurately reflect all risk factors, the authors included the effects and transmission of other STDs. The analysis did not explicitly consider the allocation of a fixed budget, but is one of the few studies to examine the effects of different combinations of HIV prevention and treatment programs and the effects of different levels of scale up.

3. Limitations of academic resource allocation studies

Despite the range of published models for HIV resource allocation, a number of important practical issues have not been fully addressed.

Existing resource allocation studies often compare two or more interventions in one specific population or risk group in a small setting. It is often unclear how transferable these results are between different settings (e.g., low-income versus high-income countries), and how the results would change at the country level.[64–66] Moreover, few studies look at how the effects (e.g., HIV infections averted) of joint interventions differ from simply superimposing two or more single interventions. Depending on which interventions are chosen, the overlap can have significant effects, since it may decrease or increase total costs or total benefits, due to synergies or non-additive results.[64] For example, the total health effect of a program that reduces risky behavior combined with a program that expands HIV treatment will be less than the sum of the two programs' separate health effects: this is because the same HIV infection cannot be prevented twice.

Only a limited number of studies have analyzed the impact of decreasing/ increasing returns to scale for specific interventions or sets of interventions, though it has been shown to be an important phenomenon.[34, 48–52] Most times, a linear relationship between funds or efforts invested and outcomes is assumed, which may distort projected results when scaling up programs.[65, 66] Brandeau and others[67] analyzed prevention interventions for MSM and IDU populations representative of California, and showed that suboptimal decisions may be made without sufficient information about prevention program production functions: without any knowledge of production functions, 83% of the budget would be allocated to MSMs and the rest to IDUs, whereas with complete knowledge, 100% of the budget would be allocated to IDUs, averting seven times as many infections. The authors also demonstrated that linear approximations are particularly inappropriate in limited-resource situations.

Most existing models consider the allocation of resources between HIV prevention programs but do not consider the simultaneous allocation of resources to HIV treatment programs. This is a major gap in the resource allocation literature. Treatment has a variety of effects on the epidemic, including extended life span and reduced infectivity of treated individuals (and thus reduced HIV transmission).[68–72] Consideration of these effects along with prevention program effects provides a more accurate estimate of the effects of HIV program scale up and allows the decision maker to gain insight into the appropriate balance of prevention and treatment in a particular setting. Recent work by Cleary and others[73] included budget limitations in an analysis of HIV treatment scale up in South Africa, but focused only on treatment and did not consider prevention interventions.

In most HIV resource allocation models, the impact of interventions on the overall health care system, in terms of resources needed (human, capital, infrastructure), is rarely considered.[74, 75] However, continuing progress in HIV control requires the expansion of structural interventions that strengthen health care systems (e.g., an increase in the capacity of rural health clinics to dispense medications), as well as combined approaches that include both behavioral and structural interventions.[13, 76]

Finally, academic attempts to create accurate models have yielded theoretical insights but have often yielded complex systems that are not user-friendly and cannot be easily adopted by decision makers, who typically are not trained in epidemic modeling, simulation, and optimization. Often, in the interest of simulating the epidemic as closely as possible, the models require a significant number of parameters as inputs, many of which are unknown or difficult to estimate in practice.

A few caveats apply to the gaps we identified in the literature. Data may be unavailable to completely reflect the effects of scaling up and overlapping interventions, or to elucidate the shapes of production functions. Even if some interventions are more cost effective than others, ethical and equity concerns may require at least a minimal level of investment in the less cost-effective options. However, a resource allocation model can be designed to address these issues by incorporating the evidence that does exist, by providing options to model multiple reasonable scenarios, and by including user-defined constraints that will ensure equity is respected.

4. Resource allocation in practice

The gap between models developed for academic purposes and models that can be used by decision makers is significant. Although many interventions have been shown to be cost-effective, decision makers, who face budget constraints and other practical considerations, do not have good tools to choose sets of interventions that will yield optimal results for their specific settings (demographics, epidemic characteristics, economic context, etc.) and financing levels.[77, 78]

The United Nations HIV/AIDS Programme (UNAIDS) provides guidelines for planners who want to intensify HIV prevention efforts.[79] In these guidelines, epidemics are classified as low-level, concentrated, generalized, or hyper-endemic, depending on total prevalence and prevalence in key risk groups. Decision makers are advised to “know their epidemic and their current response,” “match and prioritize their response,” “set ambitious, realistic and measurable prevention targets,” “tailor prevention plans,” and “utilize and analyze strategic information.”[79] However, these guidelines are insufficient: although they provide a useful framework for decision makers to analyze their epidemic, they do not fully reflect the complexity present in real-world settings and do not provide specific guidance about which sets of interventions are optimal for each setting.[27, 80]

When guidance is insufficient, decision makers often rely on political interests, personal values, historical patterns, and their own professional experience to allocate resources.[27, 34, 55, 81, 82] While such heuristics can be useful for decision making, they can lead to inconsistencies across time and settings, and to resource allocations that do not maximize health benefit. Ruiz and others[55] noted a lack of consistency in the allocation of federal HIV funds across the United States. Typical prevention funding decisions were made based on “proportionality” to reported AIDS cases. However, this strategy was found to be inadequate for the distribution of prevention resources, since it reflects the past condition of the epidemic and rewards states that are ineffectively managing their resources.[82]

