Cost-Effectiveness and the Role of Socioeconomic Support Services in Ending the HIV/AIDS Epidemic in the United States

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Abstract

There is still no cure for human immunodeficiency virus (HIV), meaning infected individuals must remain on lifelong treatment. While the United States has made substantial progress on HIV prevention, there are still more than 1.2 million people living with HIV (PLWH) in the U.S. and prevalence continues to increase. Treatment not only extends life expectancy and improves quality of life for PLWH, it also reduces the risk of HIV transmission by suppressing HIV viral loads to undetectable levels. However, only 58% of diagnosed PLWH in the U.S. were retained in care and only 66% were virally suppressed in 2019, which is well-below the National HIV/AIDS Strategy goal of reaching 95% viral suppression and ending the HIV epidemic by 2030.

This dissertation summarizes existing evidence on the cost-effectiveness of improving retention in HIV care. It then presents new findings on the potential costs, benefits, and cost-effectiveness of socioeconomic support services funded by the U.S. Ryan White HIV/AIDS Program (RWHAP), the largest federally funded program focused on HIV care for low-income populations. Specific aims are to:

1) Systematically review evidence on the cost-effectiveness of HIV retention and re-engagement interventions. A systematic review of literature published in the past 10 years on retention interventions in high-income settings was conducted. Findings on methods, cost-effectiveness, quality, and overall strength of evidence were summarized.

2) Estimate the impact of support services on sustained viral suppression among low-income PLWH. Five years (2015-2019) of RWHAP data from the Minneapolis-St. Paul region was analyzed. Logistic and linear regressions using generalized estimating equations and propensity scores to adjust for the probability of service use were used to estimate the causal effect of support service use on sustained viral suppression.

3) Investigate the barriers, opportunities, and potential costs of expanding HIV socioeconomic support services. Semi-structured interviews were conducted with service providers in Minneapolis-St. Paul to explore current barriers, potential opportunities, estimated costs, and anticipated outcomes of program expansion for food, financial, transportation, and housing support services for low-income people living with HIV.

4) Evaluate the potential cost-effectiveness of expanding food aid vouchers to fill unmet need. An individual-based microsimulation model of post-diagnosis HIV care was developed and

parameterized to reflect the RWHAP client population in the Minneapolis-St. Paul region. Using results from Aims 2 and 3, the model was used to estimate the potential cost-effectiveness of expanding food aid vouchers. Preliminary results from the base case and relevant sensitivity and scenario analyses are reported.

Outcomes from this project provide support for continued funding of programs that address socioeconomic challenges for PLWH and can be used to inform local resource allocation decisions for HIV care. Socioeconomic support programs such as food aid, financial assistance, housing, and transportation could be integrated into multifaceted strategies aimed at improving HIV outcomes and achieving national HIV treatment goals.

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Introduction

Clinical Context: Human immunodeficiency virus (HIV) emerged in the 1980s as a novel disease and quickly became a public health crisis. HIV is primarily transmitted through unprotected sex and shared needles.[1] The virus replicates and attacks immune cells in the body known as CD4 cells. This leads to high viral loads and low CD4 counts, both of which can be measured with routine blood testing. Without treatment, HIV develops into acquired immunodeficiency syndrome (AIDS), which has a high risk of serious illness and death.

Effective treatment known as antiretroviral therapy (ART) was introduced in 1996 and substantially decreased the number of people dying from HIV/AIDS. Current ART regimens greatly increase the life expectancy and quality of life for people living with HIV (PLWH) when taken daily. Adherence to ART can increase a person's CD4 count by reducing HIV viral load in the body. In individuals where ART suppresses their viral load to undetectable levels, transmission to uninfected individuals is highly unlikely. Treatment therefore has a dual purpose: improving the health of PLWH and preventing new infections. Undetectable viral load, also known as viral suppression, is the treatment goal for PLWH. Routinely seeing an HIV provider for treatment and monitoring is critical to supporting treatment adherence, monitoring drug resistance, preventing treatment failure, and achieving viral suppression.

Policy Context: With over 1.2 million individuals currently infected in the US, HIV costs approximately $28 billion per year in federal funding.[2] Infections have declined to an estimated 22,300 new infections in 2021,[3] yet with no cure, the number of people requiring lifelong treatment continues to grow. HIV care is typically conceptualized as occurring in steps from being undiagnosed to achieving viral suppression. A care continuum framework measures these steps and tracks the percentage of PLWH who are diagnosed, linked to care, received some care, retained in care, and virally suppressed. The Centers for Disease Control and Prevention (CDC) uses the following definitions:[4]

- Diagnosed: Percent of the estimated number of PLWH who have been diagnosed.
- Linked to Care: Percent of people who received an HIV diagnosis and had one or more CD4 or viral load lab tests *within 30 days* of diagnosis.
- Received Care: Percent of people diagnosed who have had at least 1 CD4 or viral load test.

- Retained in Care: Percent of people diagnosed with HIV who have had 2 or more CD4 or viral load tests conducted at least three months apart in the past year.
- Virally Suppressed: Percent of people diagnosed with HIV whose most recent viral load test result was undetectable (<200 copies/mL).

In 2019, the CDC estimated 87% of PLWH were diagnosed, and of those diagnosed, 76% received some HIV care, 58% were retained in care,[i] and 66% were virally suppressed.[5] These viral suppression rates are well-below National HIV/AIDS Strategy and Ending the HIV Epidemic goals of having at least 95% of diagnosed PLWH be virally suppressed.[6,7] Progress towards viral suppression goals has been slow: viral suppression rates increased from 63% in 2017 to 66% in 2019.[3] To achieve national goals, limited resources need to be allocated to evidence-based interventions that are both affordable and efficient.

The federal Ryan White HIV/AIDS Program (RWHAP) was established in 1990 and is a key funder in the U.S., funding both medical services and support services for approximately 500,000 PLWH.[8] The program plays an important role in HIV care, particularly for low-income PLWH who are disproportionally affected by HIV.[9] Prior studies have shown that socioeconomic conditions, such as food insecurity, housing insecurity, and financial insecurity can be substantial barriers to achieving retention in care and viral suppression.[10–12] However, the U.S. approach to ending the HIV epidemic largely focuses on biomedical approaches to improving treatment and prevention, without directly addressing prominent social determinants of health.[13] Services that address socioeconomic challenges have the potential to improve HIV outcomes, particularly if paired with evidence-based biomedical interventions.[14]

Cost-Effectiveness, Costs, and Gaps in Knowledge: Cost-effectiveness analysis (CEA) is a framework for evaluating and comparing the costs and benefits of healthcare interventions. It can inform resource allocation decisions such that limited resources are invested in interventions that most efficiently gain health. Cost-effectiveness is typically measured with incremental cost-effectiveness ratios (ICERs) where the numerator is incremental costs and the denominator is incremental quality-adjusted life years (QALYs) of one intervention compared to another. ICERs estimate the cost per additional QALY of moving from less expensive, less beneficial

[i] Note: It is common for viral suppression rates to be higher than retention in care rates due to how these metrics are defined. Retention in care is defined as have 2+ tests greater than three months apart during the year. Viral suppression is defined as having the most recent test in the year be suppressed. It is possible that some people only have records of one viral load test in a year.

interventions to more expensive, more beneficial ones. In the United States, a healthcare intervention is typically considered cost-effective if it has an ICER between $50,000- $150,000 per QALY gained.[15]

Prior research and policy work on cost-effectiveness in HIV has largely focused on HIV prevention, including cost-effectiveness of HIV screening and pre-exposure prophylaxis. Few studies have evaluated the cost-effectiveness of retention in care strategies or strategies focused on addressing patient socioeconomic needs. This may be due in part to lack of available data on costs associated with these programs as well as limited evidence on program effectiveness.

This project sought to address several of these gaps. Aim 1 systematically reviewed evidence from existing CEAs on retention in care to summarize prior findings and identify gaps in the research agenda. Aim 2 estimated the causal effect of RWHAP-funded services on achieving sustained viral suppression. Aim 3 estimated the potential costs of expanding programs that address socioeconomic needs of PLWH. Aim 4 leveraged findings from the prior aims to conduct a CEA focused on expanding a RWHAP-funded socioeconomic program (food vouchers) to fill unmet need among eligible PLWH.

Aim 1: To systematically review the cost-effectiveness of HIV retention and re-engagement interventions in high-income countries

Cost-Effectiveness of HIV Retention and Re-engagement Interventions in High-Income Countries: A Systematic Literature Review

Overview

Engagement in lifelong HIV care is critical for both patient and public health, yet there are limited resources to invest in improving HIV outcomes. We systematically reviewed evidence on the cost-effectiveness of retention and re-engagement interventions. We searched five databases for peer-reviewed studies published between 2010-2020. We assessed reporting and methods quality, extracted data on target populations, interventions, and cost-effectiveness, and evaluated overall strength of evidence. Eleven studies met inclusion criteria, and eight had moderate-high quality. Cost-effectiveness estimates ranged from cost-saving to over $1,000,000/quality-adjusted life year (QALY) gained. Of the 73 cost-effectiveness ratios reported, 64% were <$100,000/QALY gained. Interventions were more likely to be cost-effective when targeted to high-risk groups, implemented in locations where baseline retention levels were low, and when used in combination with other high-impact HIV interventions (such as prevention). Overall, existing evidence is moderately strong that retention and/or re-engagement interventions can be cost-effective in high-income countries.

Introduction

There is still no cure for human immunodeficiency virus (HIV), meaning infected individuals must remain on lifelong treatment. High-income countries have made substantial progress on HIV prevention, with new infections dropping dramatically since their peak in the 1980s and 1990s. However, there are still more than 2.3 million people living with HIV (PLWH) in high-income countries, and prevalence continues to rise.[16] Patients who are retained in care have reduced morbidity and mortality, decreased risk of hospitalization, lower rates of acquired immunodeficiency syndrome (AIDS) progression, and overall improved health.[17] Achieving high rates of retention is therefore a key part of HIV/AIDS strategies in many countries. UNAIDS 90-

90-90 goals aim to have 90% of diagnosed PLWH receiving sustained antiretroviral therapy (ART),[18] while the United States National HIV/AIDS Strategy for 2021-2025 has objectives to identify, engage, or reengage PLWH and to increase retention in care and adherence to ART. The U.S. strategy specifically aims to have 95% of people diagnosed with HIV virally suppressed, up from a baseline of 63% in 2017.[6]

There are several published interventions aimed at improving retention and re-engagement in HIV care: an overview of systematic reviews found 39 reviews that reported on retention interventions in high-income countries.[19] Likewise the U.S. Centers for Disease Control and Prevention (CDC) maintains a compendium of evidence-based HIV interventions that currently has 29 interventions shown to improve linkage, retention, and/or re-engagement.[20] Interventions include strategies such as connecting HIV patients with case managers to help them overcome barriers to HIV care and electronic medical record alerts to notify providers of patients who have not been seen recently. With several effective interventions available and limited budgets, decision makers must choose how to invest in improving patient engagement in care.

Cost-effectiveness analysis evaluates and compares the costs and benefits of interventions to determine which interventions most efficiently improve health. Even though policy makers ultimately need to make decisions based on local budgets as well as local social, political, and epidemiological contexts, cost-effectiveness is a useful method for determining what interventions provide good value and could be considered as potential options. Several systematic reviews of cost-effectiveness have been conducted for HIV interventions and policies, including ART adherence,[21] screening in high-income countries,[22] screening during pregnancy,[23] prevention interventions in the U.S.,[24] prevention more generally,[25] and pre-exposure prophylaxis.[26–28], yet none have focused on retention and re-engagement. As the world works towards reaching HIV/AIDS goals, the cost-effectiveness of HIV engagement strategies will be important to consider. Our objective was to systematically review the evidence on cost-effectiveness of HIV retention and re-engagement in high-income countries to answer two questions: 1) What interventions and populations are being assessed in cost-effectiveness studies on retention and re-engagement interventions? 2) Are these interventions cost-effective?

Methods

We followed Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) guidelines for this review.[29]

Search & Selection: We searched MEDLINE (via Ovid), Pubmed, EMBASE, EconLit, and Web of Science for relevant articles using a combination of Medical Sub-Heading (MeSH) terms and keywords (Appendix Table 1). Search algorithms were adapted for EconLit and Web of Science, and were vetted by a public health librarian. Searches were limited to English language articles published between January 2010 through October 2020 to capture most recent literature. References of included articles and relevant reviews were manually searched to identify additional articles. Titles and abstracts were screened for initial inclusion by two reviewers (MW, GK). Articles identified as relevant by either reviewer proceeded to full-text screening. Two reviewers independently assessed full-text articles for inclusion, and disagreements were resolved in consensus with a third reviewer (EE). Studies were included if they assessed the cost-effectiveness of an intervention aimed at improving retention and/or re-engagement in care for any PLWH, reported a quantitative cost-effectiveness estimate using quality-adjusted life years (QALYs) as the measure of benefit, and took place in a high-income country, defined as Organisation for Economic Cooperation and Development (OECD) member countries. Conference abstracts, letters, and non-peer reviewed articles were excluded; grey literature was not assessed. We defined retention interventions as those that aim to keep people in routine HIV care (typically seeing a HIV provider every 3-6 months) and re-engagement interventions as those that encourage people who have dropped out of care to restart routine HIV care. These are distinct from adherence interventions, which seek to improve behavior around taking daily medication, and from linkage interventions, which seek to connect newly diagnosed individuals to first-time HIV care.

Data Extraction & Analysis: Data from included articles were entered into a standardized spreadsheet. Two independent reviewers extracted data from the same three articles to compare results and revised the data extraction process as needed. Data from the remaining articles were extracted by a single reviewer (MW) and quality checked by a second (GK). Extracted data included information on analytic methods (model type, analysis perspective, time horizon, discounting, currency, year), interventions (population, targeted or untargeted, intervention type, location, context, intervention description, comparators), and results (cost-effectiveness estimates, threshold, main findings). For comparison across studies, cost-effectiveness estimates were standardized to the same currency and year (2018 U.S. dollars) using the CCEMG – EPPI-Centre Cost Converter that was developed by The Campbell and Cochrane Economics Methods Group (CCEMG) and the Evidence for Policy and Practice Information and Coordinating Centre (EPPI-

Centre).[30,31] Cost-effectiveness ratios were the principal outcome measure. Results from multiple studies were not combined into a single summary measure or meta-analysis due to differences in methods, interventions, comparators, and populations. In this review, $100,000/QALY gained was used as the threshold for cost-effectiveness. Results were synthesized qualitatively.

Quality Assessment: To inform risk of bias, we assessed reporting quality using the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) checklist[32] and methods quality using the checklist published by Drummond *et al.* in 2015.[33] Two reviewers independently evaluated the same three articles to compare assessments; remaining articles were evaluated by a single reviewer (MW) and quality checked by a second (GK). To more clearly capture reporting quality, checklist items were marked as Yes, No, Partial, Not Applicable, or Can't Answer. "Yes" meant the article fully addressed the checklist guideline, "No" meant the guideline was not adequately addressed, "Partial" meant the guideline was only partially addressed, and "Can't Answer" meant there was not enough information to answer. CHEERS and Drummond do not include or advocate for scoring systems; however, we developed a simple scoring system in an attempt to differentiate quality. Based on natural breakpoints in the number of items marked "Yes" and/or "Partial," we classified articles as High, Moderate, or Low quality for both reporting and methods. Final quality assessments were reviewed and agreed upon by three authors (MW, GK, EE). Articles rated as "Low" methods quality were not included due to concerns regarding viability of results.

Strength of Evidence: Since there is no agreed upon guidance for grading strength of evidence for cost-effectiveness analyses, strength of evidence on an outcome level was assessed using standards adapted from Agency for Healthcare Research and Quality (AHRQ) Evidence-Based Practice Centers.[34] Overall strength of evidence for the outcome of interest (cost-effectiveness ratio) was agreed upon by all authors and graded as insufficient, low, medium, or high based on four criteria:

- *Study limitations* were scored as low, moderate, or high based on the two quality assessments.
- *Directness* was scored as direct, indirect, or mixed. Direct meant studies evaluated the cost-effectiveness of stand-alone retention/re-engagement interventions. Indirect studies combined the retention/re-engagement intervention with other interventions such as linkage or screening, making it impossible to parse out the cost-effectiveness of retention

or re-engagement alone. Mixed indicated that both direct and indirect assessments were made.

- *Consistency* was scored as consistent, inconsistent, or unknown based on the range of outcomes reported between studies. Unknown meant consistency could not be assessed because there was only one study reporting the outcome of interest or evidence came from the same group of researchers/model.
- *Assessment of uncertainty* was scored as poor, fair, or good based on the overall extent to which studies evaluated uncertainty in outcomes though sensitivity and scenario analyses.

Results

Eleven studies were included (Figure 1). Three were not model-based and instead used program data and assumptions to estimate cost-effectiveness.[35–37] The remaining articles used mathematical models to project costs, clinical benefits, and cost-effectiveness (Table 1).[38–45] Studies evaluated programs in the U.S., Canada, and Spain, over time horizons ranging from 1 year to lifetime, largely from healthcare sector or societal perspectives (Appendix Table 2a).

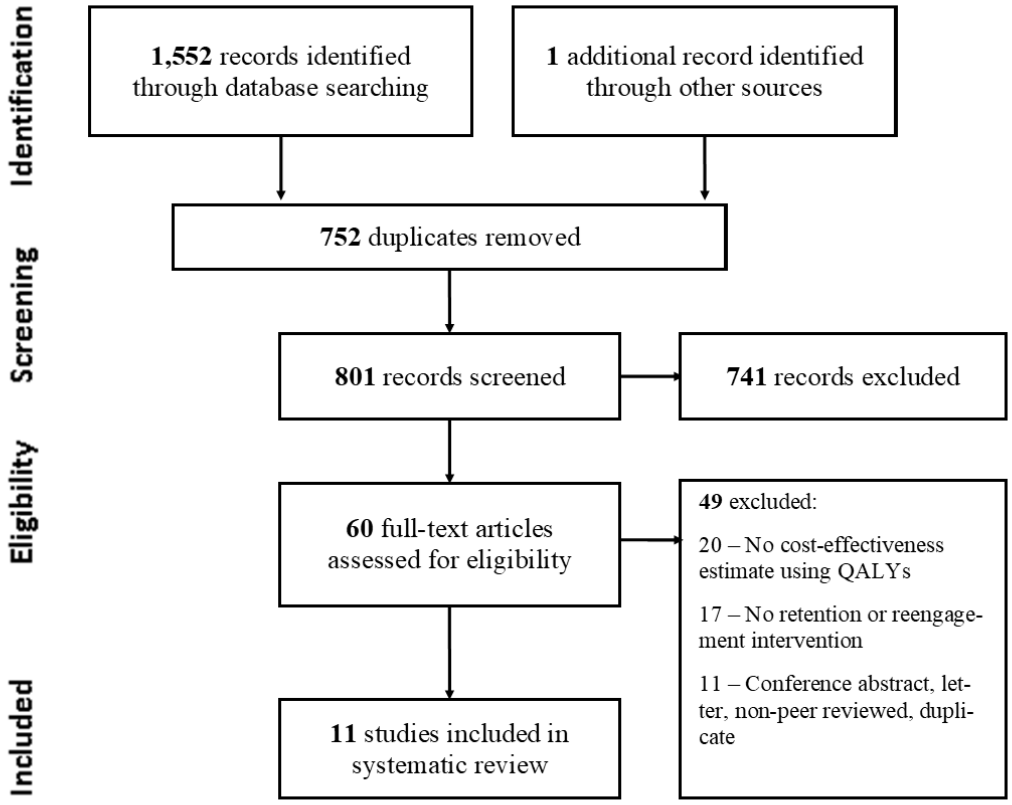


Figure 1. PRISMA flow diagram for article search and selection
1,553 records were identified and after duplicates were removed, 801 articles were screened by title and abstract. The full texts of 60 articles were reviewed and 11 were included in the final review. The most common reasons for exclusion were that articles did not have cost-effectiveness estimates using quality-adjusted life years (QALYs) as the measure of benefit or they did not evaluate retention and/or re-engagement interventions.

Quality Assessment: Reporting quality was scored as high for 4 studies, moderate for 5, and low for 2 (Appendix Table 3). Nearly all studies met CHEERS guidelines for Title, Background, Objectives, Choice of Health Outcomes, Characterising Heterogeneity, Study Findings/Limitations, Source of Funding, and Conflicts of Interest. Common areas for "Partial" scores were Time Horizon, Discount Rate, Currency/Price Date/Conversion, and Choice of Model; authors typically reported the information but did not justify it. "No" scores were scattered among the CHEERS items, with no single item standing out.

Methods quality was high for 5 studies, moderate for 3, and low for 3 (Appendix Table 4). All studies had a well-defined question and the majority adequately characterized uncertainty. Two

non-model-based studies did not adequately characterize uncertainty, which is a major limitation considering their strong reliance on assumptions for cost and QALY estimates.[36,37] Three studies did not appear to identify or include all relevant costs and consequences: Lin *et al.* included QALYs gained from infections averted but did not include QALYs gained by PLWH, while Jain *et al.* and Mauslby *et al.* did not appear to include the cost of increased ART and healthcare utilization associated with longer retention in care despite using a societal perspective, which should include all costs of a strategy. These limitations contributed to lower scores and exclusion from the analysis set.

Interventions & Populations: Studies either assessed hypothetical interventions (e.g., percentage improvements in retention or re-engagement rates, 4/11 studies) or interventions based on programs or trials that have been implemented (7/11 studies, Table 2, Appendix Table 2b). Most interventions used some combination of care coordination and case management to improve retention, and outreach to improve re-engagement. High-risk or hard-to-reach PLWH were the main target populations, although some studies assessed interventions for all PLWH (e.g., untargeted).

Table 1. Methods, Setting, and Quality of Articles Included in Review

Author, Year	Country	Setting	Methods	Reporting Quality	Methods Quality
Goyal, 2021	United States	National	Agent-based stochastic model	High	High
Nosyk, 2020	United States	Atlanta, Miami, Seattle, Los Angeles, NYC, Baltimore	Compartmental transmission model (Nosyk/Krebs)	High	High
Krebs, 2019	United States	Atlanta, Miami, Seattle, Los Angeles, NYC, Baltimore	Compartmental transmission model (Nosyk/Krebs)	High	High
Nosyk, 2018	Canada	British Columbia	Compartmental transmission model (Nosyk/Krebs)	High	High
Flash, 2019	United States	Los Angeles	Microsimulation (CEPAC-US)	Moderate	Moderate
Borre, 2017	United States	National	Microsimulation (CEPAC-US)	Moderate	Moderate
Kasaie, 2018	Spain	National	Compartmental transmission model (JHEEM)	Moderate	Moderate
Shah, 2016	United States	National	Compartmental transmission model (JHEEM)	Moderate	High
Lin, 2016	United States	National	Bernoulli model for transmission; CE estimates are not model based	Low	Low
Maulsby, 2018	United States	Boston, Chicago, NYC, San Diego, Indianapolis, St. Louis, Montgomery	Not model based	Moderate	Low
Jain, 2016	United States	Chicago, Louisiana, NYC	Not model based	Low	Low

Abbreviations: NYC: New York City; CEPAC-US: Cost-Effectiveness of Preventing AIDS Complications-United States model; JHEEM: The Johns Hopkins HIV Economic-Epidemiologic Mathematical Model; CE: Cost-effectiveness.

Table 2. Target Population, Interventions, and Cost-Effectiveness Results

Author, Year	Target Population	Interventions Assessed	Combined or Stand-Alone[a]	Cost-Effectiveness Ratios ($/QALY gained) standardized to 2018 USD
Goyal, 2021 US	All PLWH	Ryan White services, including outpatient health services, ART, and ancillary services (medical case management, mental health and substance abuse services, and other services)	Combined	RWHAP vs. No RWHAP: $30,815/QALY gained
Nosyk, 2020 US	Depends on intervention (general, MSM, PWID)	16 interventions (see Krebs 2019 below) and all possible combinations for a total of 23,040 strategies across cities	Combined	Optimal combinations had ICERs ranging from CS to $2,789,316/QALY gained, depending on city. Untargeted retention was never in optimal strategy. Among optimal combinations that were CE, between 1-4 retention/re-engmt strategies included.
Krebs, 2019 US	Depends on intervention (general, MSM, PWID)	16 interventions (5 for retention/re-engmt): 1) Care coordination for retention - all people 2) Care coordination for retention - CD4<200 3) EMR alert of suboptimal ART engmt 4) Enhanced personal contact for ART re-engmt 5) Re-linkage program	Stand-Alone	Compared to status quo, in 6 US cities: 1) Retention: $130,000-$200,000+ 2) Retention, targeted: $61,000-$108,000 3) EMR Alert: $70,000-$136,000 4) ART Re-Engmt: $65,000-$130,000 5) Re-Linkage: $65,000-$129,000
Nosyk, 2018 Canada	Adults in British Columbia ages 15-64	Ministry of Health STOP HIV/AIDS Program Case management to maintain retention/adherence and outreach to help with re-engagement among those who discontinued	Stand-Alone	Retention vs. status quo, by time horizon: 5-year: $396,713 10-year: $267,551 25-year: $ 134,277
Flash, 2019 US	High-risk PLWH stratified by acuity	Medical care coordination (MMC) - multidisciplinary teams assist with patient health, linkage, retention, adherence, risk behaviors, and psychosocial issues	Stand-Alone	MMC vs. status quo, by acuity level - All acuity levels: $28,018 - Severe acuity: $31,188 - Moderate acuity: $25,768 - Low acuity: $79,145
Borre, 2017 US	Two scenarios: - All PLWH - Black MSM	**Hypothetical** intervention that achieves NHAS targets; achieves 89% retention at 24-months for general PLWH and 86% for Black MSM	Combined	NHAS goals vs. current care levels: - General PLWH: $73,354 - Black MSM: $40,776
Kasaie, 2018 Spain	All PLWH	**Hypothetical**; Early ART initiation with improved testing, linkage, and retention. Retention modeled as 5% annual loss from care	Combined	Early ART with improved testing, linkage, and retention vs. delayed ART: $54,850
Shah, 2016 US	PLWH	**Hypothetical** intervention that results in 50% decrease in yearly rate of disengagement and 50% increase in yearly rate of re-engagement	Stand-Alone	Retention vs. status quo: $35,878/QALY gained

Lin, 2016 US	General population and PLWH	**Hypothetical** retention intervention	Stand-Alone	[b] Retention vs. status quo: $14,857/QALY gained
Maulsby, 2018, US	High-risk or out of care PLWH	Access to Care (A2C) interventions varied by city; included peer navigators, case management, telemedicine, mobile engagement teams, advocacy teams, customized care plans and social support	Stand-Alone	[b] Intervention vs. status quo, by location: - Boston: $30,273 - Chicago: $1,224 - NYC: $46,025 - San Diego: $125,258 - Indianapolis: Cost-saving - St. Louis: Cost-saving - Montgomery: $17,554
Jain, 2016 US	Hard-to-reach PLWH	Positive Charge interventions varied by city; included peer navigators, case management, support services, outreach, nurse care coordinators, and behavioral health providers	Stand-Alone	[b] Intervention vs. status quo, by location: - Chicago: $48,832 - Louisiana: $4,815 - NYC: $148,909

Abbreviations: ICER: incremental cost-effectiveness ratio; QALY: quality-adjusted life year; PLWH: people living with HIV; RWHAP: Ryan White HIV/AIDS Program; MSM: men-who-have-sex-with-men; PWID: people who inject drugs; ART: antiretroviral therapy; PrEP: Pre-exposure prophylaxis; EMR: electronic medical record; Mgmt.: management; Engmt: engagement; NHAS: US National HIV/AIDS Strategy; NYC: New York City.

[a] Combined means the retention and/or re-engagement component of the intervention was combined with other components (such as linkage or testing) so cost-effectiveness can only be determined for the combination. Stand-alone means the retention and/or re-engagement component was assessed as a separate, individual intervention so cost-effectiveness of retention /re-engagement itself can be determined.

[b] Overall methods quality was scored as "Low." These results are not included in the discussion on cost-effectiveness

Cost-Effectiveness: A total of 73 cost-effectiveness ratios that included retention/re-engagement interventions were reported in the eight moderate-high quality articles; 57 ratios (78%) came from two articles by Krebs and Nosyk (2020) that evaluated several interventions in six different U.S. cities. Of the 73 ratios, 20% were less than $50,000/QALY gained (very cost-effective), 64% were less than $100,000/QALY gained (cost-effective), and 84% were less than $150,000/QALY gained (an alternative U.S. cost-effectiveness threshold), leaving only 16% with ratios greater than $150,000/QALY gained (Figure 2). A small number of ratios were found to be cost-saving in Nosyk (2020); these were in combination with high-impact HIV prevention interventions in cities with poor baseline service levels, where large clinical gains yielded good value for money.

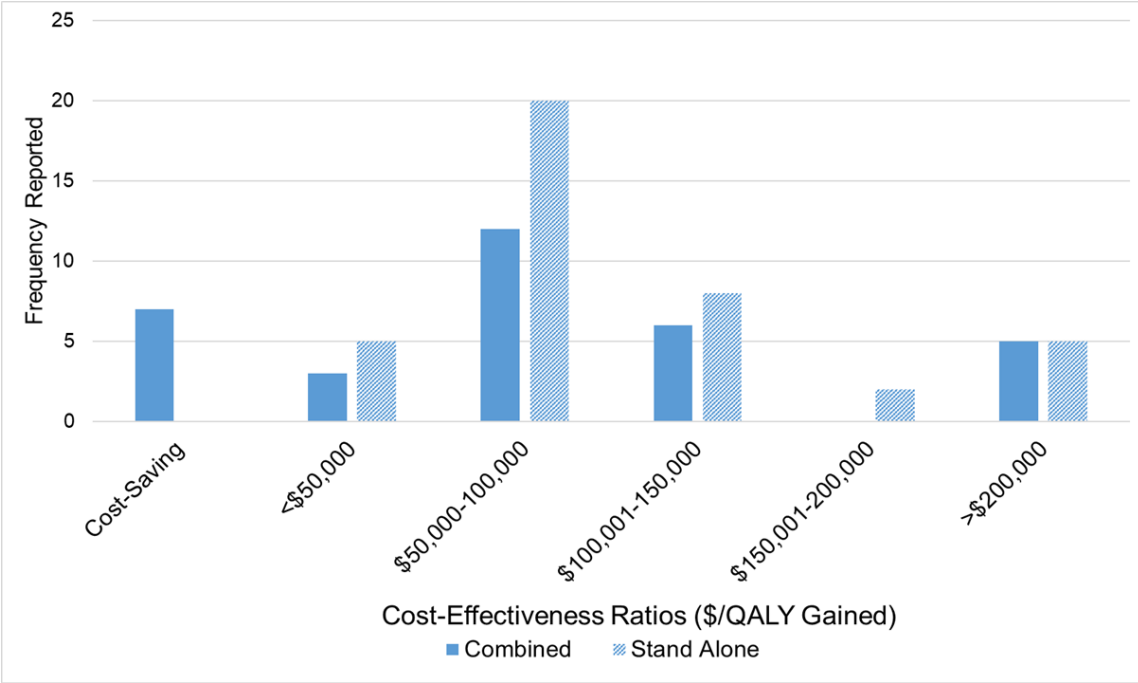


Figure 2. Cost-effectiveness ratios reported in moderate-high quality articles, by intervention type (combined vs. stand-alone).
The majority of cost-effectiveness ratios reported were between $50,000-$100,000/QALY gained, regardless of intervention type. Some interventions were found to be cost-saving when combined with other high value interventions, such as HIV prevention.

Using a $100,000/QALY gained threshold, hypothetical improvements to retention on a national scale appeared cost-effective when combined with other care cascade improvements. Borre, Kasaie, and Shah examined hypothetical improvements to HIV care on a national scale and found similar cost-effectiveness results, with ratios ranging from $35,878-$73,354/QALY gained compared to the status quo. However, since these were hypothetical, they may overestimate

effectiveness and/or underestimate costs of achieving high rates of retention across an entire country. Goyal also examined improvements on a national scale but used real-world cost and effectiveness data from the Ryan White HIV/AIDS Program (RWHAP). Goyal still found similar results as the hypothetical studies, with $30,815/QALY gained for RWHAP compared to a counterfactual scenario of no RWHAP. Importantly, with the exception of Shah, these studies looked at the cost-effectiveness of retention *combined* with other major improvements to HIV care and/or prevention, making it impossible to parse out the cost-effectiveness of the retention components alone.

Targeted interventions, meaning those that focus on specific high-risk groups, generally achieved more favorable cost-effectiveness ratios. Nosyk (2018) examined an untargeted case management and outreach intervention in British Columbia and found the cost-effectiveness ratio never dropped below CA$50,000/QALY gained ($40,050 in 2018 USD) even when doubling effectiveness and decreasing intervention costs by 90%. Untargeted retention interventions were also not cost-effective in the six U.S. cities analyzed by Krebs, and was never included in optimal combination strategies in these same cities as analyzed by Nosyk (2020). This trend is supported by Borre, who found lower cost-effectiveness ratios when targeting Black men-who-have-sex-with-men (MSM) instead of all PLWH (although both were still considered cost-effective), and by Flash, who found lower ratios when case management was targeted to moderate and high acuity MSM vs. low acuity MSM.

Cost-effectiveness of retention and re-engagement interventions can vary by location due to different epidemic contexts, baseline levels of care engagement, and limitations of scale-up feasibility. This is highlighted by Krebs and Nosyk (2020), who evaluated the same set of interventions in six different U.S. cities. For example, retention targeted to people with CD4<200 was considered cost-effective in all cities except Atlanta and Seattle. In fact, no ART retention or re-engagement strategies were considered cost-effective in Atlanta compared to the status quo; the authors state this is largely because their model captured a limited ability to scale-up interventions in the state of Georgia where Medicaid has not been expanded. In contrast, retention interventions were likely not cost-effective in Seattle due to high baseline rates of retention.[46] These types of location-specific details can have substantial impacts on estimates of cost-effectiveness for retention and re-engagement.

Differences in target population, context (national vs. local), and interventions (combined vs. stand-alone, hypothetical vs. real-world) make direct comparisons between papers often not applicable. One comparison that is suitable is between Flash and Krebs for targeted retention in Los Angeles. Flash examined medical care coordination for high-risk MSM within RWHAP and found cost-effectiveness ratios ranging from $28,000-$79,100/QALY gained (depending on acuity) compared to no medical care coordination. Krebs examined care coordination for PLWH with CD4<200 and found a ratio of $61,000/QALY gained compared to the status quo. While they had differing high-risk target populations, their cost-effectiveness findings were well-aligned, which is encouraging given the different models and assumptions used.

The studies scored as low methods quality found most retention interventions to be cost-saving or highly cost-effective. However, depending on the study, important relevant benefits or costs (such as healthcare and ART costs) did not appear to be included; details on methods (such as costs, time horizon, and discount rate) were often unclear; and assumptions regarding length of viral suppression, infections averted, and QALYs saved were poorly assessed in sensitivity analyses. While these studies provide valuable information about HIV retention, they did not adhere well to best practices and norms for cost-effectiveness analysis.

Strength of Evidence: Overall strength of evidence for cost-effectiveness ratios from the eight moderate-high quality articles was rated as medium, meaning the evidence is moderately strong that retention and/or re-engagement interventions can be cost-effective in high-income countries using a $100,000/QALY gained threshold, depending on the local context and target population (Appendix Table 5). Overall study limitations for this set of articles was rated as moderate: reporting and methods quality was moderate or high for all articles. Directness was mixed: articles were balanced in terms of whether they assessed combined or stand-alone interventions. Consistency was rated as consistent: most cost-effectiveness ratios were below $100,000/QALY gained with a small proportion being cost-saving or not-cost effective. Assessment of uncertainty was rated as good: all studies conducted deterministic sensitivity analyses on key model parameters and many studies also conducted probabilistic analyses.

Discussion

Moderate-to-high quality studies included in this systematic literature review supported that retention and re-engagement interventions can be cost-effective using a $100,000/QALY gained

threshold depending on location, baseline levels of retention, and whether retention is evaluated alone or in combination with other interventions. National-level interventions modeling hypothetical improvements along the care cascade consistently found that retention, when used in combination with other improvements, is cost-effective. Interventions modeled on a local level and based on real-world effectiveness estimates found wider variation in cost-effectiveness. Regardless of context, studies consistently showed that retention interventions were more cost-effective when targeted to high-risk groups. Overall, improvements in retention and re-engagement can offset downstream healthcare costs through infections averted and reduced hospitalizations among PLWH; however, it is unlikely for interventions to be *cost-saving* from a healthcare sector perspective due the high cost of ART incurred by people retained in care.

There are several possible reasons for differences in findings between articles. Assumptions made about the cost and effectiveness of interventions will certainly impact cost-effectiveness results. National-level, hypothetical interventions may have been overly optimistic in effectiveness estimates: Shah assumed 50% reductions in disengagement rates with 50% increases in re-engagement rates, Borre assumed 89% retention at 2-years (up from 78% in status quo), and Kasaie assumed 95% annual retention rates. In contrast, effectiveness in real-world interventions was typically lower, for example the intervention evaluated by Flash using program data increased retention to 72% from a baseline of 59%. There was also wide variation in intervention cost assumptions. Annual per-person costs (in 2018 USD) for national hypothetical analyses were assumed to be $1,065 (ranged $106-$7,985) in Shah, $449 in Borre, and $0-$1,595 in Kasaie. In contrast, Flash used program data and estimated an annual per-person cost of $2,761 for retention, while Krebs and Nosyk used microcosting to estimate intervention costs and found delivery costs as low as $1.15 per person for re-engagement interventions and annual per-person costs of $371 for retention. These wide variations in costs reflect different assumptions made by authors, different costing methods, as well as an overall lack of reliable data on costs of retention and re-engagement interventions in high-income countries. To help fill this gap in cost data, practitioners and researchers working to improve HIV care could report overall or per-person costs associated with interventions.

Differing baseline service levels and epidemic contexts also have impacts on cost-effectiveness. Retention interventions are less likely to be cost-effective in cities or regions with pre-existing high rates of retention because interventions will likely experience diminishing marginal returns. Less intensive and less expensive interventions may be sufficient to find and engage patients who

are “easy-to-reach,” yet as retention rates increase and the patients who are still out-of-care are harder to reach, increasing resources will be needed to engage fewer people. This was seen in the article by Krebs: retention was not cost-effective in Seattle where 88% of PLWH were already receiving care in 2018.[42,46] Cities with high HIV transmission rates may also have lower cost-effectiveness estimates for retention interventions due to downstream infections averted; although prevention and diagnosis strategies may still be favored when incrementally comparing strategies targeting different parts of the HIV care continuum. National-level interventions are unable to capture these differing contexts, but they illustrate that retention can be valuable on a large-scale, which is useful for national government bodies that allocate HIV funding. Achieving national rates of 90-95% retention will likely involve multiple interventions of both increasing cost and intensity to reach such high levels. The costs associated with this type of scale-up are largely unknown and were not clearly addressed in the included articles.[47] As HIV care improves, we may realistically require interventions that cost more than $100,000/QALY gained to continue making gains in ending the HIV epidemic.

A review of cost-effectiveness along the global HIV care continuum published in 2014 found substantial gaps in knowledge regarding cost-effectiveness of linkage and retention interventions.[48] Those gaps have since started to be filled: all articles included in our review were published in 2016 or later despite our search criteria including articles since 2010. Still, policy makers would benefit from more studies based on real-world interventions in local contexts to better inform decisions. More consistent use of incremental analyses where cost-effectiveness of an intervention is compared to the next best strategy (rather than only compared to a status quo) would also allow decision makers to compare the value of multiple retention/re-engagement strategies in relation to each other when deciding what strategy to adopt.

This systematic literature review has several limitations. First, we did not include adherence interventions, the outcomes of which (e.g., increased viral suppression) often overlap with retention and re-engagement. Second, while we evaluated studies for both reporting and methods quality, there could be benefits of additional quality assessments. For example, a quality assessment focused on credibility of modeling methods (such as internal and external validation, verification, and model design)[49] could provide valuable information, although, we would expect results of additional quality assessments to be relatively correlated to those found in Drummond and CHEERS. Third, our methods would be more robust if two reviewers independently

extracted data and evaluated quality for all articles, rather than just three. However, all reviewers ultimately had complete agreement on final quality scores.

Conclusions

Evidence is moderately strong that retention and re-engagement interventions can be cost-effective in high-income settings. Further research is needed on intervention and scale-up costs. As nations approach high levels of retention in care, it will likely become increasingly expensive to re-engage and retain additional patients.

Aim 2: To estimate the impact of support services on sustained viral suppression among low-income people living with HIV

Variation in Local Ryan White HIV/AIDS Program Service Use and Impacts on Viral Suppression: Informing Quality Improvement Efforts

Overview

The U.S. Ryan White HIV/AIDS Program (RWHAP) funds comprehensive services for people living with HIV to support viral suppression (VS), yet disparities in VS outcomes still exist. To inform quality improvement efforts focused on reducing disparities, we analyzed five years of RWHAP data from the Minneapolis-St. Paul region to 1) assess variation and 2) evaluate the impact of each RWHAP service on sustained VS by race/ethnicity. Receipt of AIDS Drug Assistance Program and financial aid consistently showed higher probabilities of sustained VS, while food aid and transportation aid had positive impacts on VS at higher levels of service encounters; however, the impact of services could vary by race/ethnicity. For example, financial aid increased the probability of sustained VS by at least 3 percentage points for white, Hispanic and Black/African American clients, but only 1.6 points for Black/African-born clients. Examining variation can be a useful step to understanding and addressing disparities in service use and outcomes. This study found that services addressing socioeconomic needs typically had positive impacts on VS, yet service use and impact of services often varied by race/ethnicity. This highlights a need to ensure these services are designed and delivered in ways that equitably serve all clients.

Introduction

The Ryan White HIV/AIDS Program (RWHAP) is a federally-funded HIV program that provides both medical and support services to approximately half of all people diagnosed with HIV in the United States, with eligibility for services based on income-level.[8] Prior studies have demonstrated that patients engaged in RWHAP have better HIV-related health outcomes than similar patients not engaged in RWHAP.[50,51] However, there can still be substantial disparities in viral suppression outcomes between racial and ethnic groups.[52]

Improving HIV health outcomes and addressing health disparities are two of four primary goals in the U.S. HIV National Strategic Plan for 2021-2025.[6] RWHAP funds several services that aid clients with achieving HIV-related health outcomes, either directly through medical care or indirectly through support services such as housing and food aid. State-level and national-level reports contain rich information on RWHAP client characteristics, viral suppression rates, and retention in care rates,[8] and the recently released RWHAP Compass Dashboard provides basic information on service utilization.[53] However, more detailed information on service use, and in particular, variation in service use by race/ethnicity is generally lacking. Having an in depth understanding about which services are used, how often, how much, and by whom can help uncover why disparities in viral suppression may be present. Furthermore, investigating how service use impacts Viral suppression for different groups may provide further insights on whether services are effective in aiding clients achieve favorable HIV outcomes.

In this paper, we assessed variation in RWHAP-funded service use by race/ethnicity over five years (2015-2019) in the Minneapolis-St. Paul region of Minnesota. We then estimated the causal effect of service use on achieving sustained viral suppression. Threats to validity for these causal estimates are discussed. Results can be used to provide insights on potential disparities, identify areas for quality improvement, and inform future program changes.

Methods

Setting: RWHAP serves approximately 5,000 clients annually in Minnesota, with most clients located in the thirteen-county metro area centered around Minneapolis and St. Paul. Clients are from a variety of racial/ethnic backgrounds: white and Black/African American clients account for the largest number of RWHAP recipients, followed by substantial populations of Hispanic and Black/African-born clients, and smaller populations of Asian/Pacific Islander, Native American/American Indian, and multi-racial clients. Based on the Health Resources & Services Administration (HRSA) data and definitions, 91% of Minnesota's RWHAP clients were virally suppressed and 61% were retained in care in 2019,[ii] but when stratified by race/ethnicity, these outcomes ranged between 86-100% for viral suppression and 54-75% for retention.[8] The present

[ii] Viral suppression rates are higher than retention in care rates because the definition for viral suppression requires only the most recent viral load test in a year to be suppressed. The definition for retention in care requires documentation of at least two tests greater then 3 months apart. Neither metric is perfect. For example, it is possible for a person to have one suppressed viral load test in the beginning of the year and lose suppression but not have any further tests.

study was motivated by a desire to understand how expanding RWHAP services could potentially reduce disparities in viral suppression outcomes.

Data: We obtained de-identified data from CAREWare, an electronic health record system for RWHAP recipients and providers. The dataset included viral load test results, service encounters, housing status, income level, insurance status, and demographic information for all recipients of services funded through RWHAP Part A and/or Part B in the Minneapolis-St. Paul Transitional Grant Area (TGA) between 2015 and 2019. TGAs are geographic areas highly impacted by HIV/AIDS that are eligible to receive RWHAP Part A funds. A total of 6,144 unique clients, 898,355 service encounters, and 69,272 viral load results were included in the dataset.

Of the 28 service categories recorded, seven were excluded due to low number of service encounters, low number of clients served, and/or low applicability to achieving viral suppression. These included home and community-based health services (≤50 clients served over 5 years), adult foster care (<50 clients served), early intervention services (low applicability because focused on diagnosing new patients), information & referral services (<1,300 encounters over 5 years), inreach (contacting previously engaged clients, <1,000 encounters), outreach (re-engaging clients in care, <500 encounters), and linguistic services (<200 encounters). Service categories addressing similar needs were combined to increase sample size and simplify the analysis. On-site meals, home-delivered meals, and food shelf services were combined into "Food Aid"; mental health and psychosocial services were combined; and emergency financial assistance, health insurance assistance, emergency housing assistance, and food vouchers were combined into "Financial Aid" because these are all essentially forms of cash transfer. Fifteen service categories remained in the analysis: AIDS Drug Assistance Program (ADAP), financial aid, food aid, health education, legal services, medical case management (MCM), mental & psychosocial services, medical nutrition therapy, non-medical case management, outpatient ambulatory health services, oral health, substance abuse treatment, transitional housing, transportation, and treatment adherence.[iii]

Inclusion Criteria: Observations were included in the analysis if the client was ≥ 18 years and was actively using RWHAP services at some point between 2015-2019. Being an active client was defined as using at least one RWHAP service in a given year and having complete viral load, housing, insurance, and income status data for that year since these are required and routinely

[iii] Emergency housing assistance is typically one-time financial aid/cash transfers for issues such as paying a utility bill or rent. Transitional housing is typically a two year program in which people get support with housing to keep them able to access health care while they transition to a long-term, stable living situation.

collected for RWHAP clients. Observations were excluded if clients were inactive during a year. For example, if a client was active in 2015, inactive in 2016, and active again in 2017, then 2016 for that client would be excluded, but 2015 and 2017 would be included.