A review of allocation decisions made by HIV Prevention Community Planning Groups (CPGs) in the United States, which are local community planning groups that identify and prioritize unmet HIV prevention needs and interventions to address them,[83] showed that the decision-making process, though a laudable effort, was plagued by insufficient epidemiological information, imperfect correlation between available data and decision outcomes, and lack of consistency across CPGs in the methodology for making decisions.[81] Many CPGs relied on “consensus decision making” based on their members' personal expertise and agenda (which can vary based on membership and location), or assigned “numerical weights” across interventions in order to facilitate the prioritization process. (See Kerr and Tindale[84] for an overview of research on group decision making.) While some CPGs considered the effectiveness of interventions in their decisions, not all of them took into account target population groups. Unfortunately, typical heuristics employed in practice for allocating resources (such as allocating funds in proportion to HIV incidence or reported AIDS cases) are likely to yield sub-optimal results.[55, 85] This highlights the heavy burden CPGs face when making resource allocation decisions and the tradeoff between local insights and a standardized optimal decision process.

Some of the tools available for decision makers, such as the UNAIDS Estimation and Projection Package (EPP) and the Spectrum set of tools are meant only to provide projections of prevalence, incidence, AIDS deaths, treatment needs and numbers of orphans, based on surveillance data and measured epidemic patterns.[86] However, these tools do not model epidemic dynamics, do not specifically include a range of prevention interventions, and are not intended to provide insights into economic costs and benefits of interventions.

Some researchers have developed simple models to address investment in a single type of HIV prevention. For example, the AVERT model (http://www.fhi.org/en/hivaids/pub/guide/avert.htm) is a spreadsheet-based model that estimates the number of HIV infections averted by interventions that aim to reduce sexual transmission of HIV.[87] Another spreadsheet-based model (http://www.futuresinstitute.org/pages/MaleCircumcision.aspx) estimates cost and impact (number of HIV infections averted, change in HIV incidence and prevalence) for different levels of scale up of male circumcision services and for different target populations.[88]

The HIV Prevention Funding Allocation Model (http://www.cdc.gov/hiv/topics/prev_prog/ce/resources.htm), designed for use by CPGs in the US, determines the investment in each priority population group and intervention that maximizes the weighted number of HIV infections averted over a five-year horizon, subject to budget, equity, and other constraints.[89, 90] The model quantifies the effects of multiple interventions in terms of infections averted, as a function of investment, and accounts for variability of intervention effectiveness as a function of HIV prevalence. The model allows decision makers to change constraints so as to determine the tradeoffs between different allocations of prevention funds.

At the global level, aside from decentralized country-level efforts, the most notable comprehensive model currently available to decision makers is the GOALS Model (http://www.policyproject.com/software.cfm?page=Software&ID=GOALS). The model, designed in Microsoft Excel, has a user-friendly interface and allows decision makers to compare the cost and epidemic impact (HIV prevalence, incidence, and infections averted) of various budget allocations between prevention, care, and mitigation.[91] Users input values for multiple parameters describing their local situation. When accurate parameter values are unavailable, the model defaults to a series of standard values. The model uses a simple epidemiological projection based on the size of the susceptible and infected populations, and the probability of transmission between them (calculated based on risk profiles).[92]

The GOALS model represents a notable attempt to create a practical tool for decision makers, has gained widespread use in practice, and has had a significant impact on policy making. However, the model has several limitations. Decreasing/increasing returns to scale of investment are not considered in the model, nor is the impact of combinations of interventions versus single interventions. The model does not capture uncertainty about parameters, which can be problematic if the country's epidemic has characteristics that are very different from the case considered in the default parameters (e.g., importance of different risk groups or transmission modes). Additionally, the GOALS model does not optimize health outcomes (e.g., HIV infections averted or QALYs gained) given the available level of resources. Instead, users must try various budget allocations between interventions, and then compare results, a process that may not lead to the best use of scarce resources.

Of course, even with appropriate planning tools, the success of HIV programs still depends on appropriate targeting and effective implementation. However, better planning is the essential first step towards better HIV control programs.

5. Toward a practical resource allocation model

As we have highlighted, few comprehensive practical tools exist to inform decisions about HIV prevention and treatment scale up. This section presents our recommendations for key features needed in an HIV/AIDS resource allocation model for use by decision makers, identified based on the gaps identified above, previous evaluation of the research on resource allocation for epidemic control,[46] ad hoc and informal discussions with planners and decision makers, and other studies of practical public health planning tools.[93] These characteristics are grouped into three broad categories: input flexibility, technical capability, and usability. No one class of models addresses all categories adequately by default, but any of the more complex types of models described above could be developed to incorporate these features.

The intended end-user of a model with these features is the decision maker in charge of country-level HIV planning (such as a ministry of health or a national HIV response program), but the customization embedded in the model would make it suitable for other levels of planning (regional, local, or NGO-based plans). In practice, multiple entities may be in charge of various parts of the HIV programs, and interventions may have different streams of funding. However, most countries have a coordinated national strategy[1] to which all these entities aim to adhere, so such a model could be used at upper and lower decision making levels.