Data Analysis: Data were consolidated to one observation per person per year. Viral load status was coded as "Sustained Suppression" if all tests in the year were suppressed and "Not Sustained" if tests were a mix of suppressed and not suppressed or all not suppressed. Insurance status was "Insured," "Partially Insured," or "Uninsured," with partially insured reflecting a mix of insured and uninsured throughout the year. Housing status was "Stable", "Temporary", "Unstable," "Partially Stable" for a combination of stable/temporary, and "Partially Unstable" if at least one report in the year was unstable. For each service, utilization within a given year was summarized with both binary (used vs. did not use service) and continuous (number of service encounters) variables.

Descriptive analyses on service use included the proportion of clients using the service and, among service users, the mean and standard deviation of the number of service encounters per year. Results are presented overall and stratified by race/ethnicity. A service encounter was defined as a single point of care with a service provider, such as a visit for MCM or receipt of a food voucher. The amount of service received at a single encounter was not accounted for (such as length of visit with case manager or amount of money on the voucher). For some services, such as food aid, a single service encounter could represent a single in-person meal or multiple take-home meals delivered for the week. Categories for race/ethnicity were the same as used by HRSA, except for an additional category for Black/African-born to reflect the substantial client population of African-born immigrants served by RWHAP in Minnesota. Analysis of trends in service use over time were conducted using log-binomial regression for the change in proportion of clients using a service and linear regression for the change in mean number of encounters over time, with year being the predictor in both regressions.

To estimate the causal effect of each RWHAP service on sustained viral suppression, we conducted logistic regressions using generalized estimating equations and an independent correlation structure. Propensity scores were used to adjust for the probability of service use. We predicted potential outcomes, estimated risk differences, and bootstrapped standard errors from 250 samples. The outcome, sustained viral suppression, was defined as all tests being virally suppressed for an entire year.[iv] Propensity scores for each service were calculated using client

[iv] The median number of viral load tests in a year for clients in the dataset was 2 tests and the mean was 2.6 tests.

demographics, socioeconomic information, and use of other RWHAP services. Both the impact of service use versus no service use (binary predictor) and the impact of amount of service use (i.e., number of encounters; continuous predictor) were assessed. For services that are typically provided specifically because a client is not virally suppressed (primarily treatment adherence counseling and health education counseling), lagged analyses were conducted to account for the effect of the service on viral suppression in the following year. For example, if a client received treatment adherence counseling in 2015, the model would predict sustained viral suppression for 2016. Significance was measured at the 5% level. Only white, Black/African American, Black/African-born, and Hispanic race/ethnicity groups were included in the causal regression analyses due to small sample size among the other race/ethnicity groups. All analyses were conducted in R version 4.0.2.

Results

A total of 5,243 active clients with 15,377 client-years of observations were included in the analysis; 78 clients were excluded from the analysis because they were <18 years old and 823 client-years were excluded because they did not have at least 1 year actively engaged in RWHAP (i.e., they used no services or had missing data for routinely collected metrics). Of those included, 1,268 clients had 1 year of observation, 1,003 had 2 years, 937 had 3 years, 883 had 4 years, and 1,152 had 5 years. The total number of active clients served annually grew from 2,750 in 2015 to 3,662 in 2019. Most clients were male, stably housed, insured, and had incomes <200% of the federal poverty level (**Table 3**). Mean age was 46 years (standard deviation 12.6 years). Sustained viral suppression rates were higher among people stably housed (83%) compared to those unstably housed (53%). No major demographic shifts occurred over the analysis period in gender or race/ethnicity. The proportion of clients insured over the whole year peaked in 2016 at 94% and then declined to 82% by 2019, while the proportion of clients partially insured grew during this time. Sustained viral suppression rates rose from 75% in 2015 to 81% in 2019.

Table 3. Client Characteristics and Viral Suppression Status Between 2015-2019

Client Characteristic	Number of Person-Years	Proportion of Person-Years	Number of Unique Clients*
Gender			
Female	4,471	29.1%	1,489
Male	10,567	68.7%	3,632
Transgender	399	2.2%	122
Race/Ethnicity			
American Indian	661	4.3%	197
Asian/Pacific Islander	260	1.7%	102

Black/African-born	2,253	14.7%	735
Black/African American	4,411	28.7%	1,543
Hispanic	1,800	11.7%	588
Multi-Racial	435	2.8%	137
White	5,543	36.0%	1,931
Unknown	14	0.1%	10
Housing Status			
Unstable	497	3.2%	375
Partially Unstable	1,552	10.1%	1,041
Temporary	720	4.7%	543
Partially Stable	1,313	8.5%	912
Stable	11,295	73.5%	4,219
Insurance Status			
Uninsured	622	4.0%	520
Partially Insured	1,126	7.3%	905
Insured	13,629	88.6%	4,774
Income as Percent of Federal Poverty Level			
<100%	8,378	54.5%	3,383
100-199%	4,558	29.6%	2,210
200-299%	1,911	12.4%	1,048
300-400%	530	3.4%	362
Viral Suppression Status			
Not Suppressed	1,125	7.3%	796
Partially Suppressed	2,180	14.2%	1,605
Suppressed	12,072	78.5%	4,503

*Since housing, insurance, income, and viral suppression status can change during the five-year study period, number of unique clients in these categories does not sum to the total of 5,243.

Service Utilization: During the five-year period, MCM was the most commonly used service, followed by financial aid, transportation support, ADAP, and outpatient health services (**Table 4**). Number of service encounters varied widely between services, with food aid and MCM having the highest mean number of encounters within a year. Over time, there were increases in the proportion of clients receiving ADAP, mental & psychosocial services, medical nutrition therapy, and non-medical case management, and decreases in the proportion of clients receiving health education, treatment adherence counselling, and outpatient health services. The change in mean number of encounters was highest for food aid, with 4.12 more encounters on average for each additional year in the dataset.

Table 4. Service Utilization and Trends in Service Use Over Time

RWHAP Service	Proportion of Clients Using Service	Annual Number of Encounters Among Clients Who Used Service At Least Once		Trend in Service Use Between 2015-2019	
		Mean	Standard Deviation	Proportion Using Service (Rel. Risk)[a]	Mean Encounters Among Clients Using Service [b]
Medical Case Mgmt.	56.8%	35.9	23.8	- 3.9% *	-1.13*
Financial Aid	41.8%	3.2	2.5	- 4.3% *	-0.01
Transportation	41.4%	7.7	9.6	-4.9% *	-0.30*
AIDS Drug Assistance Program	35.3%	12.9	13.2	+ 9.7% *	-1.87*
Outpatient Health Services	34.9%	4.1	3.8	-8.9% *	-0.24*
Food Aid	29.7%	37.7	50.3	+ 4.5% *	4.12*
Non-Medical Case Mgmt.	26.7%	4.4	5.8	+18.7% *	0.96*
Treatment Adherence	17.6%	5.9	6.3	- 13.1% *	-0.04
Oral Health	13.6%	2.7	2.6	-0.3%	-0.42*
Mental Health/ Psychosocial	13.5%	3.3	4.1	+ 9.8% *	0.21*
Medical Nutrition Therapy	12.5%	4.5	5.1	+15.1% *	0.39*
Legal Services	8.3%	4.0	3.8	- 4.1% *	0.12
Substance Abuse Treatment	8.0%	11.7	14.2	-0.8%	-0.15
Health Education	7.7%	3.1	5.7	- 13.4% *	0.65*
Transitional Housing	4.1%	5.0	11.6	+ 2.2%	1.45*

*Indicates significance at <0.05 alpha level; Rel. Risk: relative risk; Mgmt: management.

[a] Interpretation: For each additional year, the relative risk (RR) of participating in the AIDS Drug Assistance Program (ADAP) was higher by 9.7%. For example, a client in 2016 is 9.7% more likely to receive ADAP than a client in 2015.

[b] Interpretation: For each additional year, the average number of service encounters for ADAP was lower by 1.87 encounters among clients using ADAP.

Levels of service use varied substantially between race/ethnicity (**Figure 3**). For example, 51% of African American clients received financial aid compared to 31% of Hispanic clients, yet 61% of Hispanic clients received ADAP support compared to just 22% of African American clients. The mean number of annual service encounters ranged from 30.8/year for Asians/Pacific Islanders to 55.0/year for American Indians.

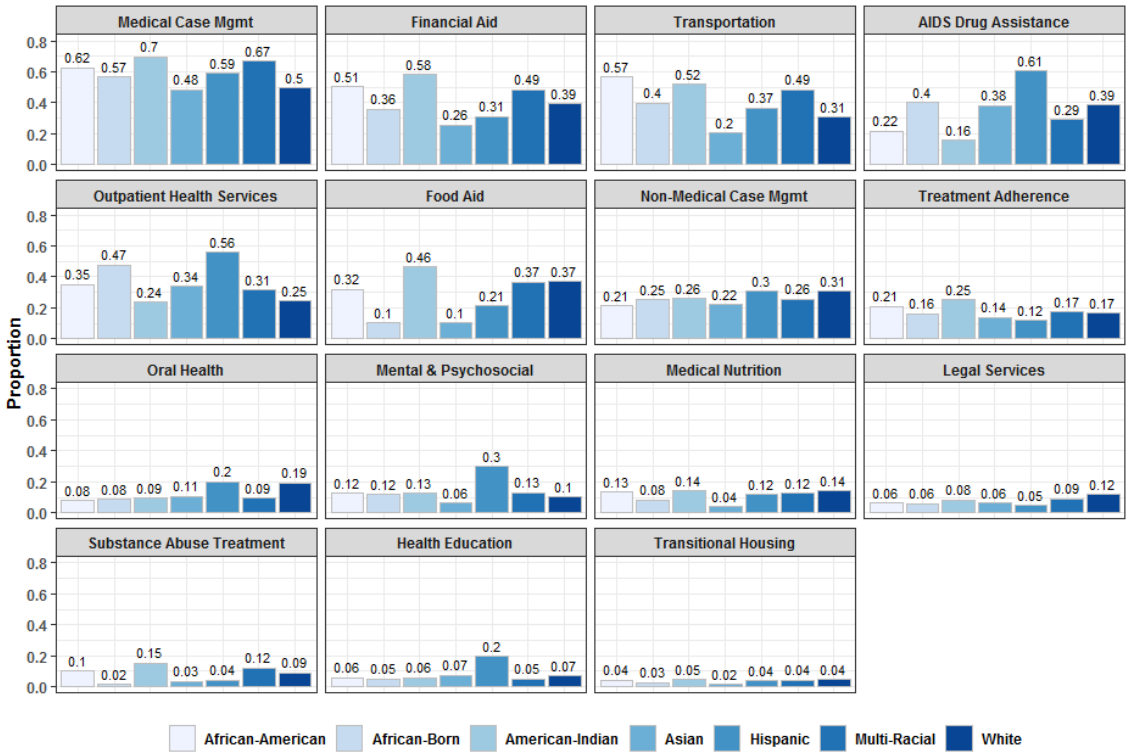


Figure 3. Proportion of Clients Using Services, by Race/Ethnicity
Utilization can vary substantially within a service, as seen with varying rates of service use between racial/ethnic groups for financial aid, transportation, ADAP, outpatient health services, and food aid. It does not appear that one group engages more in services consistently.

Service Use and Viral Suppression Outcomes: Average sustained viral suppression rates between 2015-2019 were lowest among American Indian (70%), Black/African American (72%), and multi-racial (72%) groups, and highest among Black/African-born (80%), Asian/Pacific Islander (82%), white (83%) and Hispanic (84%) groups.[v] In propensity score adjusted analyses, receipt of oral health, financial aid, and ADAP services were consistently related with higher probabilities of sustained viral suppression (**Figure 4, Supplemental Table 1)**. Compared to clients who did not receive the service, clients who received ADAP were 3.8 percentage points more likely to have sustained viral suppression (95% CI: 2.2-5.4)81.1% vs. 77.4%), clients who received financial aid were 3.0 percentage points more likely (95% CI: 1.5-4.5), and clients who received oral health services were 7.1 percentage points more likely (95% CI: 5.0-9.3). Services that were consistently related with lower probability of sustained viral suppression were health education

[v] Viral suppression rates estimated in this study are substantially lower than those reported by HRSA (in Methods, Setting) due to our definition of sustained viral suppression, which required all viral load tests to be suppressed in a year. The HRSA definition for viral suppression only requires the most recent viral load test be suppressed.

(10.0 percentage points lower [95% CI: 7.2-12.8]), substance abuse treatment (6.2 percentage points lower [95% CI: 3.5-8.9]), treatment adherence (4.5 percentage points lower [95% CI: 2.7-6.3]), and mental health services (3.1 percentage points lower [95% CI:1.1-5.2]).[vi] However, there was no evidence of negative impacts of health education and treatment adherence on viral suppression in lagged analyses.

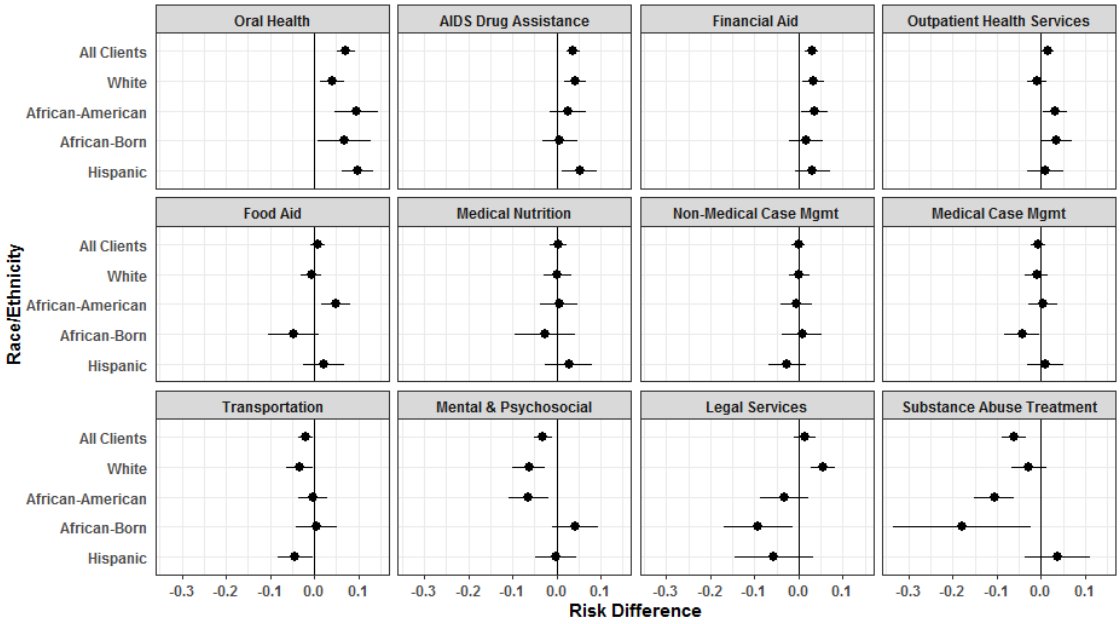


Figure 4. Risk Difference for Sustained Viral Suppression When Using a Service Compared to Not Using the Service, by Race/Ethnicity

Oral health, AIDS Drug Assistance (ADAP), and financial aid had positive impacts on sustained viral suppression for most racial/ethnic groups. Receipt of legal services had a positive impact on sustained viral suppression only for white clients; confidence intervals are wide for other groups, reflecting low numbers of clients using legal services.

Both magnitude and direction of the effect of service use on viral suppression were generally consistent across race/ethnicity groups with some notable exceptions. Receipt of financial aid increased the probability of viral suppression by at least 3 percentage points for white, Hispanic and Black/African American clients and only 1.6 points for Black/African-born clients (95% CI: -2.2 – 5.4). For white clients, receipt of legal aid increased the probability of sustained VS by 5.5 percentage points (95% CI: 2.8-8.1), but for Black/African-born clients receipt of legal aid lowered the probability of sustained viral suppression by 9.2 percentage points (95% CI: 1.4-17.1). Food aid had a non-significant impact on viral suppression for all groups, except African Americans for whom receipt of food aid increased the probability of sustained viral suppression

[vi] Services with lagged analyses (health education and treatment adherence counselling) are not depicted in the figure. Full results are available in the Supplementary Materials.

by 4.8 percentage points (95% CI: 1.6-8.0). Several other services lacked evidence of a significant effect in either direction on sustained viral suppression.

When evaluating relationships between amount of service received and sustained viral suppression, similar trends are observed for most services (**Figure 5, Supplemental Table 2**). However, in contrast to the binary regression, food aid and transportation support were strong predictors of sustained viral suppression for clients with higher intensities of service use. For every 10 additional transportation encounters, viral suppression probability was higher by 9.2, 4.7, 4.3., and 2.5 percentage points for Black/African American, white, Hispanic, and Black/African-born clients, respectively. For every 10 additional food aid encounters, viral suppression probability was higher by 0.5-1.0 percentage points for all groups except for Black/African-born clients where a negative impact of additional food aid on viral suppression was observed. This illustrates that low or inconsistent use of food or transportation aid is unlikely to have an impact on viral suppression outcomes, but that more engagement in these services could have a positive impact.

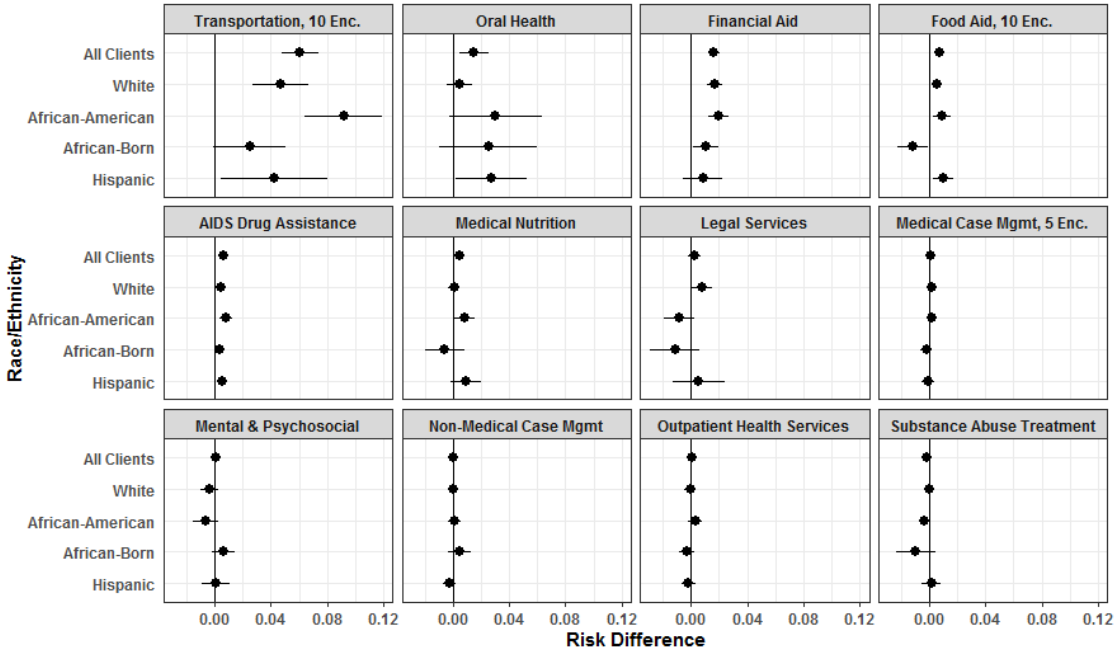


Figure 5. Risk Difference for Sustained Viral Suppression for Each Additional Service Encounter, by Race/Ethnicity

Most services did not have evidence of strong impacts on the probability of sustained viral suppression, except for transportation. For every 10 additional transportation encounters (such as receipt of bus passes or taxi rides), probability of sustained viral suppression increased across all racial/ethnic groups. Additional encounters of food aid had smaller, but still significant, positive impacts on viral suppression with the notable exception for Black/African-born clients, where a negative impact was observed. Enc: service encounter; Mgmt: management.

Discussion

There was substantial variation in RWHAP service use: between services, between racial/ethnic groups, and over time. Service use also had differing impacts on sustained viral suppression. There is evidence across all groups that services supporting socioeconomic needs, such as financial, food, and transportation aid, have positive impacts on client achievement of sustained viral suppression. However, differences in use and impact between client groups indicate that services may not be meeting the needs of all clients equitably. Analyses on variation can be used as a starting point to examine reasons why variation exists and to inform future quality improvement programs.

When examining the proportion of clients using each service, several findings warrant further investigation. The proportion of Black/African Americans and American Indians using ADAP was substantially lower than other groups. Further inquiry may reveal issues such as barriers to enrollment, lack of awareness, or access to other services (such as Medicaid) that pay for HIV medications and therefore meet client need. Use of food aid was much lower for Black/African-born and Asian clients. Further investigation may reveal challenges such as lack of culturally-specific food options, inconvenient food aid locations, and/or food aid programs not meeting the needs of clients with more family-based meal traditions. Use of legal aid was highest among white clients. Future work could examine the legal needs of different client groups, as well as the type of legal aid most commonly offered at RWHAP-funded providers. These types of investigations are just a few examples of how to begin to bring meaningful action to this study's findings on service use variation. With data on variation, program managers should speak with both staff and diverse groups of clients to understand *why* services are/are not being used and *how* services are/are not helpful. Answers could help inform quality improvement initiatives that address disparities in both service use and viral suppression outcomes.

When examining the causal effect estimates of service use on sustained VS, financial aid, food aid, transportation, and ADAP had the most consistent positive impacts on sustained viral suppression. These findings highlight the importance of services that address socioeconomic needs for low-income people living with HIV. Furthermore, we found that higher amounts of service use for food and transportation aid were most beneficial, indicating that there may be some threshold at which these services begin to have an impact on clients' health and well-being. Results stratified by race/ethnicity can again be used as starting points for further exploration. For example, program staff may want to examine why the impact of financial aid on sustained viral suppression was lowest for Black/African-born clients.