5.1 Input flexibility

A useful model will be applicable in a variety of geographical and epidemic settings, and will allow for the potential gaps in data that happen in practice.

Capability for parameter customization—Since the HIV epidemic is highly heterogeneous across the world, decision makers must be able to customize model parameters based on local conditions (key demographics, risk groups, epidemic characteristics and transmission modes, economic and political constraints, etc.). The model must also be designed to use epidemiological and behavior information that is collected in practice, so that decision makers are not forced to estimate parameters that are otherwise unavailable. For simplicity, model parameters should be restricted to key epidemic drivers, so as to avoid wasting time and effort in refining values for parameters that have limited impact on the final decision.

Incorporation of uncertainty—Even with a well developed monitoring and surveillance system, there is still a high degree of uncertainty regarding relevant epidemic and behavioral parameters in a region. To partially alleviate these uncertainties, a useful model will incorporate suggestions for typical parameter values found in similar settings. Using a deterministic approach rather than a stochastic approach reduces complexity but, to estimate the impact of uncertainty on model results, sensitivity analysis reports should be made available for informing decision makers about the variability of the recommendations when uncertain parameters vary within reasonable limits.

5.2 Technical capability

An accurate model for resource allocation will incorporate several key technical features.

Epidemic effects—For very short term planning (e.g., one year or less), epidemic effects may not be important. However, for most HIV planning decisions, a longer time horizon must be considered. Thus, a useful resource allocation model must include nonlinearity of epidemic evolution, and the effects of interventions on the parameters driving the epidemic.

Production functions—Consideration of how intervention effectiveness depends on the target population and the level of scale up is an essential part of a practical resource allocation model. A production function can capture the estimated efficacy of the recommended interventions in the given settings, adjusted according to decision maker input. Production functions allow for nonlinearity of intervention effectiveness (e.g., level of behavior change or number of people reached by an intervention) as a function of investment. For example, as people whose behavior is easier to change are reached, it may become increasingly costly to continue expanding coverage. However, it may be critical to reach those people since they engage in risky behaviors the most. Brandeau and others[67] showed that production functions for HIV interventions can be estimated based on a few simple data points.

Effects of combined interventions—A useful model will accurately capture benefit and cost differentials for packages of interventions versus single interventions. For example, there may be synergies in costs if a substitution therapy program for IDUs can be coupled with counseling sessions to improve adherence to HIV treatment. There may also be dependencies in benefits when multiple interventions are implemented. For example, expanded treatment of HIV-infected patients and scaled up risk-reduction programs may both reduce the risk of HIV transmission to uninfected individuals, but the combined programs will likely avert fewer infections than the single programs would if implemented alone (because the same infection cannot be prevented twice).

Incorporation of key constraints—Because of limitations on funding, as well as political, social, legal, and ethical considerations, not all potential allocations of funding are desirable or feasible in every setting. In addition to the goal of maximizing HIV infections averted, decision makers may be concerned with achieving equity among population groups, ensuring a minimum level of treatment access in each population group, or adhering in some way to historical funding allocations.[81, 90] A practical model will allow the decision maker to input not only the total budget constraint, but also any other relevant constraints on allowable allocations of funds.

Optimization capability—A useful model will recommend optimal or near-optimal sets of interventions, based on epidemic characteristics, local realities, and budgetary and other constraints. Optimization finds the resource allocations that maximize health outcomes using mathematical algorithms instead of empirical data, historical patterns, and decision maker experience. Using modeled communities representative of New York and Los Angeles, Zaric and Brandeau[85] showed that typical non-optimization resource allocations (based on prevalence, equity, etc.) differ significantly from those recommended by optimization. The optimized model yielded health benefits that are up to 25–50% higher than those obtained based on typical heuristics used in practice: for example, in a high-prevalence community the model recommended allocating approximately two-thirds of the budget to a needle exchange program and one-third of the budget to a condom availability program targeted to IDUs, whereas splits based on heuristics would have allocated a higher proportion of the budget to the general population. The authors showed that optimal choices are not easily identified by inspection and usually involve sets of interventions, so that even experienced decision makers would be challenged to determine the optimal resource allocation without an optimization model.

Estimation of overall health and economic impact—A useful model will estimate the impact of HIV interventions on the health care system and the resulting resource needs. This allows decision makers to identify key resource gaps (funding, infrastructure, personnel, etc.) and provides important information needed for long-term planning. Also, if the model demonstrates that small budget increases could potentially have large benefits at the health system scale, this information may help prioritize HIV expenditures.

5.3 Usability

The third critical dimension of a practical model is usability.

User-friendly design and structure—A practical model will be easy for decision makers to use and understand. Hence, it must include clear explanations for all relevant model elements, especially those requiring the user to input data or adjust parameters. The model's structure must be easy to follow: the sequence of steps involved in the model's computation should be logical and transparent. The parts that should not be modified by the users should be clearly labeled, to avoid accidental changes that will impact the model in unwanted ways. However, making the entire structure opaque to the user and providing just the final results is undesirable, since this may limit adoption and create distrust. Ensuring that decision makers understand how the model works provides them with strong arguments to support the proposed allocations.