The propensity score adjustment approach in this analysis was designed to control for confounding and more reliably estimate causal effects, i.e., how viral suppression outcomes would differ if service use changed. Since the true causal effect is unknown, causal estimation can be understood as an attempt to get as close as possible to this true underlying effect by controlling confounding based on available data. In this analysis, how close our estimates are to the true causal effect is likely different for each service due to varying degrees of unmeasured confounding as well as other factors. For substance abuse treatment, a negative causal effect on sustained viral suppression was estimated; however, having a substance abuse disorder was a significant unmeasured confounder in this analysis. Therefore, the measured effect estimate is likely far from the true causal effect. The negative impact of substance abuse treatment on viral suppression may be better understood as the effect of substance abuse itself on viral suppression. Other studies have found substance abuse treatment, such as opioid substitution therapy, to have positive impacts on viral suppression.[54,55] Results for financial aid, food aid, transportation, and ADAP more plausibly reflect estimates close to the true causal effect because they are less subject to potential bias from unmeasured confounding. Variables included in the dataset such as housing status, income level, and insurance status are likely the strongest confounders for these services and were captured by propensity scores. As another example, oral health services showed a large positive causal effect on sustained suppression, yet this is probably far from a true causal effect because while dental work could be on the causal path to suppression for some patients, it is unlikely to be the major driver behind the large effect size observed. The observed effect may instead reflect that by the time a client receives oral health services, his or her other more urgent needs are already met and their HIV infection is under control.

Several services showed mixed results, which could reflect continued presence of unmeasured confounding, a true lack of impact on viral suppression, or small sample size, particularly once service use was stratified by race/ethnicity. Medical case management and outpatient health care are core medical RWHAP services, but no strong effect was observed on viral suppression in this analysis. This may be because these services were so widely used across suppressed and unsuppressed clients, that an effect was unable to be discerned when just controlling for propensity score. Prior research has shown MCM and care coordination efforts to be effective at improving HIV outcomes.[20,56] For services such as legal aid and medical nutrition therapy, small sample size may have impacted results: in some years fewer than 30 clients from Hispanic or Black/African-born backgrounds used these services.

This study has several limitations. First, we used analysis methods to estimate causal effects, yet as discussed above, the accuracy of these methods likely varied between services. Estimates were more plausibly causal for services such as food, financial, and transportation aid, and less plausibly causal for services such as substance abuse treatment due to unmeasured confounding. Second, viral suppression was represented as a binary outcome and therefore did not capture nuances in suppression patterns. For example, clients who were mostly suppressed in a year would still be counted as not having sustained suppression in this analysis if they had one unsuppressed viral load test. Similarly, clients with only one viral load test for an entire year would be counted as having sustained suppression if that single test was suppressed. Future work could conduct sensitivity analyses using different definitions of viral suppression to determine how much this impacts results. Third, this analysis was unable to differentiate whether services are lower for some groups because there is unmet need or because individuals truly do not need the service. Further investigation would be needed to understand why use varies so much for certain services. Fourth, we were unable to calculate separate effects for Asian/Pacific Islander, American Indian, and multi-racial groups due to low sample size.

Conclusions

Understanding how service use varies by race/ethnicity allows programs to start investigating *why* differences exist, uncover where there may be disparities or inequitable programs, and improve programs to better meet the needs of different client groups. Results support continuation of programs that address socioeconomic needs of people living with HIV, but also highlight a need to ensure these services are designed and delivered in ways that equitably serve all clients.

Aim 3: To investigate the barriers, opportunities, and potential costs of expanding HIV socioeconomic support services

Barriers, Opportunities, and Potential Costs of Expanding HIV Support Services

Overview

Experiencing housing instability, food insecurity, and financial stress can negatively impact retention in care and treatment adherence for people living with HIV. Expanding services that support socioeconomic needs could help improve HIV outcomes. Our objective was to investigate barriers, opportunities, and costs of expanding socioeconomic support programs. Semi-structured interviews were conducted with organizations serving U.S. Ryan White HIV/AIDS Program clients. Costs were estimated from interviews, organization documents, and city-specific wages. Organizations reported complex patient, organization, program, and system challenges as well as several opportunities for expansion. The average one-year per-person cost for engaging new clients was $650 for food aid, $612 for financial aid, $196 for transportation, and $2,498 for short-term housing (2020 USD). Understanding potential expansion costs is important for funders and local stakeholders. This study provides a sense of magnitude for costs to scale-up programs to better meet socioeconomic needs of low-income patients living with HIV.

Introduction

Lack of food, distance from HIV care, and other socioeconomic stressors, such as housing, employment, and financial instability, are commonly reported barriers to adherence and viral suppression for people living with HIV (PLWH) in high income countries.[10–12,57,58] Furthermore, in multiple studies, meeting these needs has been shown to be important for PLWH to effectively manage their disease and achieve viral suppression.[14,59–61] The Ryan White HIV/AIDS Program (RWHAP) is the largest federal program designed to address the needs of PLWH, serving over 500,000 low-income PLWH annually in the United States.[8] In addition to medical-related services, RWHAP also funds support services such as food aid, financial assistance, housing aid, and transportation, that help alleviate socioeconomic needs.

While ample work has been published on barriers to treatment adherence for patients,[10,11] less has focused on barriers to support service provision faced by non-medical providers. Given the growing evidence on the importance of meeting socioeconomic needs for improved HIV outcomes, [14,59–61] expanded funding for these services has the potential to contribute to improved rates of retention and viral suppression for PLWH. However, little is published regarding costs of non-medical support services for PLWH.[62] The limited costing studies that are available typically focus on HIV-related interventions, including linkage and retention programs such as patient navigation and case management.[63–67] Budgets to improve HIV care are limited and lack of data on potential costs and outcomes of expanding support programs can hamper decision-making regarding funding allocations for expansion. Expanding these programs would likely cost more than the direct aid itself (e.g., cost of a meal), since additional staff, space, or outreach efforts may be required for effective scale-up. Additionally, there may be varying levels of intensity and magnitude of scale-up, with program expansion costs that may differ depending on whether service providers are expanding to more fully meet the needs of existing clients or to engage new, harder-to-reach clients.

Our objectives were to characterize current barriers to scaling-up RWHAP-funded support services from the perspective of service providers, to identify opportunities for program expansion if funding were available, and to estimate anticipated resources, costs, and outcomes associated with potential program expansion. Results of this analysis are practical for funding organizations, such as health departments and local RWHAP jurisdictions, and can also be used as inputs in budget allocation models or cost-effectiveness analyses.

Methods

We conducted interviews with RWHAP-funded service providers who support socioeconomic needs of clients in the Minneapolis-St. Paul region of Minnesota.

Setting: Funding from RWHAP supports approximately 5,000 PLWH annually in Minnesota, with most clients located in the 13-county region surrounding Minneapolis and St. Paul. According to the U.S. Health Resources and Services Administration definitions, 68% of clients were retained in care and 91% were virally suppressed in 2019 in this 13-county area.[8] For support services in 2019, 27% of clients received food aid, 26% received transportation, 18% received emergency financial assistance, and 4% received housing support.[53] Several organizations provide support services to clients, including medical centers and non-profit community-based organizations.

Interviews: Eleven semi-structured key informant interviews were conducted with seven organization leaders, including three follow-up interviews and one pilot interview. Support services of interest were food aid, financial aid, transportation, housing, and enrollment in the AIDS Drug Assistance Program (ADAP). These services were selected because they were found to have positive impacts on sustained viral suppression rates in an analysis of local RWHAP data from 2015-2019.[68] Organizations were selected for interviews by purposive sampling to capture the full range of support services of interest as well as type of organization (medical vs. community-based). Key informants were interviewed individually or in small groups and mainly directors, program managers, or administrators. Interviews took place virtually over Zoom between September-November 2021 and each lasted between 45-60 minutes.

Interview questions focused on: 1) what are the current challenges to providing support services to your clients with HIV, 2) how would your organization expand programming if funding was unlimited, 3) what would be the resources needed and expected outcomes if programs did expand, 4) how would your organization reach new clients who aren't currently engaged in services, and 5) what scale-up costs (aside from direct program costs) might be required if program expansion were to occur? Interview notes were coded for thematic analysis by a single member of the project team (MW). The codebook and emerging analysis were reviewed by a qualitative research expert (KW). This project was part of a quality improvement initiative and was therefore exempt from human subject research Institutional Review Board approval.

Cost Estimation: We used information collected in interviews to determine potential costs of program expansion. In interviews, estimates on the potential resources needed for a program were elicited. Depending on the program, resources included staff time, materials/resources, overhead, and/or other costs. Staff time was approximated as number of full-time equivalents for specific staff job titles noted in interviews. In the absence of salary estimates from interviews, we used job titles to look up city-specific average wages from the U.S. Bureau of Labor and Statistics (BLS).[69] Costs for materials and resources were estimated from relevant online sources (e.g., Staples.com for office supplies). Final cost estimates incorporated information obtained from interviews, organization annual reports or budgets, online sources, and wage estimates from BLS. Final cost estimates were reviewed and validated by interviewees via email. All costs were reported in 2020 USD.

Results

Barriers & Challenges: Organizations reported a variety of challenges to service provision, which were categorized into client, organization, program, and system-level barriers (**Table 5**). Client-level refers to barriers mainly experienced by PLWH, organization-level refers to barriers experienced by the organizations who receive RWHAP funding to provide services, program-level refers to barriers related to RWHAP, and system-level refers to contextual barriers outside the scope of RWHAP. On a client-level, organizations reported that clients face a barrage of complex socioeconomic, medical, and logistical barriers that together often prevented HIV from being among clients' top priorities. These barriers, along with a combination of mistrust, stigma, and/or lack of awareness, were reported to be factors that could prevent patients from engaging in the services that organizations are working to provide. A program manager at an HIV clinic stated it can be challenging *"trying to work with individuals who don't have cell phones, who don't have stable housing, who have a background of injecting drugs, etc...We need to try to triage what we can do."*

On an organization level, care coordination inefficiencies and staff-related challenges were the most reported barriers. Care coordination inefficiencies included issues such as referrals taking too long when immediate support was needed and multiple providers spending time collecting the same documents (i.e., redundancy). Staff-related challenges included hiring, turnover, burnout, lack of cultural competency, lack of staff capacity to fully meet client needs, and high client-to-staff ratios. Notably, staff-related challenges were mainly reported at community-based organizations and not at medical centers. Community-based organizations reported challenges in hiring and retaining staff in part due to low salaries and less competitive benefits. It was noted that RWHAP funding does not always cover all necessary staff positions to provide services, so organizations need to secure additional funding from other sources to cover these positions. Another common barrier was related to limited funding and ethical dilemmas of staff needing to decide who gets to receive a service and who does not when there is not enough funding to meet the needs of everyone.

Table 5. Barriers to Service Provision, by Client, Organization, Program, and System Level

Level	Challenges and Barriers
Client	• High level of socioeconomic need (housing, food, financial) • Complex comorbidities and social histories (mental health, criminal backgrounds, substance abuse, etc.) • Transportation, logistic, and language barriers (hard to carry food from pantry on bus, no good bus routes to medical appointments, etc.) • Too many other competing needs in life to prioritize HIV management • Stigma, mistrust, unwillingness, and/or lack of awareness to engage in services • Inability to pay (fees to obtain IDs, security deposits, etc.)
	"*Transportation is a definite barrier. A lot of the time the location of where a person is living – there may not be bus service when you get out of the city or it may stop at 6 o'clock at night."* - Case manager, Medical organization
Organization/ Service Provider	• Staff-related challenges (burnout, lack of capacity, hiring, etc.) • Care coordination inefficiencies • Ethics of limited funding and rationing services, mainly for transportation • Operational (lack of physical space, out-of-date technology, etc.) • Disconnected leadership or lack of leadership support
	"If I had unlimited transportation for our clients I think I would melt. We really have to ration because we get a small amount." - Case manager, Medical organization
Program (RWHAP)	• Administrative burden and complexity • Funding caps and restrictions limit ability to aid clients • Misalignment of client priorities with program goals/services • Lack of funding to meet all client needs through allowable uses • Non-diversified funding contracts (same organizations get money to support food or financial needs, while others don't get any)
	"We provide $60. Is that enough food aid a month? What we're doing, is it really beneficial? Is it really going to make that much of a difference?" - Program manager, HIV-specific community organization
System	• Lack of affordable housing options • COVID-related challenges (client outreach, vaccination, hiring, etc.) • Unsafe or insufficient temporary housing options (rape, theft, and unsanitary conditions at shelters) • Social unrest and violence in neighborhoods
	"*Housing is the number one barrier that we have for our patients. Food and transportation are probably next. But really housing is the dominant challenge."* - HIV clinic program manager, Healthcare organization

On a program-level, administrative burden and complexity, lack of funding to fully meet client needs, misalignment of program objectives with client needs, and funding caps and restrictions were reported as challenges across nearly all organizations. Administrative burden affected both clients, with amount of documentation they need to obtain to be eligible for services, and organizations, with the complex documentation processes they need to follow to get reimbursed by RWHAP. When asked about administrative or program challenges, a director from a community-based organization responded straightforwardly: *"The amount of paperwork. And the amount of repetitive paperwork."* Misalignment of programs with client needs included organizations only being allowed to offer bus passes when their clients needed a taxi ride or

organizations offering single healthy meals for clients with HIV when in reality clients needed healthy meals for their families too. Funding caps and restrictions included limits in the amount of aid that can be provided to clients, restrictions on how funds can be used to aid clients, and restrictions on using funds to support certain staff costs. Related to funding caps, a medical case manager stated: "*The bus cards are only $10 and they'd like us only to give one a month. So that's really not all that helpful*."

On a system-level, six organizations reported challenges with housing; five reported challenges related to COVID-19; and one reported challenges related to social unrest and violence in the neighborhoods where staff and clients live. Housing challenges encompassed both lack of affordable housing (including lack of landlords willing to rent to clients, lack of housing options for large families, and lack of housing options in neighborhoods clients want to live in) and unsafe or insufficient temporary housing (including rape, theft, or unsanitary conditions at shelters and strict requirements for maintaining residence).

Barriers related specifically to the five service areas of interest are described below.

Food Barriers: Lack of culturally-specific food options and funding caps were major barriers reported for food aid. There were also logistical challenges such as being unable to transport enough food back home by bus/bike/foot, lack of space to store meals at home, lack of healthy food options, incompatibility of frozen meals for people without microwaves, and ineffectiveness of groceries for people who are homeless with no place to cook. A case manager from a medical organization said: *"Food is a barrier for everyone. Food shelfs can only do so much. There are not a lot of options for nutritional fruits and vegetables and more healthy eating."*

Transportation Barriers: The most reported challenge with transportation was that bus passes do not meet the needs of clients. Examples of barriers noted in interviews included: no good bus routes, buses take too long, clients cannot carry home all the food they need from the pantry by bus, and walking on icy sidewalks to get to bus stops in winter is dangerous. Additionally, since there is very limited funding for taxi rides, organizations commonly reported ethical challenges with needing to choose who gets limited taxi rides and for what services.

Financial Barriers: Major barriers were funding caps and not enough funding available to help all clients. Some organizations need to use their own funds to help clients with basic needs. Related to this is the challenge of non-diversified contracts since some organizations receive large amounts of RWHAP funds to support client financial needs and others don't receive any.

Providers note this is problematic because immediate aid is often critical for supporting clients and clients may disengage through a referral process to another organization.

Housing Barriers: Main barriers were lack of affordable housing and lack of flexibility to help clients with housing-related costs. For example, barriers to obtaining housing can include prior debts, criminal or eviction backgrounds that need to be expunged, inability to pay security deposits, and inability to pay rent differences between market rates and rates set by the U.S. Department of Housing and Urban Development. Providers reported lack of flexibility to support costs associated with these types of barriers with RWHAP funding. It was also noted that the process for Coordinated Entry can result in inefficiencies in getting clients housed immediately when units open.[vii]

AIDS Drug Assistance Program (ADAP) Barriers: Documentation burden was the only barrier reported for ADAP enrollment. Most organizations did not perceive any barriers to ADAP. One organization reported that the ability to enroll by phone has reduced barriers.

Opportunities for Program Expansion: All seven organizations described the need for and specific ways in which they would expand both the *amount* and *scope* of services provided to clients if funding were available (**Table 6**). Expanding *amount* involved offering existing services on more days, at more locations, and/or increasing the amount of aid provided to clients. Expanding *scope* involved branching out to new service areas where they observe unmet need, such as offering mental health support or small on-site food pantries.

Organizations also emphasized the need for increased flexibility in how funds can be used to support clients. For example, having flexibility to cover different client costs or provide funding over existing per-person caps to help clients in need. With unlimited funding, a program manager at an HIV organization stated they could provide "*better transportation to allow for more support service activities. You can only go four times in a month [currently]. Wouldn't it be great if you could give unlimited rides to go to have a hot meal every day?"* Five organizations reported they would partner more with other providers and would also focus on staff-related improvements, such as hiring more staff and offering higher salaries and/or better benefits. Organizations highlighted that staff retention is important for building strong, stable relationships with clients. A program director at a community-based organization said, "*The more programs Ryan White clients are in the more stable they are in our program too. So when we refer clients to other*

[vii] Coordinated Entry is the assessment system that needs to be used by recipients of U.S. Housing and Urban Development funding to assess client needs and prioritize who gets limited housing.

organizations, they also do better in our program. If we had more staff we'd probably be connecting them to more care than we are now." Three organizations reported they would improve marketing and advertising to make clients more aware of the services they offer and who is eligible. A medical case manager stated, *"It would be wonderful to be able to advertise all the different services and pay for that advertising."*

Table 6. Opportunities for Program Expansion, By Support Service

Service	Program Expansion Opportunities
Food Aid	• Provide gift cards to more people with more money allowed per person • Start a small on-site food pantry or provide Ensure to patients to take home from medical appointments • Improve culturally-specific food options (both for delivery and in-person) • Provide in-person meals and open pantry on more days, including weekends • Start a delivery program for food pantry items, particularly for Greater Minnesota • Open additional locations for meals and pantry
Financial Aid	• Provide gift cards to more people with more money allowed per person • Provide basic needs items and winter clothing • Expand aid to people above 400% of the federal poverty level
Transportation	• Provide taxis or ride shares instead of bus passes • Offer more taxi rides to reduce rationing and make rides reliable for clients • Offer rides to more support services rather than prioritizing only medical appointments
Housing	• Increase affordable housing by purchasing/renovating existing properties or building new ones • Support home ownership programs • Provide more rental assistance and increase caps on allowable rental assistance • Pay for hotel stays for homeless clients
ADAP Enrollment	• No suggestions provided since enrollment in ADAP was not perceived as having major barriers
Outreach & Access to Services	• Expand drug co-pay programs or start mail-based medication program • Start community-based mobile services, especially to reach homeless clients • Increase diversity of medical staff to better reflect client demographics • Provide cell phones to patients who don't have them • Host outreach events to reach new clients • Improve marketing and communication

ADAP: AIDS Drug Assistance Program.

Cost Estimates: Proposed ideas reported for program expansion in the Minneapolis-St. Paul metro area could reach from 20 to 1,360 new clients and up to 2,500 total (new and existing) clients, depending on the project. Total project expansion costs ranged from $12,000 to $16 million, with establishing new long-term housing being the most expensive due to costs of purchasing property and construction (**Table 7**). Costs typically increased as programs expanded to further meet the needs of clients. The average one-year per-person cost for engaging new clients across proposed

project expansions was $196 for transportation, $612 for financial aid, $650 for food aid, and $2,498 for short-term housing support (**Figure 6**). The average annual per-person cost for increasing aid to existing clients was $121 for transportation, $274 for financial aid, $371 for food aid, and $1,199 for short-term housing. These costs were lower because existing clients already receive some services, so expansions would increase the total amount of aid they receive. The average cost to establish new long-term housing options (e.g., apartment units) was $91,250 per person, with annual per-person costs thereafter of $15,000. Annual costs included facility maintenance, program staffing, and overhead.

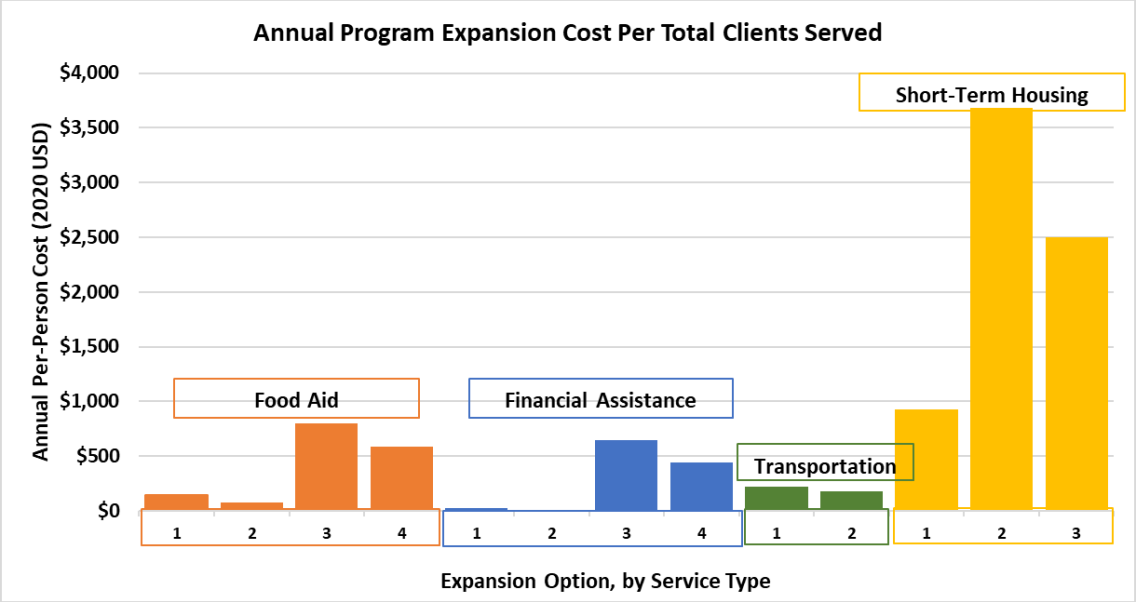


Figure 6. Annual program expansion cost per total clients served, by service type
Expanding food aid and financial assistance had similar costs, with some proposed expansion projects having low per-person costs (<$250) and other proposed projects having higher per-person costs (>$500). The two proposed expansions for transportation were approximately $200/person and focused on expanding taxi rides. Per-person costs for expanding short-term housing aid were substantially higher than costs of expanding food, financial, or transportation aid.

Cost estimates varied substantially by organization since organizations provided different types of services and had different ideas for program expansion. Some program expansion options would require changes to current restrictions in place for RWHAP programs. For example, the current limit for food aid vouchers for an individual was $60/month and several program expansion options for food aid involved providing more than $60/month. Details of proposed project expansion, expected costs, and anticipated benefits are presented as examples for an HIV-specific

community-based organization (**Supplementary Table 1)** and a medical center that operates an HIV care clinic (**Supplementary Table 2**).

Table 7. Estimated Costs and Outcomes of Program Expansion, by Service Type

Service	Project Expansion Scope	Additional Estimated Cost*	Additional No. of New Clients	No. of Clients Receiving More Services	Total Clients Served	Cost per New Client	Cost per Existing Client	Cost Per Total Served
Food**	Small food pantry	$55,800	-	385	385	-	$145	$145
	Vouchers ($100/yr)	$80,000	550	450	1,000	$100	$56	$80
	Vouchers ($900/yr)	$802,000	-	1,000	1,000	-	$802	$802
	Vouchers ($1,200/yr)	$940,000	500	1,100	1,600	$1,200	$480	$588
Financial	Basic needs items	$20,000	750	0	750	$27	-	$27
	Winter clothing	$12,000	250	750	1,000	$12	$12	$12
	Increase aid from $400 to $1,000/yr	$1,300,000	200	1,800	2,000	$1,010	$610	$650
	Increase outreach and aid to $1,200	$1,100,000	500	2,000	2,500	$1,400	$200	$440
Transportation	Taxi rides	$44,000	-	200	200	-	$220	$220
	Taxi rides	$270,000	1,360	140	1,500	$196	$21	$180
Transitional Housing & Rental Support	Rental assistance	$930,000	987	13	1,000	$939	$273	$930
	Hotel vouchers	$405,000	110	-	110	$3,682	-	$3,682
	Flexible funds to cover housing costs	$200,000	40	40	80	$2,875	$2,125	$2,500
Long-Term Housing	Purchase & renovate existing units	$1,650,000	20	-	20	$82,500	-	$82,500
	Build new units	$16,000,000	160	-	160	$100,000	-	$100,000

*Costs are annual, except for long-term housing where costs represent total project costs for establishing new housing units.
**There were additional expansion ideas for food aid, particularly on-site meals, however final cost estimates were not obtained.

A common theme was that if funding for support services were to increase, the size of staff teams would also need to increase to coordinate and distribute aid. However, some new staff roles may not billable, which would leave current staff over-burdened or require organizations to fund necessary staff positions independently. For example, for expanding in-person meals, non-kitchen staff such as intake coordinators and safety officers are critical to help manage new and current clients with complex needs, but organizations reported they needed to fundraise independently for these types of roles. Cost estimates showed that staff and other costs can account for between 0-85% of total project budgets, with an average of 21%. Expanding food or financial aid through gift cards typically had lower organization costs since gift cards require little to no additional staff. Expanding transportation and housing typically had higher percentage of staff and organizational costs due to increased time and complexity required for these services.

Scale-up costs were briefly discussed in six interviews. Costs associated with administration, operations, and management were the most common scale-up costs. Other scale-up costs included staff training, office equipment, and physical space requirements such as additional office or meal preparation space. Four organizations emphasized that more staff would be needed if they offered more services and three organizations also noted that the biggest costs after direct aid are often staff-related. Two organizations reported that scale-up costs would likely be relatively low for increasing the *amount* of existing services but would rise more quickly if organizations expanded the *scope* of their services.

Discussion

This study investigated barriers, opportunities, and potential costs of expanding services that support socioeconomic needs for PLWH in Minnesota. Common barriers included complex patient comorbidities and social histories, administrative burden, funding restrictions, and lack of affordable housing options. With additional funding, organizations would expand both the amount and scope of services they offer. In addition to expanding direct services, several organizations would also pursue more partnerships, make staff-related improvements, and improve marketing strategies. Costs of program expansion varied by service and expansion scope. Average annual per-person costs for reaching new clients ranged from $196 for transportation to $2,498 for short-term housing. Establishing new long-term housing units was the most expensive at an estimated $91,250 per person upfront with an additional $15,000 per person annually thereafter.

Understanding potential scale-up costs is important for funders and stakeholders when planning budgets and making resource allocation decisions. While costs in this analysis were not measured directly from existing programs, they provide a sense of magnitude for costs to expand programs to better meet socioeconomic needs of low-income PLWH. An important consideration for funders is the indirect cost of implementation, including staff and administrative costs, which may not be covered by current funding sources and which could add an additional fundraising burden on already stretched-thin community organizations.

The per-person costs for support service expansion opportunities identified in this study were relatively low compared to other HIV-related interventions, such as patient navigation, which a recent study estimated to cost $272-4,432 (2020 USD) per person,[63] and linkage/retention interventions, with a study reporting per-person costs between $1,410-9,631 (2020 USD) depending on location.[65] Given literature supporting higher viral suppression rates among patients with stable housing and among patients who have food and financial security, increased funding for socioeconomic support services may be warranted. Expanding taxi rides was a particularly low-cost option and would address a substantial barrier to accessing HIV-related services. A recent study found lack of transportation had a direct effect on adherence to HIV treatment,[12] providing empirical support for improving transportation services. Further work could be conducted using cost-effectiveness analysis to assess the incremental value of these program expansion opportunities in comparison to each other to further aid decision-making. In fact, a recent paper underscored the importance and usefulness of cost-effectiveness analysis in implementation science to enhance uptake and scale-up of effective public health interventions, but also highlighted a need for more program implementation cost estimates.[70] This study helps fill the need for data on program expansion costs, which could be used to assess cost-effectiveness.

This study has several limitations. First, estimates of program expansion costs were rough approximations and interviewees emphasized that further time and effort would be needed by their organizations to determine more accurate predicted costs for each project. Cost estimates are therefore uncertain and should be interpreted as potential ranges that provide a sense of magnitude. Further evaluation of organization budgets, past program expansion, and program plans would be needed to ascertain more accurate estimates. Second, we did not conduct follow-up interviews with all organizations to get detailed cost estimates due to time and resource constraints. Costs presented in this paper are largely from three organizations, selected for the

range in services they provide. Third, interview notes were coded by only one researcher; however, the codebook and coding process was reviewed in depth by a qualitative research expert. Lastly, program expansion opportunities varied based on organization type, service focus area, and the scope and depth of services organizations already provide. Costs were also specific to the local context and client population (e.g., PLWH in the Minneapolis-St. Paul region served by RWHAP-funded providers). Results from this study therefore may not be widely generalizable; however, cost estimates may be reasonable approximations for other mid-size cities in the U.S. in the absence of other context-specific cost data.

Conclusions

Services that support client socioeconomic needs, such as housing, food, transportation, and financial aid, have the potential to help improve HIV outcomes. Understanding potential scale-up costs is important for funders and stakeholders when planning budgets and making resource allocation decisions. This study provides a sense of magnitude for costs to scale-up programs to better meet socioeconomic needs of low-income PLWH and can be used to inform future cost-effectiveness analyses.

Aim 4: To evaluate the potential cost-effectiveness of expanding food aid vouchers to fill unmet need

Cost-Effectiveness of Expanding Food Vouchers to Fill Unmet Need Among People Living with HIV Served by the U.S. Ryan White HIV/AIDS Program

Overview

Background: Given evidence on the adverse impacts of food, housing, and financial insecurity on adherence to HIV treatment, expanding programs that support socioeconomic needs for people living with HIV (PLWH) could be an effective strategy to improve health outcomes. This study evaluated the potential cost-effectiveness of expanding food vouchers through the Ryan White HIV/AIDS Program (RWHAP), a federal program funding services for low-income PLWH.

Methods: An individual-based model that reflects the population and HIV care dynamics of RWHAP clients in the Minneapolis-St. Paul region was developed, calibrated, and validated. Two strategies were compared over a 10-year intervention period: 60% of clients needing food vouchers received them (status quo) and 100% of clients needing food vouchers received them (intervention). Health benefits were measured in quality-adjusted life-years (QALYs) and the proportion of clients who achieved viral suppression (VS). Cost-effectiveness was estimated from a healthcare sector perspective over a lifetime horizon, with costs and QALYs both discounted at 3% annually. Additional scenarios of expanded food aid were assessed.

Results: Expanding food vouchers resulted in limited gains in population-level VS rates, from 73.5% to 74.4%. When only QALYs gained from increased VS were considered, the intervention strategy had an incremental cost-effectiveness ratio (ICER) of $31,100/QALY gained. When QALYs gained from both increased VS and reduced food insecurity were considered, the intervention had an ICER of $3,937/QALY gained and was even cost-saving in 41% of simulations. Further expanding food aid by offering more money per monthly voucher and by offering more vouchers per year, was cost-effective when QALYs gained from VS and food security were considered. Only when dollar amount tripled to $180/voucher *and* provided for an average of 12 months out of the year, did the intervention strategy become not cost-effective using a $100,000/QALY gained threshold for cost-effectiveness.

Conclusion: Expanding food vouchers to fill unmet need could be very cost-effective and potentially cost-saving for low-income PLWH. Expansion of food voucher programs could be integrated into multifaceted strategies aimed at improving HIV outcomes and achieving national HIV treatment goals.

Introduction

Both the U.S. National HIV/AIDS Strategy for 2022-2025 and the Ending the HIV Epidemic initiative include goals of achieving 95% viral suppression among people diagnosed with HIV,[7,71] however progress has been slow. Between 2017 and 2019, national rates of viral suppression only rose from 63.1% to 65.5%.[3] Achieving 95% viral suppression will require multifaceted approaches to addressing barriers to retention in care and adherence to antiretroviral therapy (ART).

Food insecurity is a well-known barrier to HIV treatment adherence and achievement of viral suppression.[12,57,58] Furthermore, evidence suggests that meeting food and other basic needs can improve adherence among people living with HIV (PLWH).[57] The federal Ryan White HIV/AIDS Program (RWHAP) provides funding for medical care and other support services for low-income PLWH. With RWHAP serving approximating 50% of all PLWH in the U.S.,[8] expanding food aid and other support services for RWHAP clients could be one of the many mechanisms needed to achieve national goals of 95% viral suppression.

Food vouchers, in particular, are a promising intervention strategy because implementation barriers are relatively low compared to other interventions: RWHAP already funds food vouchers across the U.S. and expanding vouchers may not require as much training, staff, time, and resources as implementing other interventions such as treatment adherence counseling or managed problem solving, which can require several phone or in-person sessions as well as extensive follow-up.[72,73] In addition to improving adherence, addressing food insecurity could also have the added benefit of improving health-related quality of life (HRQoL) independent from health gained from achieving HIV viral suppression.[74]

However, little work has been done to establish the cost-effectiveness of food-related interventions for PLWH, despite calls for research in this area.[57] Within HIV, prior studies have assessed the cost-effectiveness of financial incentives to promote adherence[75,76] and the cost-effectiveness of the RWHAP program as a whole,[45] yet no specific studies on cost-effectiveness

of food aid for PLWH in the U.S. have been published to our knowledge. In this study, our objective was to investigate the potential costs, benefits, and cost-effectiveness of expanding food vouchers to fill unmet need among RWHAP clients who are experiencing food insecurity.

Methods

Study Setting: We assessed the cost-effectiveness of expanding food vouchers to fill unmet need for PLWH who were eligible for RWHAP services in Minnesota. To be eligible for RWHAP services, individuals must be earning income less than 400% of the federal poverty level. A local, rather than national, study setting was chosen since prior work has shown that cost-effectiveness results can vary substantially in different regions of the U.S.[77,78] RWHAP in Minnesota serves a diverse population of clients, with most clients located in the thirteen-county region surrounding Minneapolis-St. Paul grant.

Model Description: An individual-based model of HIV care with annual time steps was developed that simulates care dynamics for PLWH eligible for RWHAP services (see Appendix for full details). Individuals entered the model upon diagnosis and each year had a probability of transitioning between four main states: 1) *In RWHAP/Virally Suppressed*, 2) *In RWHAP/Not Virally Suppressed*, 3) *Out of RWHAP/Virally Suppressed*, and 4) *Out of RWHAP/Not Virally Suppressed*. "In RWHAP" was defined as using RWHAP services for six or more months out of the year (i.e., actively engaged). "Out of RWHAP" was defined as using no services or using services for less than six months out of the year. Virally suppressed was defined as sustained viral suppression, meaning the client was suppressed for the entire year. The model did not include HIV transmission due to the study's focus on retention and adherence post-diagnosis. Model inputs were parameterized using five years of local RWHAP demographic, viral load, and service use data, published sources, and calibration when data was not available **(Table 8).** The model was initialized with 4,000 individuals, of whom 71% were male, 66% had chronic HIV, 34% had AIDS, and mean age was 45 years (range 18-89 years). In the absence of intervention, 54% of individuals were *In RWHAP/VS*, 10% were *In RWHAP/Not VS*, 21% were *Out of RWHAP/VS*, and 15% were *Out of RWHAP/Not VS*. An average of 232 new patients entered the model each year, which reflects the number of new, RWHAP-eligible HIV diagnoses between 2017-2019. Model validation involved ensuring model results reflected historic all-cause and HIV-related mortality rates. Each year, individuals accrued costs and quality-adjusted life years (QALYs) based on their CD4 cell count, RWHAP engagement, viral suppression status, and food security status.

Comparator and Intervention Strategies: The comparator/status quo strategy reflected the current state of RWHAP service engagement, viral suppression rates, and food voucher use. A recent survey-based needs assessment found an estimated 50% of RWHAP clients in Minneapolis-St. Paul did not need food vouchers, 30% needed and received vouchers, and 20% needed but did not receive vouchers (i.e., 20% unmet need overall, or 40% unmet need among those who needed food vouchers).[79] Clients who needed food aid experienced a HRQoL decrement of 0.11 because food insecurity adversely impacts an individual's health and ability to participate in social roles.[74] The average number of food vouchers received per year was 3.8 with an average cost of $60 per voucher. Based on an analysis evaluating the impact of RWHAP services on sustained viral suppression, receiving food vouchers was associated with a 3 percentage point higher probability of achieving viral suppression.[68]

The intervention strategy filled unmet need for food vouchers, providing vouchers to the 20% of clients who needed but did not receive them, such that all clients who needed vouchers received them. However, it was assumed that only clients *In RWHAP* could receive food vouchers because local data showed than only 2.6% of clients *Out of RWHAP* (receiving <6 months of services) engaged in food voucher services. It was assumed the voucher cost and average number of vouchers received was the same in the intervention and comparator strategies (3.8 vouchers/year at $60/voucher). The intervention strategy had costs associated with outreach: $6,240 in year 1 to reach and engage the 20% of clients with unmet need and $960 in subsequent years to maintain current clients and engage newly diagnosed clients in need of food vouchers. Estimated outreach costs were obtained through correspondence with the Minneapolis-based non-profit organization that currently administers RWHAP-funded food vouchers in the region.

For the base case, the status quo and intervention strategies were assessed under two scenarios. In Scenario 1, receiving food vouchers only improved the probability of gaining viral suppression and had no impact on HRQoL due to food insecurity. In Scenario 2, receiving food vouchers both improved the probability of gaining viral suppression *and* eliminated the food insecurity HRQoL decrement. Scenario 1 was chosen because it was supported by evidence from local RWHAP data and results reflect the cost-effectiveness if policy makers were concerned only with gains in QALYs due to improved viral suppression. Scenario 2 was chosen to reflect the potential broader health gains achieved from addressing food insecurity alongside gains in viral suppression.

The model began simulation in 2020 and used a 10-year intervention period to align with plans to reach national goals by 2030. The model continued simulation until 2040 to capture downstream

residual effects of the intervention (such as higher rates of viral suppression that extend beyond the intervention end date). After 2040, no newly diagnosed people entered the model and the lifetime costs and QALYs for the people remaining in the model were calculated for the cost-effectiveness analysis.

Table 8. Selected Model Parameter Values

Parameter	Value	Source
Intervention-Related Parameters		
Proportion of clients who need food aid	50%	RWHAP 2020 Needs Assessment[79]
Proportion of clients who receive food aid among those who need it	60%	
Mean number of $60 food vouchers received in a year, per-person	3.8 (sd 2.2)	Local data analysis
HRQoL decrement when experiencing food insecurity (Scenario 2 only)	0.11	Hanmer 2021[74]
Multiplier on probability of gaining VS in RWHAP if experiencing food insecurity	0.44	Local data analysis; calibration
Average cost per food voucher received	$60	Local data analysis
Upfront outreach/operational cost (year 1)	$6,240	Personal correspondence (5/10/2022)
Annual outreach/operational cost (yrs 2-10)	$960	
CD4 Cell Count (cells/µl)		
Annual increase when VS	16	Trotta 2010[80]
Annual decrease *Out of RWHAP/Not VS*	66	Touloumi 2013[81]
Annual decrease *In RWHAP/Not VS*	20	Schultze 2018[82]
Maximum count	1500	Veterans Affairs 2019[83]
Health-Related Quality of Life Utility Values		
In or Out of RWHAP, VS, CD4<200	0.87	Miners 2014[84]
In or Out of RWHAP, VS, CD4>200	0.89	
In RWHAP, Not VS, CD4<200	0.85	
In RWHAP, Not VS, CD4>200	0.89	
Out of RWHAP, Not VS, CD4<200	0.82	
Out of RWHAP, Not VS, CD4>200	0.87	
Age-Adjustment	-0.003	
Medical Costs for Patients In RWHAP/VS, In RWHAP/NotVS, and Out of RWHAP/VS		
CD4<500	$45,714	Enns 2019[85]
CD4 200-499	$46,419	
CD4 <200	$49,695	
Medical Costs for Patients Out of RWHAP/Not VS		
CD4<500	$5,242	Enns 2019[85]
CD4 200-499	$6,319	
CD4 <200	$13,455	
Ryan White HIV/AIDS Program Service Costs		
Virally Suppressed	$5,545	Goyal 2020[45]
Not Virally Suppressed	$10,374	

Costs are in 2018 USD.

Model Outcomes: For each strategy, the total lifetime costs, total 10-year intervention cost, total lifetime QALYs gained, average viral suppression rates over the 10-year intervention period, and

incremental cost-effectiveness ratios (ICERs) were reported. ICERs were calculated by dividing the difference in total discounted costs by the difference in discounted QALYs for the comparator vs. intervention strategy. Costs were standardized to 2018 USD using the U.S. consumer price index for medical care. Following best practice recommendations, both costs and QALYs were discounted 3% annually and calculated over a lifetime horizon.[86] A cost-effectiveness threshold of $100,000/QALY gained was used.

Additional Analyses: Plausible policies to further expand food aid through vouchers include increasing the dollar amount per monthly voucher and increasing the number of vouchers per year that patients can receive. Under both Scenarios 1 and 2, analyses were conducted that doubled ($120), tripled ($180), and quadrupled ($240) the dollar amount per voucher. Analyses were also conducted that increased the mean number of food vouchers received from 3.8 to 12 per year (SD=2.2), reflecting a policy where all monthly food voucher requests from patients were fulfilled (this policy was actually implemented by the Minneapolis-St. Paul RWHAP jurisdiction starting in 2020). In all additional analyses that expanded food aid, it was assumed effectiveness remained at the same level as in the base case since there was no available data to support estimates for increased effectiveness.

Results

The model was well-fit to calibration and validation targets (additional details are presented in the Appendix). In both base case scenarios, only small gains in population-level viral suppression rates were achieved, from 73.5% without expanded food vouchers to 74.4% with expanded food vouchers (**Table 9**). In Scenario 1, where food vouchers only impacted the probability of gaining viral suppression, gains in QALYs were limited, with only 78 QALYs (discounted) gained in the population. However, the intervention had an ICER of $31,100/QALY gained, which was still considered cost-effective in the U.S. context.

In Scenario 2, where food vouchers improved viral suppression rates and HRQoL, there were much larger gains in QALYs, with 612 QALYs gained in the population. Compared to the status quo, the intervention strategy had an ICER of $3,937/QALY gained, which was highly cost-effective. Regarding affordability, compared to the status quo the intervention strategy cost an additional $1,476,600 (undiscounted) over 10 years, or an average of $147,660 additional per

year. This accounted for a 58% increase in the total amount spent on food vouchers in the status quo strategy.

Table 9. Base Case Results

Strategy	Avg. Viral Suppression Rate	QALYs (disc)	Total Cost (disc, millions)	10-Year Intervention Cost (undisc, millions)	ICER (Cost/QALY Gained)
Scenario 1: Food Vouchers Only Improve Probability of Viral Suppression					
Status Quo	73.5%	103,683	7,132.8	2.54	-
Intervention	74.4%	103,760	7,135.2	4.01	-
Difference	0.9%	78	2.4	1.48	$31,110
Scenario 2: Food Vouchers Improve HRQoL and Probability of Viral Suppression					
Status Quo	73.5%	106,950	7,132.8	2.54	-
Intervention	74.4%	107,563	7,135.2	4.01	-
Difference	0.9%	612	2.4	1.48	$3,937

Avg.: average; QALY: quality-adjusted life year; disc: discounted at 3%, USD: U.S. dollars; ICER: incremental cost-effectiveness ratio. Costs are reported in 2018 USD.

Increasing costs of the program through further food voucher expansions while keeping effectiveness assumptions at base case levels was not cost-effective when only considering QALYs gained from increased viral suppression (**Table 10, Scenario 1; Figure 7**). However, when QALYS gained from increased viral suppression and reduced food insecurity were considered, most food aid expansions remained cost-effective (**Table 10, Scenario 2; Figure 7**). Only when the cost per voucher was tripled to $180/month or higher *and* provided for an average of 12 months did food aid expansion become not cost-effective (ICER>$100,000/QALY gained).

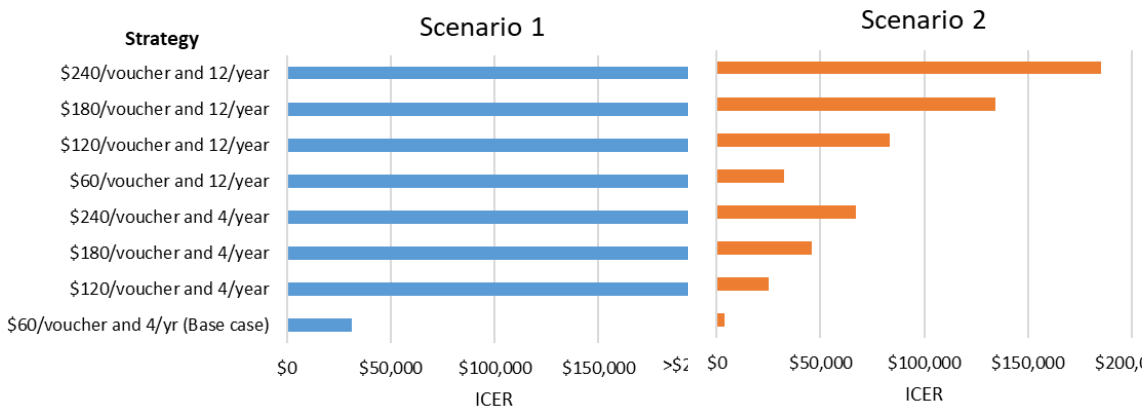


Figure 7. Incremental Cost-Effectiveness Ratios Compared to Status Quo Strategy
Under Scenario 1, where only QALYs gained from improved viral suppression is accounted for, most strategies have ICERs >$200,000/QALY gained. Under Scenario 2, where QALYs gained from improved viral suppression and improved food security are accounted for, most strategies are below $150,000/QALY gained.

Regarding intervention costs, further expansion strategies cost between $5.47 million to $36.16 million (undiscounted) more than the status quo strategy over 10 years. Average annual intervention costs were an additional $547,404/year for doubling voucher amounts to $120/month and up to $3.6 million additional/year for quadrupling voucher amounts to $240/month *and* providing an average of 12 vouchers per year.