Accessibility—Accessibility to decision makers in all settings is an essential requirement for a model that can be widely adopted in practice. Thus, a practical planning model must be made publicly available (for example, via the worldwide web) and must be easy to adopt by end users. This means that the software package required to run the model must be readily available and easy to use. Spreadsheet models are ideal for such a purpose, but other types of models may work well, too. Simple planning models have been developed and made publicly available for a variety of public health planning purposes such as pandemic influenza planning[94, 95] and design of mass prophylaxis, vaccination, and dispensing centers.[96, 97] A similar effort for HIV resource allocation could provide enormous benefits.

Calibration and validation tools—The model design should include features that allow for easy verification of key model parameters and outputs using independent sources (e.g., the size of key risk populations and HIV incidence and prevalence in each, etc.). Providing credible and verifiable insights to decision makers helps to increase trust in such a model and thus increase adoption.

6. Conclusion

The global HIV epidemic continues to grow, and much remains to be accomplished in order to reach the Millennium Development Goal of achieving universal access to HIV treatment for all those who need it by 2010 and halting the spread of HIV by 2015. These ambitious goals require a significant scale up of global HIV prevention and treatment efforts, but little guidance exists to help decision makers make the best use of limited HIV prevention and treatment resources. Ongoing efforts are underway to better understand the HIV epidemic and response to the epidemic in different regions of the world;[98] now the challenge is to use that information to improve the response to HIV in each country. We have identified the key limitations of the resource allocation literature, and the progress still needed to translate such concepts into practical tools. Resource allocation theory has made and can continue to make a significant contribution to decision making about HIV prevention and treatment scale up. What remains now is to develop more models that can bridge the gap between theory and practice.

Acknowledgments

This research was funded by the National Institute on Drug Abuse, Grant Number R01-DA15612. Sabina Alistar is also supported by a Stanford Graduate Fellowship.

Financial support for this study was provided by the National Institute on Drug Abuse, Grant Number R01-DA15612, and by a Stanford Graduate Fellowship. The funding agreement ensures the authors' independence in designing the study, interpreting the data, and writing and publishing the report.

References

[1]. World Health Organization (WHO). 2008 Report on the Global AIDS Epidemic. World Health Organization; Geneva: 2008.

[2]. Merson MH. The HIV-AIDS pandemic at 25 -- the global response. N Engl J Med. Jun 8; 2006 354(23):2414–7. [PubMed: 16760441]

[3]. United Nations (UN). The Millennium Development Goals Report 2009. United Nations; New York, NY: 2009.

[4]. United Nations (UN). United Nations Millennium Declaration. UN; New York: 2000.

[5]. Joint United Nations Programme on HIV/AIDS (UNAIDS). What Countries Need: Investments Needed for 2010 Targets. UNAIDS; Geneva: 2009.

[6]. Celentano DD, Davis WW, Beyrer C. Epidemiology of HIV/AIDS in low- and middle-income countries: where global AIDS is and where it is going. Public Health Aspects of HIV/AIDS in Low and Middle Income Countries. 2008:3–17.

[7]. World Health Organization (WHO). Towards Universal Access: Scaling Up Priority HIV/AIDS Interventions in the Health Sector - Progress Report 2009. WHO; Geneva: 2009.

[8]. Stover J, Bertozzi S, Gutierrez J-P, Walker N, Stanecki KA, Greener R, et al. The global impact of scaling up HIV/AIDS prevention programs in low- and middle-income countries. Science. March 10; 2006 311(5766):1474–6. 2006. [PubMed: 16456039]

[9]. World Health Organization (WHO). Joint United Nations Programme on HIV/AIDS (UNAIDS). UNICEF. Towards Universal Access: Scaling Up Priority HIV/AIDS Interventions in the Health Sector. World Health Organization, UNAIDS, UNICEF; Geneva: 2008.

[10]. Global HIV Prevention Working Group. Bringing HIV Prevention to Scale: An Urgent Global Priority. Global HIV Prevention Working Group; Washington, DC: 2007.

[11]. Merson MH, O'Malley J, Serwadda D, Apisuk C. The history and challenge of HIV prevention. Lancet. Aug 15; 2008 372(9637):475–88. [PubMed: 18687461]

[12]. Coates TJ, Richter L, Caceres C. Behavioural strategies to reduce HIV transmission: how to make them work better. Lancet. Aug 29; 2008 372(9639):669–84. [PubMed: 18687459]

[13]. Piot P, Bartos M, Larson H, Zewdie D, Mane P. Coming to terms with complexity: a call to action for HIV prevention. Lancet. Sep 12; 2008 372(9641):845–59. [PubMed: 18687458]

[14]. Horton R, Das P. Putting prevention at the forefront of HIV/AIDS. Lancet. Aug 15; 2008 372(9637):421–2. [PubMed: 18687463]

[15]. Collins C, Coates TJ, Curran J. Moving beyond the alphabet soup of HIV prevention. AIDS. 2008; 22(Suppl(2)):S5–S8. [PubMed: 18641471]

[16]. Joint United Nations Programme on HIV/AIDS (UNAIDS). [Jul 22, 2009] Resource Needs for an Expanded Response to AIDS in Low- and Middle-Income Countries. 2005. Accessed at <http://data.unaids.org/publications/irc-pub06/resourceneedsreport_en.pdf>

[17]. Schmid, C.; McColl, W. The AIDS Drug Assistance Program: Securing HIV/AIDS Drugs for the Nation's Poor and Uninsured. The AIDS Institute and the AIDS Action Foundation; Washington, DC: 2008.