Table 10. Scenario Analyses Expanding Food Voucher Aid While Effectiveness Remains Constant

Strategy	Avg. VS Rate	QALYs (disc)	Total Cost (disc, millions)	10-Yr Intervention Cost (undisc, millions)	ICER Compared to Status Quo (Cost/QALY Gained)
Scenario 1: Food Vouchers Only Improve Probability of Viral Suppression					
Status Quo	73.5%	103,683	7,132.8	2.54	-
$120/voucher	74.4%	103,760	7,148.1	8.01	$197,212
$180/voucher			7,161.0	12.01	$363,314
$240/voucher			7,173.8	16.00	$529,416
$60/voucher and 12/year			7,152.8	9.68	$257,993
$120/voucher and 12/year			7,183.9	19.35	$659,670
$180/voucher and 12/year			7,215.1	29.02	$1,061,348
$240/voucher and 12/year			7,246.2	38.69	$1,463,025
Scenario 2: Food Vouchers Improve HRQoL and Probability of Viral Suppression					
Status Quo	73.5%	106,950	7,132.8	2.54	-
$120/voucher	74.4%	107,563	7,148.1	8.01	$24,960
$180/voucher			7,161.0	12.01	$45,983

$240/voucher			7,173.8	16.00	$67,006
$60/voucher and 12/year			7,152.8	9.68	$32,653
$120/voucher and 12/year			7,183.9	19.35	$83,491
$180/voucher and 12/year			7,215.1	29.02	$134,329
$240/voucher and 12/year			7,246.2	38.69	$185,168

VS: Viral suppression; QALY: quality-adjusted life years; disc: discounted at 3% annually; undisc: undiscounted; ICER: incremental cost-effectiveness ratio.

Discussion

Expanding food vouchers to fill unmet need was highly cost-effective when the broader HRQoL gains associated with reduced food insecurity were taken into account. Clinical gains in viral suppression rates were limited, with only a 0.9% increase associated with expanded food vouchers during the intervention period. This increase does not come close to the substantial gains needed to reach the U.S. national goal of 95% viral suppression by 2030. However, given the slow progress on improving viral suppression rates nationwide, with only approximately 1% absolute increases each year between 2017 and 2019,[3] the addition of expanded food vouchers to other interventions aimed at treatment adherence and retention may be worthwhile. Furthermore, expanding food vouchers could be a relatively easy-to-implement strategy since RWHAP already has an infrastructure and system in place for distributing food vouchers to low-income PLWH.

In the base case, expanding food vouchers at $60/month with an average of 3.8 vouchers/year such that 100% of patients who needed vouchers received them had an ICER of between $3,937/QALY gained to $31,110/QALY gained compared to the status quo, depending on whether or not QALYs gained from reducing food insecurity were included. Regardless, both scenarios are highly cost-effective in the U.S. context where $50,000-$100,000/QALY gained has long been considered a threshold for cost-effectiveness, with some making the case that $150,000/QALY gained is a more appropriate threshold for the U.S. health system.[15,87] Expanding food vouchers to fill unmet need would therefore be a high value intervention. Even when intervention costs were increased through higher dollar amounts per voucher and/or more vouchers per year, the intervention was still cost-effective in most expansion strategies when broader HRQoL gains from reduced food insecurity were accounted for.

No prior literature was identified that estimated the cost-effectiveness of food aid or food vouchers for PLWH in the U.S. The most comparable studies assessed the cost-effectiveness of incentivizing healthy food purchases through Medicare and Medicaid or through the

Supplemental Nutrition Assistance Program (SNAP); both studies assessed benefits gained in terms of reduced cardiovascular disease and/or diabetes.[88,89] In HIV, the most comparable intervention was the use of financial incentives to promote viral suppression. Two recently published studies assessed the cost-effectiveness of trial-based financial incentive programs.[75,76] The first assessed results of the HPTN 065 study that provided up to $70/quarter for suppressed viral load test results to PLWH in New York City and Washington DC.[75] This modeling study used a healthcare sector perspective and lifetime horizon, finding an ICER of $49,877/QALY gained (2017 USD) for financial incentives compared to no incentives. In the second study, patients could earn up to $3,650/year to achieve and maintain viral suppression in Baltimore.[76] Using intervention costs, assumptions about QALYs gained from averted infections and viral suppression, and assumptions about averted lifetime HIV costs due to averted infections, the study team estimated an ICER of $28,888/QALY gained (2019 USD). Both studies found financial incentives to be a cost-effective strategy to improve viral suppression. Notably, these studies included QALYs gained and costs averted from averted HIV infections when estimating ICERs. Our study on food vouchers did not include benefits gained or costs averted from HIV infections prevented due to more people being virally suppressed. If the benefits of HIV prevention were included, the food voucher intervention could have even more favorable ICERs.

Care coordination programs are also common interventions to encourage improvements in viral suppression. A study of medical care coordination for men-who-have-sex-with-men in Los Angeles County found the intervention was cost-effective, with ICERs ranging from $25,200-$77,400/QALY gained over a lifetime horizon depending on patient acuity level (2017 USD).[44] In contrast, a study on scale-up care coordination for high risk PLWH in New York City found the intervention to be not cost-effective, with ICERs ranging from $423,721-$720,970/QALY gained over a 20-year horizon depending on assumptions made about enrollment (2017 USD). These authors concluded that the NYC-based intervention would need reduced costs and/or more targeted scale-up to become cost-effective, but noted that the intervention may be more cost-effective in cities with lower baseline viral suppression rates. In a similar vein, a study analyzing HIV treatment and prevention interventions in six U.S. cities found substantial variation in ICERs between cities for each intervention. Untargeted ART retention was not cost-effective in any city, targeted ART retention had ICERs between $61,000-$108,000/QALY gained, and ART re-initiation had ICERs between $65,000-$130,000/QALY gained, depending on location (2018 USD). Compared to these care coordination and ART-focused interventions, our study found that

expanding food vouchers typically had lower ICERs ($3,937-$31,110/QALY gained, 2018 USD) in the local context of Minneapolis-St. Paul.

Limitations:

- Deterministic sensitivity and scenario analyses conducted in this study focused on food voucher costs and basic HRQoL assumptions since these were highly policy-relevant parameters. Future work could more fully explore the impact of uncertainty in model parameters on cost-effectiveness results through more extensive deterministic sensitivity analyses or a probabilistic sensitivity analysis. Sensitivity analyses could incorporate other key model parameters such as those related to the intervention (including intervention effectiveness) as well as model parameters related to HIV disease progression and care dynamics (including changes in CD4 count, rate of AIDS-defining events, and probabilities of gaining or losing viral suppression).
- Entry into the model was assumed to be constant over a 20-year period, with an average of 232 new diagnoses per year. While HIV infections have remained relatively stable over the past five years, it is difficult to predict the trajectory of HIV incidence and diagnosis 20 years into the future. Reductions in HIV diagnoses is an area that has actually made substantial progress in recent years on a national scale: diagnoses were relatively stable at 37,000/year between 2017-2019, but have since dropped to approximately 22,300 in 2021, making gains towards national goals of achieving less than 10,000 new diagnoses in 2025 and less than 4,000 in 2030.[3] Additional model analyses could vary the assumption of constant HIV diagnoses, and instead assume decreases in new diagnoses over time.
- In Scenario 2 where food vouchers impacted both viral suppression rates and HRQoL due to food insecurity, it is possible that receiving food vouchers would not completely eliminate the HRQoL decrement associated with food insecurity. In interviews with service providers who administered RWHAP food vouchers, program staff voiced concerns about whether the status quo value of food vouchers ($60/month) was truly effective in helping clients who were experiencing food insecurity.[90] Scenarios that increased dollar amount per voucher and increased vouchers received to 12 per year would more plausibly reduce or eliminate the HRQoL decrement from food insecurity, however these scenarios were more expensive and had higher ICERs. Future analyses could assess partial elimination of the food insecurity HRQoL decrement with food voucher use, with impact on HRQoL dependent on the amount of food aid received.

- The decrement in HRQoL due to food insecurity was 0.11, which was higher than any HRQoL decrements related to HIV progression and treatment status. A recent nationally-representative U.S. study found HRQoL decrements associated with food insecurity to be between 0.11-0.21; to be conservative, the lowest value of 0.11 was used for the analysis.[74] In contrast, the largest HIV-related HRQoL decrement was 0.07 between individuals who were virally suppressed with CD4 counts>200 (HRQoL=0.89) and individuals who were out of RWHAP, not virally suppressed, and had CD4 counts<200 (HRQoL=0.82).[84] While this is not explicit limitation, readers should be aware that the cost-effectiveness of the intervention was more dependent on QALYs gained from addressing food insecurity than from improving HIV-related outcomes. As noted above, further work could be done to assess uncertainty and assumptions made about food insecurity HRQoL.
- As noted earlier, this study did not include the potential benefits and averted costs due to HIV prevention with higher viral suppression rates, making the cost-effectiveness estimates more conservative. If HIV prevention benefits and averted costs were included, ICERs for expanding food vouchers would be even lower. However, the overall gain in viral suppression was limited (0.9%), so the impact on ICERs if benefits associated with HIV prevention were included may be small.
- This analysis was conducted in the local context of the 13-county RWHAP jurisdiction surrounding Minneapolis-St. Paul in Minnesota, which is both a strength and limitation. Prior cost-effectiveness studies in the U.S. have shown that results can be highly dependent on the context of where an intervention is implemented.[77,78] An intervention may be cost effective in one U.S. city, but not in another, depending on the location-specific HIV epidemiology, patient risk groups, and current state of HIV care. By conducting the analysis in the Minnesota context, a strength is that local data was used whenever possible to inform model parameters such that results would be tailored to reflect cost-effectiveness of the intervention in a real-world setting. However, the generalizability of the results to other cities or regions may be limited.

Directions for Future Research: In addition to addressing the limitations described above, future work could examine the cost-effectiveness of other socioeconomic support programs such as housing support, transportation aid, financial assistance, and meal-based food aid. These programs could be assessed as stand-alone interventions and in combination with one another. From a policy perspective, having cost-effectiveness evidence for these types of socioeconomic

programs can be useful for making the case for continued and/or increased funding to support them. Future studies could also work to inform resource allocation decisions by modeling several interventions and intervention combinations, including both socioeconomic interventions and more traditional biomedical or public health interventions. By simulating different interventions within the same model (rather than comparing across models and publications), a more straightforward understanding of how to allocate resources within a given context would be gained. Lastly, future work could investigate how expanding programs might help reduce disparities in HIV outcomes. For example, analyses could further target interventions towards populations with worse HIV outcomes and/or higher levels of need, such as having the monthly amount per food voucher scaled by income level (e.g., people living below 100% of the federal poverty level could receive higher dollar amounts per month than people living between 300-400% of the federal poverty level).

Conclusions

Findings suggest that expanding food vouchers to fill unmet need could be very cost-effective when QALYs gained from reduced food insecurity and improved HIV outcomes are both considered. Results support continued funding for food vouchers and similar programs that address socioeconomic challenges for PLWH. Expansion of food voucher programs could be integrated into multifaceted strategies aimed at improving HIV outcomes and achieving national HIV treatment goals.

Final Discussion

HIV continues to have a significant impact on public health and healthcare system spending, with over 1.2 million people infected in the U.S. and an estimated lifetime cost of $1,080,000 per person (2019 USD, undiscounted).[91] Recent efforts have been undertaken on a national scale to end the HIV epidemic in the U.S. by 2030.[6,7] Alongside diagnosis and prevention, goals have been set for improved care retention and treatment adherence. Yet with limited funding, decisions need to be made about how to efficiently use available resources to work towards National HIV/AIDS Strategy goals.

This dissertation focused on retention in care and adherence to treatment, which typically receive less attention than initiatives related to diagnosis and prevention despite being critical to the long-term health of PLWH. This dissertation contributed four key findings to the field:

1) A systematic review of the literature found that retention and re-engagement efforts were usually cost-effective in high-income settings, depending on the local context of implementation.
2) A causal analysis of local data from the federal Ryan White HIV/AIDS Program found services that directly addressed socioeconomic needs of low-income PLWH typically had positive impacts on viral suppression.
3) Qualitative interviews with HIV service providers revealed several opportunities for expanding socioeconomic support services at relatively low annual costs per patient.
4) A cost-effectiveness analysis found that expanding food vouchers to fill unmet need could be highly cost-effective, particularly when the broader health benefits of reducing food insecurity were taken into account.

There is growing evidence on the importance of social determinants of health on improving HIV outcomes. This dissertation applied a wide range of health services research methods to advance our knowledge of the costs, benefits, and cost-effectiveness of strategies to improve retention and adherence, with a focus on socioeconomic programs. Furthermore, it is one of few, if not the only, published study that evaluates the cost-effectiveness of programs designed to address HIV patient food needs in the U.S. Research into the cost-effectiveness of socioeconomic support programs to improve HIV outcomes is still in a nascent stage. There is ample opportunity for future research to investigate the cost-effectiveness of additional socioeconomic support services, or more comprehensive support such as universal income approaches, as well as the combination

of socioeconomic support offered alongside more traditional medical and public health approaches to improving HIV health outcomes.

Final Conclusion

Retention in care and adherence to treatment are critical steps to ending the HIV epidemic in the U.S. Multifaceted strategies will be needed to make meaningful progress towards achieving national goals. Services that address the socioeconomic needs of people living with HIV could be effective and cost-effective approaches to improve HIV outcomes, particularly if paired with other evidence-based programs.

Appendices

Aim 1 Appendix

Contents

Table 1. Search Strategies, by Database

Database	Search Term
MEDLINE (via OVID)	1. exp HIV/ 2. hiv*.mp. 3. cost-effective*.mp. 4. cost-utility.mp. 5. exp "Costs and Cost Analysis"/ 6. exp Cost-Benefit Analysis/ 7. economic evaluation.mp. 8. economic impact.mp. 9. retain.mp. 10. retention.mp. 11. non-retention.mp. 12. engage*.mp. 13. re-engage*.mp. 14. disengage*.mp. 15. re-link*.mp. 16. re-entry.mp. 17. re-enter.mp. 18. care cascade.mp. 19. continuum.mp. 20. 3 or 4 or 5 or 6 or 7 or 8 21. 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 22. 1 or 2 23. 20 and 21 and 22 24. limit 23 to english 25. limit 24 to dt=20100101-20201031
EMBASE	1. exp HIV/

	2. hiv*.mp. 3. cost-effective*.mp. 4. cost-utility.mp. 5. exp "Costs and Cost Analysis"/ 6. exp Cost-Benefit Analysis/ 7. economic evaluation.mp. 8. economic impact.mp. 9. retain.mp. 10. retention.mp. 11. non-retention.mp. 12. engage*.mp. 13. re-engage*.mp. 14. disengage*.mp. 15. re-link*.mp. 16. re-entry.mp. 17. re-enter.mp. 18. care cascade.mp. 19. continuum.mp. 20. 3 or 4 or 5 or 6 or 7 or 8 21. 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 22. 1 or 2 23. 20 and 21 and 22 24. limit 23 to english 25. limit 24 to dd=20100101-20201031
PubMed	(("Costs and Cost Analysis"[Mesh]) OR "Cost-Benefit Analysis"[Mesh] OR cost-effective* OR cost-utility OR "economic evaluation" OR "economic impact") AND ("HIV"[Mesh] OR HIV OR HIV/AIDS) AND (retain OR retention OR non-retention OR engage* OR re-engage* OR disengage* OR re-link OR re-entry OR re-enter OR "case cascade" OR continuum)
EconLit	(cost-effective* OR "cost-utility" OR "economic evaluation" OR "economic impact") AND (hiv OR HIV/AIDS)
Web of Science	(ALL = ((cost-effective* OR cost-utility OR "economic evaluation" OR "economic impact") AND ("HIV" OR "HIV/AIDS") AND (retain OR retention OR non-retention OR engage* OR re-engage* OR disengage* OR re-link OR re-entry OR re-enter OR "case cascade" OR continuum))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) Timespan: 2010-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.

Table 2a. Extracted Data, Analytic Methods

Author, Year	Country	Model Type	Perspective	Time Horizon	Intervention Period	Discounting	Currency Year
Goyal, 2021	United States	Agent-based stochastic model	Healthcare sector	50 years	NA; used counterfactual scenarios	3% costs and QALYs	USD 2016
Nosyk, 2020	United States	Dynamic compartmental transmission model (Nosyk/Krebs)	Healthcare sector	20 years	10 years	3% costs and QALYs	USD 2018
Krebs, 2019	United States	Dynamic compartmental transmission model (Nosyk/Krebs)	Healthcare sector	20 years	10 years, including 18-month scale up	3% costs and QALYs	USD 2018
Nosyk, 2018	Canada	Dynamic compartmental transmission model (Nosyk/Krebs)	Government or 3rd party-payer	5, 10, and 25 years	2 years	3% costs and QALYs	CAD 2015
Flash, 2019	United States	Microsimulation (CEPAC-US)	Healthcare sector	Lifetime	2 years	3% costs and QALYs	USD 2017
Borre, 2017	United States	Microsimulation (CEPAC-US)	NR; appears to be healthcare sector	5 and 20 years	NA; used counterfactual scenarios	3% for ICERs	USD 2014
Kasaie, 2018	Spain	Compartmental transmission model during system of ODE (JHEEM)	Healthcare sector	20 years	NA; used counterfactual scenarios; secondary analysis used 20-yr intervention period and 10-20 yr follow-up	3% costs and QALYs	EUR 2017
Shah, 2016	United States	Compartmental transmission model during system of ODE (JHEEM)	Societal, but appears to be healthcare sector	20 years	NR; seems to be for duration of entire time horizon (e.g., counterfactuals)	3% costs and QALYs	USD 2014
Lin, 2016	United States	Bernoulli process model for transmission; CE estimates are not model based	Societal, but appears to be healthcare sector	NR	NR	3% costs; QALY discounting appears to be 3%	USD 2012

Maulsby, 2018	United States	Not model based	Societal	NR; seems to be 1 year	3-5 years	Lifetime cost of care is discounted but rate is NR	USD 2013
Jain, 2016	United States	Not model based	Societal; reported in Kim 2015	NR; seems to be ~3 years	3 years	QALYs are discounted, but rate is NR	USD; year NR – likely 2013

Abbreviations: QALYs: quality-adjusted life years; USD: United States dollars; CAD: Canadian dollars; EUR: euros; CEPAC-US: Cost-Effectiveness of Preventing AIDS Complications- United States model; JHEEM: The Johns Hopkins HIV Economic-Epidemiologic Mathematical Model; ICERs: incremental cost-effectiveness ratios; NR: not reported; NA: not applicable; CE: cost-effectiveness; ODE: ordinary differential equations.

Table 2b. Extracted Data, Interventions

Author, Context	Population	Intervention Type	Intervention Description	Comparators
Goyal, 2021 National Real-World	PLWH in United States	Retention Targeted	Ryan White services that consist of: outpatient ambulatory health services (OAHS), ART, and ancillary services, including medical case management (MCM), mental health and substance abuse services, and other services (non-MCM, transportation, etc.)	Counterfactual scenario with no Ryan White program. Assumed that in the absence of Ryan White only uninsured clients would lose access to medical/support services.
Nosyk, 2020 Urban Real-World	Depends on intervention (general, MSM, PWID)	Both retention and re-engmt Targeted and untargeted scenarios for retention	16 interventions (5 related to retention/re-engmt) from CDC Compendium and recent literature. All possible combinations of interventions for a total of 23,040 unique strategies 1) Care coordination for ART retention - all people 2) Care coordination for ART retention - CD4<200 3) EMR alert of suboptimal ART engmt 4) Enhanced personal contact for ART re-engmt 5) Re-linkage program (outreach intervention using clinical and surveillance data)	Intervention/combination strategies compared to next best strategy Other interventions included: **HIV prevention**: 6) Syringe exchange, 7) MOUD - methadone, 8) MOUD - buprenorphine, 9) PrEP **Testing**: 10) Opt-out PCP, 11) Opt-out ED, 12) EMR reminder, 13) Nurse initiated rapid testing, 14) integrated rapid testing **ART initiation**: 15) Case mgmt for ART initiation, 16) RAPID ART initiation
Krebs, 2019 Urban Real-World	Depends on intervention (general, MSM, PWID)	Both retention and re-engmt Targeted and untargeted scenarios for retention	16 interventions (5 related to retention/re-engmt) from CDC Compendium and recent literature: 1) Care coordination for ART retention - all people 2) Care coordination for ART retention - CD4<200 3) EMR alert of suboptimal ART engmt 4) Enhanced personal contact for ART re-engmt 5) Re-linkage program	All interventions compared to status quo Other interventions same as Nosyk 2020 above

Nosyk, 2018 Urban Real-World	Adults in British Columbia ages 15-64	Both retention and re-engmt Untargeted	BC Ministry of Health STOP HIV/AIDS Pilot Program (2011-2013) 1) Retention: Case management to maintain adherence and help with re-engagement among those who discontinued. Adherence support provided one-on-one on an as needed basis. Outreach to locate disengaged patients was conducted by outreach workers	All interventions compared to status quo Other interventions included: 2) Hospital-based testing 3) ED testing 4) Outpatient testing 5) ART initiation 6) Combined interventions, effect for 2 years 7) Combined, sustained effect after 2 years
Flash, 2019 Urban Real-World	High risk PLWH in Los Angeles county; stratified by acuity	Retention only Targeted	Medical care coordination - multidisciplinary teams at Ryan White clinics assist with patient needs related to health, linkage, retention, adherence, risk behaviors, and psychosocial issues	Status quo: No medical care coordination
Borre, 2017 National Hypothetical	Two scenarios: 1) General PLWH in US 2) Black MSM	Both retention and re-engmt Targeted and untargeted scenarios	Hypothetical intervention that achieves NHAS targets of 90% diagnosed and 80% virally suppressed; includes increased testing rates, linkage rates, and high impact intervention for adherence and retention that achieves 89% retention at 24-months for general PLWH and 86% retention for Black MSM	Status quo: Current pace of detection, linkage, retention, and viral suppression
Kasaie, 2018 National Hypothetical	PLWH in Spain	Both retention and re-engmt Untargeted	Primary analysis: Early ART at any CD4 count Secondary analysis: Early ART initiation with improved testing, improved linkage, and improved retention. Retention modeled as 5% annual loss from care	Status Quo: Delayed ART initiation until CD4 <350
Shah, 2016 National Hypothetical	PLWH in United States	Both retention and re-engmt Untargeted	Hypothetical intervention that results in 50% decrease in yearly rate of disengagement and 50% increase in yearly rate of re-engagement	All strategies are compared to <u>status quo:</u> Early ART and current levels of care Other strategies include: targeted screening, general screening, targeted screening with improved linkage, and targeted screening with improved linkage & retention
Lin, 2016 National Hypothetical	General population and PLWH	Retention only Retention is untargeted	Hypothetical retention intervention; few details provided	Status quo; few details provided

Maulsby, 2018 Urban & Rural Real-World	PLWH; Depends on intervention: 1) Out of care 2) Out of care 3) Mental health or substance abuse 4) Women of color 5) Black MSM, Latinx, women of color, youth 6) Out of care 7) Rural	Both retention and re-engmt Targeted	Access to Care (A2C) Intervention: National linkage, retention, & re-engagement 1) Boston: Advocacy teams; Economic stability 2) Chicago: Peer navigators & case mgmt for continuous medical and social support 3) NYC: Mobile engmt teams with intensive navigation, case mgmt, and re-engmt spport 4) San Diego: Mobile and home peer navigation 5) Indianapolis: Linkage specialist; customized care plans 6) St. Louis: Care team address barriers, supports engmt 7) Montgomery: Telemedicine for rural areas	Not directly defined – assumed to be status quo in absence of intervention
Jain, 2016 Urban Real-World	Hardest-to-reach PLWH, varied by site: 1) High-risk MSM 2) High-risk 3) Low-income	Both retention and re-engmt Targeted	Positive Charge Intervention: Designed to improve linkage, retention, and re-engagement 1) Chicago: Peer navigation, case mgmt, support services, peer-led group intervention for treatment efficacy (6-9 mo.) 2) Louisiana: Patient navigation, prison release case mgmt, linkage case mgmt and support from specialist (3-6 months) 3) NYC: Case mgmt, HIV PCP, nurse care coordinator, peer outreach, navigators, behavioral health providers (as needed)	Not directly defined – assumed to be status quo in absence of intervention

Abbreviations: PLWH: people living with HIV; MSM: men-who-have-sex-with-men; PWID: people who inject drugs; ART: antiretroviral therapy; PrEP: Pre-exposure prophylaxis; CDC: Centers for Disease Control and Prevention; PCP: primary care provider; ED: emergency department; EMR: electronic medical record; MOUD: medication for opioid use disorder; Mgmt.: management; Engmt: engagement; NHAS: US National HIV/AIDS Strategy.

Table 2c. Extracted Data, Cost-Effectiveness Results

Author, Year Country	Cost-Effectiveness Ratio (Cost/QALY gained) as reported in original papers	Cost-Effectiveness Threshold	Main Finding about Retention or Re-Engagement
Goyal, 2021 United States	RWHAP vs No RWHAP: $29,573/QALY gained	1x GDP per capita for very cost-effective ($57,467 in 2016)	RWHAP program is very cost-effective and has substantial impact on retention in care; cannot determine cost-effectiveness of specific components of RWHAP, such as ancillary services, that impact retention directly
Nosyk, 2020 United States	Optimal combination strategies had ICERs ranging from cost-saving to $2,789,316/QALY gained, depending on city: Atlanta: Cost-saving (CS) to $136,718 Baltimore: CS to $2,789,316 Los Angeles: CS to $138,018 Miami: All CS New York City: CS to $465,013 Seattle: CS to $1,692,430	$100,000/QALY gained	- Untargeted retention is never in optimal strategy - Among combination strategies that were cost-effective, between 1-4 retention/re-engagement strategies were included, depending on city. EMR alert was least commonly included. - Among strategies that were optimal but not cost-effective, all 4 retention/re-engagement strategies were included in all cities
Krebs, 2019 United States	Compared to status quo, in 6 U.S. cities: ART Retention: $130,000-$200,000+ ART Retention, targeted: $61,000-$108,000 EMR Alert: $70,000-$136,000 ART Re-Engmt: $65,000-$130,000 Re-Linkage: $65,000-$129,000	$100,000/QALY gained	- Cost-effectiveness varied by city - Untargeted retention was not cost-effective in any city - Remaining interventions were mostly cost-effective in all cities except Atlanta - ICERs were comparable between retention and re-engagement strategies by city
Nosyk B, 2018 Canada	ART Retention vs. status quo, by time horizon: 5-year: $CAD 471,385 10-year: $CAD 317,911 25-year: $CAD 159,551	3x GDP per capita ($51,135x3 = $CAD 153,405 in 2015)	- Retention was not cost-effective, even at 25-yr horizon - Retention ICER never fell below $50,000 even when doubling effectiveness and decreasing costs by 90%
Flash, 2019	MMC vs. status quo, reported by acuity level: All acuity levels: $27,400 Severe Acuity: $30,500	$100,000/QALY gained	Cost-effective for all patient subgroups; best ICER when moderate acuity patients are targeted

United States	Moderate Acuity: $25,200 Low Acuity: $77,440		
Borre, 2017 United States	NHAS Goals vs. status quo, by target population: General U.S. Population: $68,900 Black MSM: $38,300	$100,000/QALY gained	Cost-effective for both general population and for high risk population (Black MSM)
Kasaie, 2018 Spain	Early ART with improved testing, linkage, and retention vs. delayed ART: €34,400 (95% CI: €15,600-49,200)	€30,000/QALY gained	Not cost-effective at €30,000/QALY gained threshold; would be cost-effective if €80,000 threshold is used as some suggest should be done
Shah, 2016 United States	Retention vs. status quo: $33,700 (95% CI: $20,000-$60,600) Comprehensive package of interventions vs. status quo: $45,300 ($27,800-72,300 95% CI)	Evaluates multiple thresholds, with focus on $50,000 and $100,000	Retention is cost-effective
Lin, 2016 United States	Interventions vs. status quo: Retention: $13,460 Clinical Testing: Cost-saving Linkage to Care: Cost-saving Adherence to ART: Cost-saving	$100,000/QALY gained	Retention is cost-effective Note: Only includes QALYs gained from infections averted and does not include QALYs gained by PLWH who have improved retention in care
Maulsby, 2018 United States	Reported cost-utility ratios, by location: 1) Boston: $27,907 2) Chicago: $1,128 3) NYC: $42,428 4) San Diego: $115,468 5) Indianapolis: -$14, 371 (Cost-saving) 6) St. Louis: -$41,440 (Cost-saving) 7) Montgomery: $16,182	3x GDP per capita ($163,889/QALY gained)	All programs were cost-effective or cost-saving
Jain, 2016 United States	Reported cost-utility ratios, by location: 1) Chicago: $45,108 2) Louisiana: $4,439 3) NYC: $137,271	3x GDP per capita ($159,429/QALY gained)	All programs were cost effective, with some being highly cost-effective

Abbreviations: QALY: quality-adjusted life year: ICER: incremental cost-effectiveness ratio; CS: cost-saving; GDP: gross domestic product; NYC: New York City; ART: antiretroviral therapy: CI: confidence interval; RWHAP: Ryan White HIV/AIDS Program; PLWH: people living with HIV; MMC: medical care coordination; NHAS: US National HIV/AIDS Strategy; CAD: Canadian dollars; MSM: men-who-have-sex-with-men

Table 3. Assessment of Reporting Quality Using Consolidated Health Economic Evaluation Reporting Standards (CHEERS) Checklist

Section	CHEERS Recommendation	Goyal, 2021	Nosyk, 2020	Krebs, 2019	Noysk, 2018	Flash, 2019	Borre, 2017	Kasaie, 2018	Shah, 2016	Lin, 2016	Maulsby, 2018	Jain, 2016
Title	Identify the study as an economic evaluation or use more specific terms such as "cost-effectiveness analysis", and describe the interventions compared.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Abstract	Provide a structured summary of objectives, perspective, setting, methods (including study design and inputs), results (including base case and uncertainty analyses), and conclusions.	Partial	Yes	Yes	Yes	Yes	Partial	Partial	Partial	Partial	No	No
Background	Provide an explicit statement of the broader context for the study.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Objectives	Present study question and its relevance for health policy or practice decisions.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Target Pop & Subgroups	Describe characteristics of the base case population and subgroups analysed, including why they were chosen.	Partial	Yes	Partial	Yes	Yes	Yes	Partial	Yes	Partial	Yes	No
Setting & Location	State relevant aspects of the system in which the decision needs to be made.	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Partial	No	Partial	No
Study Perspective	Describe perspective and relate this to costs being evaluated.	Yes	Yes	Yes	Yes	Yes	No	Yes	Partial	Partial	Yes	No
Compar-ators	Describe interventions/strategies and why they were chosen.	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Partial	Yes	Partial

Section	CHEERS Recommendation	Goyal, 2021	Nosyk, 2020	Krebs, 2019	Noysk, 2018	Flash, 2019	Borre, 2017	Kasaie, 2018	Shah, 2016	Lin, 2016	Maulsby, 2018	Jain, 2016
Time Horizon	State time horizon(s) over which costs and consequences are being evaluated and why appropriate.	Partial	Yes	Yes	Yes	Partial	Partial	Partial	Partial	No	No	Partial
Discount Rate	Report discount rate for costs and outcomes and why appropriate.	Yes	Yes	Partial	Partial	Partial	Partial	Partial	Partial	Partial	No	No
Choice of health outcomes	Describe what outcomes were used as the measure(s) of benefit and their relevance for the type of analysis performed.	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Partial	Yes	Yes
Measure of Effective-ness	*Single study-based estimates:* Describe fully the design features of the single effectiveness study and why study was a sufficient source of effectiveness data.	NA	N/A	N/A	Yes	Partial	N/A	N/A	N/A	N/A	Partial	Partial
Measure of Effective-ness	*Synthesis-based estimates:* Describe fully the methods used for identification of included studies and synthesis of clinical effectiveness data.	Partial	Yes	Yes	N/A	N/A	N/A	No	N/A	Yes	N/A	N/A
Measurement and valuation of preference based outcomes	If applicable, describe the population and methods used to elicit preferences for outcomes.	Yes	Yes	No	Yes	No	No	Yes	Yes	Partial	Partial	N/A

Section	CHEERS Recommendation	Goyal, 2021	Nosyk, 2020	Krebs, 2019	Noysk, 2018	Flash, 2019	Borre, 2017	Kasaie, 2018	Shah, 2016	Lin, 2016	Maulsby, 2018	Jain, 2016
Estimating resources and costs	*Single study-based evaluation:* Describe approaches used to estimate resource use associated with alternative interventions. Describe primary or secondary research methods for valuing resource items in terms of unit cost. Describe adjustments made to approximate opportunity costs.	NA	NA	N/A	Yes	Partial	N/A	N/A	N/A	N/A	Yes	Partial
	Model-based evaluation: Describe approaches and data sources used to estimate resource use associated with model health states. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate opportunity costs.	Yes	Partial	Yes	Yes	Yes	Partial	No	Partial	No	N/A	N/A
Currency, price date, and conversion	Report dates of estimated resource quantities and unit costs. Describe methods for adjusting unit costs to year of reported costs if necessary. Describe methods for converting costs to common currency and the exchange rate.	Yes	Partial	Partial	Partial	Partial	Yes	Yes	Partial	Partial	Partial	No

Section	CHEERS Recommendation	Goyal, 2021	Nosyk, 2020	Krebs, 2019	Noysk, 2018	Flash, 2019	Borre, 2017	Kasaie, 2018	Shah, 2016	Lin, 2016	Maulsby, 2018	Jain, 2016
Choice of model	Describe and give reasons for the specific type of decision-analytical model used. Providing a figure to show model structure is strongly recommended.	Yes	Yes	Yes	Partial	Partial	Partial	Partial	Yes	Partial	Yes	N/A
Assump-tions	Describe all structural or other assumptions underpinning the model.	Yes	Yes	Yes	Yes	Partial	Partial	Partial	Yes	Partial	Partial	Partial
Analytical methods	Describe all analytical methods supporting the evaluation. This could include methods for dealing with skewed, missing, or censored data; extrapolation methods; methods for pooling data; approaches to validate or make adjustments to a model; methods for handling heterogeneity and uncertainty.	Yes	Yes	Yes	Yes	Partial	Partial	Partial	Partial	Partial	Partial	Partial
Study parameters	Report values, ranges, references, and, if used, probability distributions for all parameters. Report reasons or sources for distributions used to represent uncertainty where appropriate. Providing a table of input values is strongly recommended.	Partial	Partial	Partial	Yes	Partial	Partial	Partial	Partial	Yes	Yes	Partial
Incremental costs and outcomes	For each intervention, report mean values for the main categories of estimated costs and outcomes of interest, as	Yes	Partial	Partial	Yes	Yes	Yes	Yes	Partial	Partial	Partial	Partial

Section	CHEERS Recommendation	Goyal, 2021	Nosyk, 2020	Krebs, 2019	Noysk, 2018	Flash, 2019	Borre, 2017	Kasaie, 2018	Shah, 2016	Lin, 2016	Maulsby, 2018	Jain, 2016
	well as mean differences between the comparator groups. If applicable, report ICERs.											
Characterising uncertainty	*Single study-based evaluation:* Describe the effects of sampling uncertainty for the estimated incremental cost and incremental effectiveness parameters, together with the impact of methods assumptions (such as discount rate, study perspective).	NA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Partial	No
Characterising uncertainty	*Model-based evaluation:* Describe the effects on the results of uncertainty for all input parameters, and uncertainty related to the structure of the model and assumptions.	Partial	Yes	Partial	Yes	Partial	Partial	Yes	Partial	Partial	N/A	N/A
Characterising hetero-geneity	If applicable, report differences in costs, outcomes, or cost-effectiveness that can be explained by variations between subgroups of patients or other observed variability in effects that are not reducible by more information.	N/A	Yes	Yes	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes
Study findings, limitations,	Summarise key study findings and describe how they support the conclusions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial

Section	CHEERS Recommendation	Goyal, 2021	Nosyk, 2020	Krebs, 2019	Noysk, 2018	Flash, 2019	Borre, 2017	Kasaie, 2018	Shah, 2016	Lin, 2016	Maulsby, 2018	Jain, 2016
generalisability, current knowledge	reached. Discuss limitations, generalisability, and fit with current knowledge.											
Source of funding	Describe how the study was funded and the role of the funder in the identification, design, conduct, and reporting of the analysis. Describe other non-monetary sources of support.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Conflicts of interest	Describe any potential for conflict of interest of study contributors in accordance with journal policy. In the absence of a policy, we recommend authors comply with ICMJE recommendations.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Yes
Count	**Yes**	18	21	18	23	15	11	13	12	7	14	7
	No	0	0	1	0	1	3	2	0	4	3	7
	Not Applicable (N/A)	4	3	3	2	2	4	4	5	3	3	5
	Partial	6	4	6	3	10	10	9	11	14	8	9
Scoring	**% Yes, out of applicable**	75%	84%	72%	88%	58%	46%	54%	52%	28%	56%	30%
	% Yes or Partial, out of applicable	100%	100%	96%	100%	96%	88%	92%	100%	84%	88%	70%
	Average of above percentages	**88%**	**92%**	**84%**	**94%**	**77%**	**67%**	**73%**	**76%**	**56%**	**72%**	**50%**
Overall Reporting Quality[a]		**High**	**High**	**High**	**High**	**Mod.**	**Mod.**	**Mod.**	**Mod.**	**Low**	**Mod.**	**Low**

[a] Count and scoring is not included in or advocated for in the CHEERS checklist; it was developed by authors of this paper to provide a rough estimate of reporting quality such that quality of studies could be differentiated from each other. Overall reporting quality was considered High if average score was ≥80%, Moderate if 60-79%, and Low if <60%. These thresholds reflect natural breakpoints in reporting quality seen in the included articles.

Table 4. Assessment of Methods Quality Using Drummond 2015 Checklist

Question	Goyal, 2020	Nosyk, 2020	Krebs, 2019	Noysk, 2018	Flash, 2019	Borre, 2017
1. Was a well-defined question posed in answerable form?	Yes	Yes	Yes	Yes	Yes	Yes
2. Was a comprehensive description of competing alternatives given?	Yes	Yes	Yes	Yes	Yes	Yes
3. Was the effectiveness of the programs or services established?	Partial - Several assumptions about no RWHAP.	Yes	Yes	Yes	Yes	No – Evaluated hypothetical HIV care cascade improvements.
4. Were all important and relevant costs and consequences for each alternative identified?	Yes	Yes	Yes	Yes	Partial – Little information provided about costs considered in status quo.	Partial – Analysis may not have fully captured costs of implementation for care cascade improvements.
5. Were costs and consequences measured accurately in appropriate units prior to valuation?	Yes	Yes	Yes	Yes	Can't Answer – Full costing description in Appendix is not accessible.[a]	Yes
6. Were costs and consequences valued credibly?	Yes	Yes	Yes	Yes	Can't Answer – Appendix not accessible.[a]	Yes
7. Were costs and consequences adjusted for differential timing?	Yes	Yes	Yes	Yes	Yes	Partial – Discounted in ICERS, but undiscounted in other results.
8. Was an incremental analysis of costs and consequences of alternatives performed?	Yes	Yes	Partial – Interventions only compared to status quo.	Partial – Interventions only compared to status quo.	Yes	Yes

9. Was uncertainty in the estimates of costs and consequences adequately characterized?	Yes	Yes	Yes	Yes	Yes	Yes
10. Did the presentation and discussion of study results include all issues of concern to users?	Yes	Yes	Partial – Feasibility and uncertainty not well-discussed.	Partial – No comparisons; little disc. of feasibility.	Yes	Yes
Overall Methods Quality**	**High**	**High**	**High**	**High**	**Moderate**	**Moderate**

Table 4. Assessment of Methods Quality Using Drummond 2015, continued

Question	Kasaie, 2018	Shah, 2016	Lin, 2016	Maulsby, 2018	Jain, 2016
1. Was a well-defined question posed in answerable form?	Yes	Yes	Yes	Yes	Yes
2. Was a comprehensive description of competing alternatives given?	Yes	Yes	Partial – Frequency, reach, and other aspects not described.	Yes	Yes
3. Was the effectiveness of the programs or services established?	No – Evaluated hypothetical HIV care cascade improvements.	No – Evaluated hypothetical HIV care cascade improvements.	Partial – Unclear how interventions impacted different subgroups.	Yes	Yes
4. Were all important and relevant costs and consequences for each alternative identified?	Partial – Unclear if costs associated with testing and linkage interventions included.	Yes	No – Does not include QALYs gained by PLWH.	No – Uses societal perspective but does not include health care costs (e.g., costs of ART).	No – Uses societal perspective but does not include health care costs (e.g., costs of ART).
5. Were costs and consequences measured accurately?	Yes	Yes	Partial – Some detail provided, but difficult to determine methods.	Partial – Consequences for QALYs largely based on assumption.	Partial – Consequences for QALYs largely based on assumption.
6. Were costs and consequences valued credibly?	Partial – Some intervention costs not included or justified.	Yes	No – Identified sources but no further methods for valuation.	Partial – Several assumptions; full methods not described.	No – Conseq. based on assumption; costs perhaps not fully valued.
7. Were costs and consequences adjusted for differential timing?	Yes	Yes	Partial – Costs discounted; unclear if QALYs are discounted.	Partial – Unclear if QALYs are discounted.	Partial – Unclear if costs are discounted. Rate not stated.

8. Was an incremental analysis of costs and consequences of alternatives performed?	Partial – Interventions only compared to status quo.	Yes	Partial – Interventions only compared to status quo.	Yes	Yes
9. Was uncertainty in the estimates of costs and consequences adequately characterized?	Yes	Yes	Yes	No – Only two sensitivity analyses included.	No – No sensitivity analyses performed.
10. Did the presentation and discussion of study results include all issues of concern to users?	Yes	Yes	Partial – Feasibility, generalizability, and uncertainty not well-addressed.	No – Does not discuss feasibility, uncertainty, or generalizability.	No – Does not discuss feasibility, uncertainty, or generalizability.
Overall Methods Quality[b]	**Moderate**	**High**	**Low**	**Low**	**Low**

Abbreviations: RWHAP: Ryan White HIV/AIDS Program; PLWH: people living with HIV; QALY: quality-adjusted life year; ART: antiretroviral therapy.

[a] The journal was contacted regarding availability of the online appendix; however, it was still unavailable at the time this paper was submitted for publication.

[b] Overall methods quality was considered High if ≥8 categories were "yes", Moderate if 5-7 categories were "yes", and Low if <5 were "yes."

Table 5. Evaluation of Overall Strength of Evidence

Comparison	Outcome	Finding	Number of studies included	Study Limitations	Directness	Consistency	Assessment of Uncertainty	Overall Grade
Retention/reengagement in moderate-high methods quality articles	Cost-effectiveness ratio	Interventions can be cost-effective in high-income settings	8	Moderate	Mixed	Consistent	Good	**Medium**

Table 6. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Checklist

Section/topic	#	Checklist item	Reported
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	Title page
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	Abstract, partial
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	Intro ¶1-3
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	Intro ¶3
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	No protocol
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	Search & Selection
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	Search & Selection
Search	8	Present full electronic search strategy for at least one database, including any limits, such that it could be repeated.	Appendix Table 1
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	Search & Selection
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	Data Extraction
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	Data Extraction
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	Quality Assessment

Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	Data Extraction
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	Data Extraction
Section/topic	**#**	**Checklist item**	**Reported**
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	NA
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	NA
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	Figure 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Results ¶1, Table 1 & 2, Appendix Table 2
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	Table 1, Appendix Table 3 & 4
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Table 2, Appendix Table 2
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	Cost-Effectiveness (qualitative summary)
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	NA
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	NA
DISCUSSION			

Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	Discussion ¶1
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	Discussion ¶2-3
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	Discussion ¶2-3
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	Funding Source

Aim 2 Appendix

Supplemental Table 1. Risk Difference of Sustained Viral Suppression for Clients Who Received a Service

RWHAP Service	All Clients n=15,377		White n=5,543		Black/African American n=4,411		Black/African-Born n=2,253		Hispanic n=1,800	
	RD	95% CI	RD	95% CI	RD	95% CI	RD	95% CI	RD	95% CI
Medical Case Management	-0.0062	(-0.024 , 0.011)	-0.0096	(-0.036 , 0.017)	0.0044	(-0.028 , 0.037)	-0.0426	(-0.082 , -0.003)	0.0110	(-0.030 , 0.052)
Financial Aid	0.0302	(0.015 , 0.045)	0.0333	(0.009 , 0.058)	0.0361	(0.006 , 0.067)	0.0164	(-0.022 , 0.054)	0.0313	(-0.009 , 0.072)
Transportation	-0.0196	(-0.035 , -0.004)	-0.0333	(-0.063 , -0.003)	-0.0025	(-0.035 , 0.030)	0.0059	(-0.040 , 0.052)	-0.0433	(-0.083 , -0.004)
AIDS Drug Assistance	0.0378	(0.022 , 0.054)	0.0427	(0.018 , 0.068)	0.0262	(-0.014 , 0.067)	0.0073	(-0.032 , 0.047)	0.0522	(0.012 , 0.093)
Outpatient Services	0.0155	(0.002 , 0.029)	-0.0085	(-0.031 , 0.014)	0.0325	(0.005 , 0.061)	0.0359	(0.000 , 0.072)	0.0102	(-0.031 , 0.051)
Food Aid	0.0079	(-0.009 , 0.025)	-0.0069	(-0.030 , 0.016)	0.0481	(0.016 , 0.080)	-0.0479	(-0.105 , 0.009)	0.0223	(-0.024 , 0.068)
Non-Medical Case Mgmt.	-0.0008	(-0.016 , 0.015)	0.0014	(-0.021 , 0.024)	-0.0048	(-0.040 , 0.030)	0.0072	(-0.037 , 0.051)	-0.0263	(-0.068 , 0.016)
Adherence	-0.0451	(-0.063 , -0.027)	-0.0354	(-0.062 , -0.008)	-0.0275	(-0.062 , 0.007)	-0.0928	(-0.146 , -0.040)	-0.1381	(-0.204, -0.072)
Oral Health	0.0714	(0.050 , 0.093)	0.0400	(0.012 , 0.068)	0.0955	(0.045 , 0.146)	0.0690	(0.009 , 0.129)	0.0984	(0.062 , 0.135)
Mental Health	-0.0313	(-0.052 , -0.011)	-0.0619	(-0.099 , -0.025)	-0.0636	(-0.109 , -0.018)	0.0425	(-0.009 , 0.094)	-0.0001	(-0.047 , 0.046)
Medical Nutrition	0.0037	(-0.016 , 0.023)	0.0021	(-0.030 , 0.034)	0.0058	(-0.037 , 0.049)	-0.0257	(-0.094 , 0.042)	0.0279	(-0.025 , 0.081)
Legal Services	0.0144	(-0.010 , 0.039)	0.0548	(0.028 , 0.081)	-0.0326	(-0.089 , 0.023)	-0.0923	(-0.171 , -0.014)	-0.0561	(-0.146 , 0.033)
Substance Abuse Treatment	-0.0620	(-0.089 , -0.035)	-0.0268	(-0.066 , 0.012)	-0.1057	(-0.150 , -0.061)	-0.1786	(-0.335 , -0.022)	0.0369	(-0.037 , 0.110)

Health Education	-0.0999	(-0.128 , -0.072)	-0.0993	(-0.145 , -0.053)	-0.0861	(-0.151 , -0.021)	-0.1894	(-0.287 , -0.092)	-0.0397	(-0.103 , 0.024)
Transitional Housing	0.0031	(-0.032 , 0.038)	0.0047	(-0.040 , 0.050)	0.0377	(-0.027 , 0.102)	0.0206	(-0.077 , 0.118)	-0.0846	(-0.191 , 0.022)
Analyses With Outcome Lagged by 1 Year*										
Health Education	-0.0025	(-0.037 , 0.032)	-	-	-	-	-	-	-	-
Adherence	-0.0157	(-0.036 , 0.004)	-	-	-	-	-	-	-	-

n is the number of observations or client-years (not number of individuals); RD: risk difference; CI: 95% confidence interval

* In lagged analyses, the outcome (sustained viral suppression) was lagged by 1 year after receipt of the service. To be included, clients had to have two consecutive years of data available.