[18]. Bassett IV, Farel C, Szmuilowicz ED, Walensky RP. HIV/AIDS: AIDS Drug Assistance Programs in the era of routine HIV testing. Clin Inf Dis. 2008; 47(5):695–701.

[19]. The World Bank. Averting a Human Crisis During the Global Downturn: Policy Options from the World Bank's Human Development Network. The World Bank; Washington, DC: 2009.

[20]. Joint United Nations Programme on HIV/AIDS (UNAIDS). HIV Prevention Needs and Successes: A Tale of Three Countries. An update on HIV Prevention Success in Senegal, Thailand and Uganda. UNAIDS; Geneva: 2001.

[21]. Committee on HIV Prevention Strategies in the United States. No Time To Lose: Getting More from HIV Prevention. Institute of Medicine, Division of Health Promotion and Disease Prevention; Washington, DC: 2001.

[22]. Kerr T, Wodak A, Elliott R, Montaner JS, Wood E. Opioid substitution and HIV/AIDS treatment and prevention. Lancet. Dec 3; 2004 364(9449):1918–9. [PubMed: 15566992]

[23]. Gibson DR, Flynn NM, Perales D. Effectiveness of syringe exchange programs in reducing HIV risk behavior and HIV seroconversion among injecting drug users. AIDS. 2001; 15(11):1329–41. [PubMed: 11504954]

[24]. McFarlane DR. Reproductive health policies in President Bush's second term: old battles and new fronts in the United States and internationally. J Public Health Policy. 2006; 27(4):405–26. [PubMed: 17164806]

[25]. Anonymous. HIV prevention policy needs an urgent cure. Lancet. Apr 15.2006 367(9518):1213. [PubMed: 16631857]

[26]. Nelson R. Report shows mixed results for PEPFAR. Lancet Infect Dis. 2006; 6(4):194.

[27]. Bertozzi SM, Laga M, Bautista-Arredondo S, Coutinho A. Making HIV prevention programmes work. Lancet. Sep 12; 2008 372(9641):831–44. [PubMed: 18687457]

[28]. Hogan DR, Baltussen R, Hayashi C, Lauer JA, Salomon JA. Cost effectiveness analysis of strategies to combat HIV/AIDS in developing countries. BMJ. Dec 17; 2005 331(7530):1431–7. [PubMed: 16282380]

[29]. Hillier, FS.; Lieberman, GJ. Introduction to Operations Research. McGraw-Hill; Boston: 2005.

[30]. Lasry A, Richter A, Lutscher F. Recommendations for increasing the use of HIV/AIDS resource allocation models. BMC Public Health. Nov 18.2009 9(Suppl 1):S8. [PubMed: 19922692]

[31]. Lasry A, Carter MW, Zaric GS. S4HARA: System for HIV/AIDS resource allocation. Cost Eff Resour Alloc. 2008; 6:7. [PubMed: 18366800]

[32]. Kermack WO, McKendrick AG. Contributions to the mathematical theory of epidemics, Part I. Proceedings of the Royal Statistical Society, Series A. 1927; 115:700–21.

[33]. Kermack WO, McKendrick AG. Contributions to the mathematical theory of epidemics, Part II. Proceedings of the Royal Statistical Society, Series A. 1932; 138:55–83.

[34]. Kaplan, EH. Economic evaluation and HIV prevention community planning: a policy analyst's perspective. In: Holtgrave, DR., editor. Handbook of Economic Evaluation of HIV Prevention Programs. Plenum Press; New York: 1998.

[35]. Hethcote HW. The mathematics of infectious diseases. SIAM Review. 2000; 42(4):599–653.

[36]. Hethcote HW. Qualitative analyses of communicable disease models. Math Biosci. 1976; 28:335–56.

[37]. Wickwire K. Mathematical models for the control of pests and infectious diseases: A survey. Theoretical Population Biology. 1977; 11(2):182–238. [PubMed: 325679]

[38]. Sethi SP. Optimal quarantine programmes for controlling an epidemic spread. J Operational Res Soc. 1978; 29(3):265–8.

[39]. Sethi SP, Preston WS. Optimal control of some simple deterministic epidemic models. J Operational Res Soc. 1978; 29(2):129–36.

[40]. Greenhalgh D. Control of an epidemic spreading in a heterogeneously mixing population. Math Biosci. 1986; 80(1):23–45.

[41]. Friedrich, CM.; Brandeau, ML. Using simulation to find optimal funding levels for HIV prevention programs with different costs and effectiveness. In: Anderson, JG.; Katzper, M., editors. Proceedings of the 1998 Medical Sciences Simulation Conference; San Diego, CA. Society for Computer Simulation International; 1998. 1998

[42]. Richter A, Brandeau ML, Owens DK. An analysis of optimal resource allocation for prevention of infection with human immunodeficiency virus (HIV) in injection drug users and non-users. Med Decis Making. April 1; 1999 19(2):167–79. 1999. [PubMed: 10231079]

[43]. Revelle C, Feldmann F, Lynn W. An optimization model of tuberculosis epidemiology. Manage Sci. 1969; 16(4):B190–B211.

[44]. Longini IM, Ackerman E, Elveback LR. An optimization model for influenza A epidemics. Math Biosci. 1978; 38(1–2):141–57.

[45]. Hethcote HW, Yorke JA, Nold A. Gonorrhea modeling: a comparison of control methods. Math Biosci. 1982; 58(1):93–109.

[46]. Brandeau, ML. Allocating resources to control infectious diseases. In: Brandeau, ML.; Sainfort, F.; Pierskalla, WP., editors. Operations Research and Health Care: Methods and Applications. Kluwer Academic Publishers; Norwell, MA: 2004. p. 443-64.

[47]. Zaric GS. Resource allocation for control of infectious disease epidemics. Comments on Theoretical Biology. 2003; 8:475–96.

[48]. Dandona L, Kumar SP, Ramesh Y, Rao MC, Kumar AA, Marseille E, et al. Changing cost of HIV interventions in the context of scaling-up in India. AIDS. Jul; 2008 22(Suppl 1):S43–9. [PubMed: 18664952]

[49]. Dandona L, Sisodia P, Kumar S, Ramesh Y, Kumar A, Rao M, et al. HIV prevention programmes for female sex workers in Andhra Pradesh, India: outputs, cost and efficiency. BMC Public Health. 2005; 5:98. [PubMed: 16181491]

[50]. Guinness L, Kumaranayake L, Hanson K. A cost function for HIV prevention services: is there a 'u' -shape? Cost Eff Resour Alloc. Nov 5.2007 5:13. [PubMed: 17983475]

[51]. Kaplan EH. Economic analysis of needle exchange. AIDS. 1995; 9(10):1113–9. [PubMed: 8519446]

[52]. Marseille E, Dandona L, Marshall N, Gaist P, Bautista-Arredondo S, Rollins B, et al. HIV prevention costs and program scale: data from the PANCEA project in five low and middle-income countries. BMC Health Services Research. 2007; 7(1):108. [PubMed: 17626616]

[53]. Kim SY, Goldie SJ. Cost-effectiveness analyses of vaccination programmes. Pharmacoeconomics. 2008; 26(3):191–215. [PubMed: 18282015]

[54]. Long, EF.; Brandeau, ML. OR's next top model: Decision models for infectious disease control. In: Gray, P., editor. TutORials in Operations Research. Institute for Operations Research and the Management Sciences (INFORMS); Baltimore, MD: 2009. p. 123-38.

[55]. Ruiz, M.; Gable, A.; Kaplan, EH.; Stoto, M.; Fineberg, H.; Trussell, J., editors. No Time to Lose: Getting More from HIV Prevention. National Academy Press; Washington, DC: 2001.

[56]. Martello, S.; Toth, P. Knapsack Problems: Algorithms and Computer Implementations. Wiley; New York: 1990.

[57]. Kaplan EH, Pollack H. Allocating HIV prevention resources. Socio-Econ Plann Sci. 1998; 32(4): 257–63.

[58]. Kahn JG. The cost-effectiveness of HIV prevention targeting: how much more bang for the buck? Am J Public Health. December 1; 1996 86(12):1709–12. 1996. [PubMed: 9003125]

[59]. Paltiel, D. Timing is of the essence - Matching AIDS policy to the epidemic life cycle. In: Kaplan, EH.; Brandeau, ML., editors. Modeling the AIDS Epidemic: Planning, Policy, and Prediction. Raven Press, Ltd.; New York, NY: 1994.

[60]. Zaric GS, Brandeau ML. Resource allocation for epidemic control over short time horizons. Math Biosci. 2001; 171(1):33–58. [PubMed: 11325383]

[61]. Anderson, RM.; May, RM. Infectious Diseases of Humans: Dynamics and Control. Oxford University Press; Oxford: 1991.

[62]. Bernstein RS, Sokal DC, Seitz ST, Auvert B, Stover J, Naamara W. Simulating the control of a heterosexual HIV epidemic in a severely affected East African city. Interfaces. 1998; 28(3):101–26.

[63]. Robinson NJ, Mulder DW, Auvert B, Hayes RJ. Modelling the impact of alternative HIV intervention strategies in rural Uganda. AIDS. 1995; 9(11):1263–70. [PubMed: 8561980]

[64]. Bautista-Arredondo S, Gadsden P, Harris JE, Bertozzi SM. Optimizing resource allocation for HIV/AIDS prevention programmes: an analytical framework. AIDS. 2008; 22:S67–S74. [PubMed: 18664956]

[65]. Brandeau ML, Zaric GS. Optimal investment in HIV prevention programs: more is not always better. Health Care Manage Sci. 2009; 12(1):27–37.

[66]. Kumaranayake L. The economics of scaling up: cost estimation for HIV/AIDS interventions. AIDS. 2008; 22:S23–S33. [PubMed: 18664950]

[67]. Brandeau ML, Zaric GS, De Angelis V. Improved allocation of HIV prevention resources: Using information about prevention program production functions. Health Care Manage Sci. 2005; 8(1):19–28.

[68]. Castilla J, del Romero J, Hernando V, Marincovich B, Garcia S, Rodriguez C. Effectiveness of highly active antiretroviral therapy in reducing heterosexual transmission of HIV. J AIDS. 2005; 40(1):96–101.

[69]. Egger M, May M, Chêne G, Phillips AN, Ledergerber B, Dabis F, et al. Prognosis of HIV-1-infected patients starting highly active antiretroviral therapy: a collaborative analysis of prospective studies. Lancet. 2002; 360(9327):119–29. [PubMed: 12126821]

[70]. Grabar S, Moing VL, Goujard C, Leport C, Kazatchkine MD, Costagliola D, et al. Clinical outcome of patients with HIV-1 infection according to immunologic and virologic response after 6 months of highly active antiretroviral therapy. Ann Intern Med. Sep 19; 2000 133(6):401–10. [PubMed: 10975957]

[71]. Royce RA, Sena A, Cates W, Cohen MS. Sexual transmission of HIV. N Engl J Med. Apr 10; 1997 336(15):1072–8. [PubMed: 9091805]

[72]. Wood E, Hogg RS, Yip B, Harrigan PR, O'Shaughnessy MV, Montaner JSG. Effect of medication adherence on survival of HIV-infected adults who start highly active antiretroviral therapy when the CD4+ cell count is 0.200 to 0.350 × 109 cells/L. Ann Intern Med. Nov 18; 2003 139(10):810–6. [PubMed: 14623618]

[73]. Cleary SM, McIntyre D, Boulle AM. Assessing efficiency and costs of scaling up HIV treatment. AIDS. 2008; 22(Suppl(1)):S35–S42. [PubMed: 18664951]

[74]. Broomberg J, Söderlund N, Mills A. Economic analysis at the global level: a resource requirement model for HIV prevention in developing countries. Health Policy. 1996; 38(1):45–65. [PubMed: 10160163]

[75]. El-Sadr WM, Abrams EJ. Scale-up of HIV care and treatment: Can it transform healthcare services in resource-limited settings? AIDS. Oct; 2007 21(Suppl 5):S65–70. [PubMed: 18090271]

[76]. Gupta GR, Parkhurst JO, Ogden JA, Aggleton P, Mahal A. Structural approaches to HIV prevention. Lancet. Sep 5; 2008 372(9640):764–75. [PubMed: 18687460]

[77]. Rauner MS, Brandeau ML. AIDS policy modeling for the 21st century: An overview of key issues. Health Care Manage Sci. 2001; 4(3):165–80.

[78]. Hirschhorn LR, Ojikutu B, Rodriguez W. Research for change: Using implementation research to strengthen HIV care and treatment scale-up in resource-limited settings. J Infect Dis. 2007; 196(s3):S516–S22. [PubMed: 18181704]

[79]. Joint United Nations Programme on HIV/AIDS (UNAIDS). UNAIDS Practical Guidelines for Intensifying HIV Prevention - Towards Universal Access. UNAIDS; Geneva: 2007.

[80]. Wilson D, Halperin DT. "Know your epidemic, know your response": a useful approach, if we get it right. Lancet. Aug 15; 2008 372(9637):423–6. [PubMed: 18687462]

[81]. Johnson-Masotti AP, Pinkerton SD, Holtgrave DR, Valdiserri RO, Willingham M. Decision-making in HIV prevention community planning: An integrative review. J Community Health. 2000; 25(2):95–112. [PubMed: 10794204]

[82]. Kaplan EH, Merson MH. Allocating HIV-prevention resources: balancing efficiency and equity. Am J Public Health. Dec; 2002 92(12):1905–7. [PubMed: 12453805]

[83]. Centers for Disease Control and Prevention. [Jun 14, 2010] HIV Prevention Community Planning Process. 2006. Accessed at http://www.cdc.gov/hiv/topics/cba/resources/guidelines/hivcp/section3.htm

[84]. Kerr NL, Tindale RS. Group performance and decision making. Ann Rev Psychol. Feb.2004 55:623–55. [PubMed: 14744229]

[85]. Zaric GS, Brandeau ML. Optimal investment in a portfolio of HIV prevention programs. Med Decis Making. October 1; 2001 21(5):391–408. 2001. [PubMed: 11575489]

[86]. Joint United Nations Programme on HIV/AIDS (UNAIDS). [Jun 14, 2010] Epidemiological Software and Tools. 2009. Accessed at http://www.unaids.org/en/KnowledgeCentre/HIVData/Epidemiology/EPI_software2009.asp

[87]. Family Health International. [Sep 10, 2009] AVERT: A Tool for Estimating Intervention Effects on the Reduction of HIV Transmission. 2009. Accessed at <http://www.fhi.org/en/hivaids/pub/guide/avert.htm>

[88]. Futures Institute. [Sep 10, 2009] Decision-Makers' Programme Planning Tool for Male Circumcision Scale-up. 2009. Accessed at <http://www.futuresinstitute.org/pages/MaleCircumcision.aspx>

[89]. Earnshaw SR, Hicks K, Richter A, Honeycutt A. A linear programming model for allocating HIV prevention funds with state agencies: a pilot study. Health Care Manage Sci. Sep; 2007 10(3): 239–52.

[90]. Richter A, Hicks KA, Earnshaw SR, Honeycutt AA. Allocating HIV prevention resources: a tool for state and local decision making. Health Policy. Sep; 2008 87(3):342–9. [PubMed: 18342388]

[91]. Stover, J.; Bollinger, L.; Cooper-Arnold, K. GOALS Model for Estimating the Effects of Resource Allocation Decisions on the Achievement of the Goals of the HIV/AIDS Strategic Plan. The Futures Group International; Washington, DC: 2003.

[92]. Stover J, Walker N, Garnett GP, Salomon JA, Stanecki KA, Ghys PD, et al. Can we reverse the HIV/AIDS pandemic with an expanded response? Lancet. 2002; 360:73. [PubMed: 12114060]

[93]. Brandeau ML, McCoy JH, Hupert NA, Holty J-E, Bravata DM. Recommendations for modeling crisis response in public health and medicine: A position paper of the Society for Medical Decision Making. Med Decis Making. 2009; 29:438–60. [PubMed: 19605887]

[94]. Centers for Disease Control and Prevention. [Jul 22, 2009] FluSurge 2.0. 2006. Accessed at <http://www.cdc.gov/flu/tools/flusurge/>

[95]. Centers for Disease Control and Prevention. [Jul 22, 2009] FluAid 2.0. 2000. Accessed at www.cdc.gov/flu/tools/fluaid <http://www.cdc.gov/flu/tools/fluaid>

[96]. Agency for Healthcare Research and Quality. [Sep 10, 2009] The Weill/Cornell Bioterrorism and Epidemic Outbreak Response Model (BERM). 2003. Accessed at <http://www.ahrq.gov/research/biomodel/index.asp>

[97]. [Apr 13, 2010] University of Maryland and the Advanced Practice Center for Public Health Emergency Preparedness and Response of Montgomery County Maryland. Software for improving mass dispensing and vaccination clinic operations. 2008. Accessed at <http://www.isr.umd.edu/Labs/CIM/projects/clinic/software.html>

[98]. Colvin, M.; Gorgens-Albino, M.; Kasedde, S. [Sep 10, 2009] Analysis of HIV prevention response and modes of transmission: The UNAIDS-GAMET supported synthesis process. 2008. Accessed at www.unaidsrstesa.org/files/MoT_0.pdf <http://www.unaidsrstesa.org/files/MoT_0.pdf>

Table 1

Examples of academic models of HIV resource allocation

	Description	Objective	Intervention(s) Considered	Production Functions
Linear models				
Kaplan and others[55]	A simple model with linear HIV epidemic growth	Maximize infections averted subject to a fixed budget	Prevention programs targeted to independent high-risk populations	Linear
Kaplan[34]	A simple model with linear HIV epidemic growth that incorporates general production functions	Maximize infections averted subject to a fixed budget	Prevention programs targeted to independent high-risk populations	General
Dynamic models				
Kahn[58]	A dynamic model of HIV in multiple independent populations	Evaluate infections averted for different allocations of a fixed budget	Prevention programs targeted to independent high-, medium- or low-risk populations, early or late in an epidemic	Linear
Paltiel[59]	A dynamic model of HIV in a single population	Evaluate cost per QALY saved	Prevention programs targeted to infected or susceptible individuals in a single population, or general prevention programs, early or late in an epidemic	Linear
Richter and others[42]	A dynamic model of HIV in two independent populations	Maximize infections averted subject to a fixed budget	Prevention programs targeted to independent populations, one low risk and one high risk	General
Zaric and Brandeau[60]	A theoretical model with dynamic epidemic growth that allows for multiple interacting sub-populations and general types of interventions	Maximize infections averted or QALYs gained subject to a fixed budget	General interventions that can change any epidemic parameters	General
Simulation models				
Bernstein and others[62]	A simulation model of HIV in a severely affected east African city	Evaluate HIV prevalence and incidence	Prevention programs	Linear
Robinson and others[63]	A simulation model of HIV and two other sexually transmitted diseases (STDs) in rural Uganda	Evaluate HIV infections averted, HIV prevalence, HIV incidence	Prevention programs	Linear
Hogan and others[28]	A simulation model of HIV and other STDs in sub-Saharan Africa and Southeast Asia	Evaluate effectiveness and cost-effectiveness (cost/DALY averted)	Prevention and treatment programs	Linear