Supplemental Table 2. Risk Difference of Sustained Viral Suppression for Each Additional Service Encounter

RWHAP Service	All Clients n=15,377		White n=5,543		Black/African American n=4,411		Black/African-Born n=2,253		Hispanic n=1,800	
	RD	95% CI	RD	95% CI	RD	95% CI	RD	95% CI	RD	95% CI
Medical Case Mgmt., 5 Enc.	0.001	(0.000 , 0.003)	0.002	(-0.001 , 0.005)	0.002	(-0.001 , 0.005)	-0.002	(-0.006 , 0.002)	-0.001	(-0.005 , 0.004)
Financial Aid	0.016	(0.012 , 0.020)	0.017	(0.011 , 0.023)	0.020	(0.012 , 0.027)	0.011	(0.001 , 0.020)	0.008	(-0.006 , 0.022)
Transportation, 10 Encounters	0.061	(0.048 , 0.074)	0.047	(0.027 , 0.067)	0.092	(0.064 , 0.119)	0.025	(-0.001 , 0.050)	0.043	(0.005 , 0.080)
AIDS Drug Assistance	0.006	(0.005 , 0.008)	0.005	(0.002 , 0.007)	0.008	(0.004 , 0.012)	0.003	(0.000 , 0.006)	0.006	(0.003 , 0.009)
Outpatient Health Services	0.001	(-0.002 , 0.003)	-0.001	(-0.004 , 0.003)	0.003	(-0.002 , 0.008)	-0.003	(-0.009 , 0.003)	-0.002	(-0.007 , 0.003)
Food Aid, 10 Encounters	0.007	(0.005 , 0.009)	0.005	(0.002 , 0.008)	0.009	(0.003 , 0.016)	-0.011	(-0.022 , -0.001)	0.010	(0.003 , 0.017)
Non-Medical Case Mgmt.	0.000	(-0.002 , 0.002)	0.000	(-0.003 , 0.003)	0.001	(-0.004 , 0.005)	0.005	(-0.003 , 0.013)	-0.003	(-0.007 , 0.002)
Treatment Adherence	-0.003	(-0.005 , -0.002)	-0.004	(-0.006 , -0.001)	0.001	(-0.003 , 0.004)	-0.010	(-0.015 , -0.004)	-0.012	(-0.019, -0.005)
Oral Health	0.015	(0.005 , 0.025)	0.005	(-0.004 , 0.014)	0.030	(-0.003 , 0.063)	0.025	(-0.009 , 0.060)	0.027	(0.002 , 0.053)
Mental Health	0.000	(-0.003 , 0.004)	-0.004	(-0.010 , 0.002)	-0.007	(-0.016 , 0.002)	0.006	(-0.002 , 0.014)	0.001	(-0.009 , 0.011)
Medical Nutrition	0.004	(0.001 , 0.008)	0.001	(-0.003 , 0.005)	0.008	(0.000 , 0.016)	-0.006	(-0.020 , 0.008)	0.009	(-0.002 , 0.020)
Legal Services	0.002	(-0.002 , 0.007)	0.008	(0.001 , 0.015)	-0.008	(-0.019 , 0.002)	-0.012	(-0.029 , 0.006)	0.005	(-0.013 , 0.024)
Substance Abuse Treatment	-0.001	(-0.003 , 0.000)	0.000	(-0.001 , 0.001)	-0.003	(-0.006 , -0.001)	-0.010	(-0.024 , 0.004)	0.001	(-0.005 , 0.008)
Health Education	-0.011	(-0.016 , -0.006)	-0.004	(-0.013 , 0.004)	-0.011	(-0.019 , -0.003)	-0.040	(-0.093 , 0.013)	-0.035	(-0.067 , -0.002)

Transitional Housing	0.002	(-0.001 , 0.005)	0.002	(-0.005 , 0.009)	0.001	(-0.011 , 0.012)	0.002	(-0.008 , 0.013)	0.006	(-0.003 , 0.015)

n is the number of observations of client-years (not number of individuals); RD: risk difference; CI: 95% confidence interval; Mgmt: management; Enc: service encounters.

Aim 3 Appendix

Supplementary Table 1. Estimated Resources, Costs, and Outcomes for Program Expansion: Example from a Community Organization

Program Expansion	Resources Needed	Estimated Annual Costs	Anticipated Outcome of Expanded Aid
Food Aid			
Currently provide limited food vouchers	• 1.5 FTE staff • Money for food vouchers	Total Program Cost: $1M • Vouchers: $800,000 • Staff & Other: $200,000	• 1,100 clients served per year • Average $600-720 per client/year (max $720)
Provide food vouchers for more people at higher amounts	• Money for food vouchers • Materials (envelopes, etc.) • Additional 0.5 FTE staff (2 FTE total)	Total Cost: $1.94M • Staff: $90,000 • Vouchers: $1.8M • Other: $50,000	• 1,500-1,700 clients served per year • Average $1,200 per client/year
Emergency Financial Assistance (EFA)			
Previously provided aid to clients <200% FPL	• 1.3 FTE staff • Max $400/client/year	Total Program Cost: $1.2M • EFA: $720,000 • Staff & Other: $480,000	• 1,800 clients served per year • Average $400 per client/year
Currently provide aid to clients <400% FPL	• 2.1 FTE staff • Max $2,000/client/year	Total Program Cost: $2.5M • EFA: $2M • Staff & Other: $500,000	• 2,000 clients served per year • Average $1,000 per client/year
Increase outreach to clients <400% FPL about program	• Additional 0.5 FTE staff	Total Program Cost: $3.6M • EFA: $3M • Staff & Other: $600,000	• 2,500 clients served per year • Average $1,200 per client/year
Transportation			
Currently provide limited taxis to clients	• 1.2 FTE staff • $9,000/month on taxis	Total Program Cost: $212,000 • Transportation: $108,000 • Staff & Other: $104,000	• 200 people receive transportation support per year • 300 taxi rides per month

Provide taxis to access more support services and not ration/cut rides	• Additional $1,500/month on taxis • Additional 0.5 FTE staff	Total Program: $256,000 • Transportation: $126,000 • Staff & Other: $130,000	• 200 people receive transportation support • 350 taxis rides/month
Additional scale-up would require re-assessment of eligibility. Many clients in need of taxi services are unable to and are instead required to use bus passes.			
Housing Support			
Currently run transitional housing and housing access services program	• 9 FTE staff	Total Program: $1.63M • Housing: $1M • Staff: $500,000 • Overhead/Other: $130,000	• 87 people currently housed in 2-year THP • 125-150 clients/year receive support with housing • 200-300 people enter waitlist for housing when it opens; house 40-50 people/year off waitlist
Increase flexibility and amount to spend on deposits, HUD rent differences, and other barriers to housing (e.g., prior debts)	• Money for housing aid • Funds would be distributed by current staff	Additional Costs: • Deposits: $25,000-$50,000 • Rent differences: $50,000 • Barriers: $115,000	• 100 people housed in 2-year THP • 150-175 clients/year receive support with housing • 50-60 people per year housed off waitlist • ~40 people aided with long-term barriers

FTE: Full-time equivalent; THP: Transitional housing program; HUD: US Department of Housing and Urban Development.

Supplementary Table 2. Estimated Resources, Costs, and Outcomes for Program Expansion: Example from a Medical Center

Program Expansion	Resources Needed	Estimated Annual Costs	Anticipated Outcome of Expanded Aid
Food Aid			
Currently provide limited food vouchers	• 800 gift cards at $25 each • Current social services staff	Vouchers: $20,000	• Currently serve 400-500 people/year • Average $44 per person/year
Provide food vouchers for more people	• Money for food vouchers • No additional staff costs	Vouchers: $100,000	• Serve 500-600 additional people (1,000 total) • Average $100 per person/year
Establish small food pantry and provide Ensure to clients on-site	• Ensure and food pantry items • 0.5 FTE staff to operate pantry • Storage for Ensure	Staff: $45,000 Food: $9,000 Storage Space: $1,800	• 120 patients per month would receive Ensure • 250-300 patients/year would access pantry
Provide food vouchers on monthly basis	• Money for food vouchers • Distributed by current staff	Vouchers: $900,000 Materials/Postage: $2,000	• 1,000 clients served (no additional people but needs are more fully met) • Average $75 per person/month
Housing Support			
Currently provide limited rental assistance	• Rental assistance vouchers • Current social services staff	Vouchers: $7,500 ($4,000-$10,500)	• Currently support 10-15 people/year • Average $400-700 per person/year
Assisting homeless clients with hotel costs	• Money for hotel rooms: $25-$50/day for 3-month stays • 0.25-0.5 FTE staff	Staff: $33,750 Hotel Vouchers: $371,250 ($225,000-$540,000)	• Serve 100-120 people/year • Average $3,375 per person/year
One-time rental assistance	• Money for rental assistance • 1.0 FTE social worker	Staff: $80,000 Rental Vouchers: $850,000	• Serve 1,000 people/year • Average $850 per person/year
Financial Aid			
Currently provide limited financial aid	• Money for financial aid • Current social services staff	Financial Aid: $2,250 ($1,000-$4,000)	• Currently support 10-20 people/year • Average $100-200 per person/year
Provide basic needs items	• Bulk basic needs items • No additional staff/storage costs	Financial Aid: $20,000	• Serve 750 people/year

Provide winter clothing and other winter gear	• Winter coats, boots, hats, etc. • No additional staff/storage costs	Financial Aid: $12,000	• Serve 1,000 people/year (250 additional)
Transportation			
Currently provide limited bus passes to clients	• Money for bus passes and taxis	• Taxis: $20,000 • Bus passes: $40,000	• Currently support 140 people with taxis and 700 people with bus passes • Average 1 bus pass per person/month • Average 2 roundtrip taxi rides/year
Provide taxis for clients	• Ride costs ($140-$185 per client) • 0.5 FTE staff	Staff: $45,000 Taxis: $210,000-$280,000	• 1,500 clients (1,360 additional clients receive taxi rides)

FTE: Full-time equivalent.

Aim 4 Appendix

MODEL DETAILS

1. Model Structure

This individual-based model was designed to simulate HIV care after diagnosis for HIV patients eligible for Ryan White HIV/AIDS Program (RWHAP) services in the 13-county metro area surrounding Minneapolis-St. Paul in Minnesota. Patients are eligible for RWHAP services if they are earning income less than 400% of the federal poverty level (FPL). An individual-based model structure was selected to capture heterogeneity in patient characteristics and RWHAP service use. The model focused on transitions in and out of RWHAP services, HIV viral suppression outcomes, and use of RWHAP food aid vouchers. Individuals could be active in RWHAP services or not active and be virally suppressed, or not, resulting in four main model states (**Figure 1**):

- In RWHAP and virally suppressed (*In RWHAP/VS*),
- In RWHAP and not virally suppressed (*In RWHAP/Not VS*),
- Out of RWHAP and virally suppressed (*Out of RWHAP/VS*), and
- Out of RWHAP and not virally suppressed (*Out of RWHAP/Not VS*).

Individuals entered the model upon diagnosis and exited the model upon death. It was assumed entry and exit from RWHAP due to people moving into and out of the RWHAP jurisdiction was balanced, and thus was ignored in the model. It was assumed movement in and out RWHAP due to changing eligibility status, i.e., earning more or less than 400% of the FPL, was negligible because the majority (>95% of RWHAP clients) earn less than 300% of the FPL and over half are earning less than 100% according to local RWHAP data.

Being *In RWHAP* meant patients were actively engaged in RWHAP services, defined as using RWHAP services for 6 or more months in a year. Being *Out of RWHAP* included patients:

- who used less than 6 months of RWHAP services in a given year,
- who used no RWHAP services but were still engaged in medical care (e.g., they had records of viral load tests), and
- who were fully out of care (no records of viral load tests or RWHAP services).

Six months of service use was chosen as a threshold for in vs. out of RWHAP because receiving services for half a year or longer was assumed to be meaningful and active engagement in RWHAP. In 2019, 64% of all clients used ≥6 months of services and 32% of all clients used 12 months of services (i.e., used at least one RWHAP service every month of the year). Using a 6-

month threshold also roughly aligned local data with retention rates in national Health Resources and Services Administration (HRSA) patient-level data for 2019, which reported 68% of patients retained (defined as at least two outpatient health care visits at least 90 days apart during a year).[8]

Viral suppression in the model was defined as sustained suppression, in which all viral load tests in a year are suppressed. Sustained viral suppression is the ultimate goal of HIV care and RWHAP services.

Patient characteristics included in the model were age, sex, HIV stage, CD4 count, food aid need status, and food aid receipt status. Food aid need was an indicator (yes/no) for whether a patient was food insecure and needed food aid; it was assumed to remain constant for the entire model duration. Food aid receipt status was an indicator for whether a patient who needed food aid received it, and could vary from year to year based on the probability of receiving food aid. The model also tracked how much food aid a person received (i.e., number of food vouchers received each year).

The model used annual time steps because this aligned with RWHAP data received to inform inputs and because it was less computationally burdensome while still granular enough to capture relevant costs and outcomes associated with the intervention of interest (food vouchers).

A lifetime time horizon was used to calculate the cost and quality-adjusted life year (QALY) outcomes used in cost-effectiveness calculations. Model simulations began in 2020 and interventions were implemented for 10 years (intervention period) to align with timing of achieving U.S. Ending the HIV Epidemic goals by 2030.[7] After the intervention period, the model was run for another 10 years with interventions "turned off" to capture any residual downstream effects of interventions on HIV outcomes, such as higher viral suppression rates that extend beyond the intervention end date before returning to status quo levels. After this combined 20 year horizon (10 years intervention on + 10 intervention off), an end year horizon was used to estimate remaining lifetime costs and QALYs. During the end year horizon, no new individuals entered the model and the model ran until all individuals who were alive in the model at year 20 had died.

An annual discount rate of 3% for both costs and QALYs was used as is standard practice in the U.S.[92] A health care perspective was used for calculating costs and QALYs.

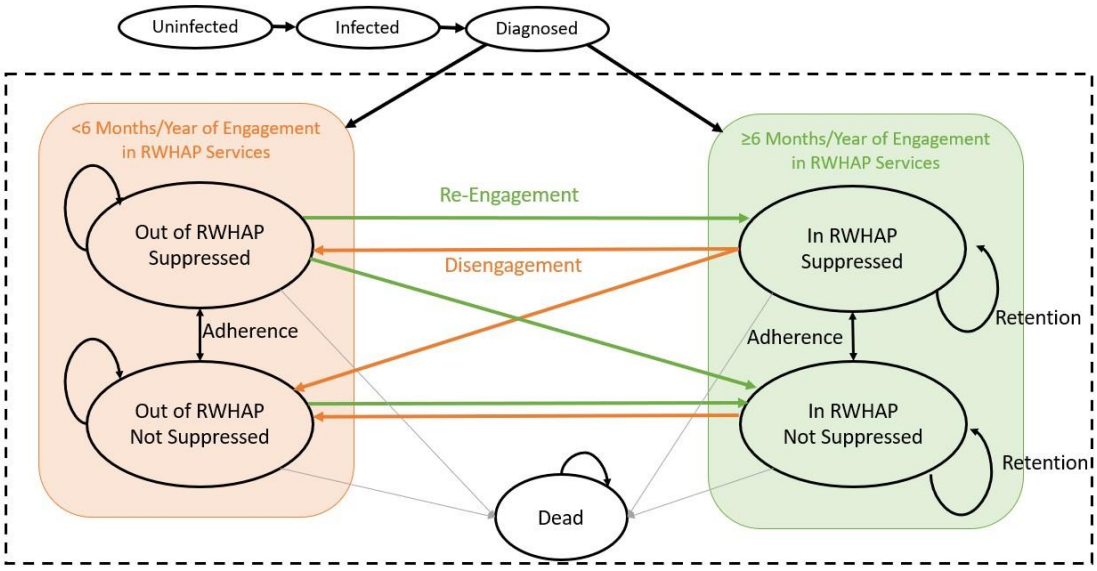


Figure 1. Model Diagram. Clients can move into and out of RWHAP, representing re-engagement and disengagement from services. Clients can gain or lose viral suppression, representing adherence. Clients can stay in RWHAP, representing retention. Patients in all states face a probability of death. New clients enter the model upon being diagnosed with HIV and are distributed between the four states.

1.1 Parameterization & Data Sources

When possible, patient characteristics were parameterized with data from the Ryan White HIV/AIDS Program in Minnesota. Other model inputs were obtained from published literature when available or were calibrated in the absence of data. Calibration is described further in Section 2.

For local RWHAP data, we obtained de-identified data from CAREWare, an electronic health record system for RWHAP recipients and providers. The dataset included viral load test results, service encounters, and housing status, income level, insurance status, and demographic information for all recipients of services funded through RWHAP Part A and/or Minnesota Department of Human Services Part B in the Minneapolis-St. Paul Transitional Grant Area (TGA) between 2015-2019. TGAs are geographic areas highly impacted by HIV/AIDS that are eligible to receive RWHAP Part A funds. Part A funds are awarded to eligible metropolitan areas or transitional grant areas to provide medical and support services to cities and counties most severely affected by HIV.[93] Part B funds are awarded to states to improve the quality of and access to HIV health care and to provide medications through the AIDS Drug Assistance Program. A total of 6,144 unique clients, 898,355 service encounters, and 69,272 viral load results were included in the dataset.

To obtain patient data on an annual level, data were consolidated to one observation per person per year. To capture sustained viral suppression outcomes, viral load status was coded as "Virally Suppressed (VS)" if all tests in the year were suppressed and "Not Virally Suppressed (Not VS)" if tests were a mix of suppressed and not suppressed or all not suppressed. Service utilization within a given year was summarized with both binary (used vs. did not use service) and continuous (number of service encounters) variables.

1.2 Initial Patient Characteristics & Model Entry

The model was initialized with 4,000 adult people living with HIV (PLWH). At initialization, individuals in the model were assigned an HIV stage (chronic, AIDS), age (18-100 years), sex (male, female), CD4 count (0-1500, dependent on HIV stage), and an initial care/viral suppression status (*In RWHAP/VS*, *In RWHAP/Not VS*, *Out of RWHAP/VS*, *Out of RWHAP/Not VS*). The model then simulates how these characteristics change over time.

Patient characteristics were parameterized using local RWHAP data. The number of individuals starting in the prevalent population was set to 4,000, reflecting the RWHAP population observed in 2019 of 3,936 clients. A slightly higher starting population was selected because it was assumed some PLWH who are eligible for RWHAP were not using RWHAP services at all and were therefore not reflected in the dataset.

Age, gender, and HIV stage distributions for the prevalent population were based on individuals who were ≥18 years old and diagnosed before 2014 (i.e., not recent diagnoses). Individuals who had unknown date of birth, unknown HIV status, were HIV-negative, or were HIV-indeterminant status were excluded; 4,495 unique individuals were included. The dataset included 2% transgender individuals, which were excluded since the model did not include parameters for transgender individuals. The resulting prevalent population was 70.7% male and 29.3% female. The HIV stage of individuals in the dataset were 34% AIDS, 44% chronic HIV (non-AIDS), and 22% HIV-positive (AIDS status unknown). It was assumed that individuals with unknown AIDS status were in the chronic HIV (non-AIDS) stage, resulting in 33.8% AIDS and 66.2% chronic HIV in the prevalent population.

Proportion of the population in each model state was based on the service use and viral suppression distribution of local RWHAP clients in 2019. To estimate these proportions from the dataset, clients were included if they received any services between 2015-2019 and excluded if they had unknown date of birth, were <18 years old, or had unknown, indeterminate, or negative

HIV status. With these inclusion and exclusion criteria, there were no clients with missing viral load data. As described above, being *In RWHAP* was defined as using RWHAP services for 6 or more months out of the year. In 2019, 54% of clients included in the dataset were *In RWHAP/VS*, 10% were *In RWHAP/Not VS*, 27% were *Out of RWHAP/VS,* and 9% were *Out of RWHAP/Not VS*. However, it was assumed that the population *Out of RWHAP/Not VS* would be larger than that observed in the data, since the dataset would not have records for people who were fully out of care (e.g., patients with no record of RWHAP services and no record of viral load tests in 2019). A study published in 2016 that linked Minnesota state surveillance data with electronic medical record data from one of the largest HIV providers in the state found that 14.9% of clients were fully out of care.[94] The proportion of individuals *Out of RWHAP/Not VS* in the model was therefore assumed to be higher than observed at 15% and the proportion *Out of RWHAP/VS* was assumed to be lower than observed at 21%.

Viral suppression status did not depend on HIV stage (i.e., it was not assumed that people with AIDS had lower viral suppression rates). This is because in a clinical setting AIDS diagnoses are permanent. Even if a patient's health improves dramatically, a patient diagnosed with AIDS does not revert to being diagnosed with chronic HIV. According to the local RWHAP data, VS rates were 79% for patients with AIDS, 81% for people with HIV (AIDS status unknown), and 77% for people with chronic HIV (not AIDS), indicating no clear trend for VS based on HIV stage.

New individuals entered the model at the beginning of each time step. It was assumed that new individuals have been newly diagnosed and linked to care. Neither the process of infection nor the dynamics of sexual networks were represented in the model; instead, new individuals entered the model based on a constant Poisson distribution that reflected the number of new individuals diagnosed with HIV who were eligible for RWHAP services each year. The number of new individuals entering the population each year was based on a 6-year average of new diagnoses recorded in the RWHAP dataset, which ranged from 284 individuals in 2014 to 178 in 2019, with an average of 232 individuals per year.

Patient characteristics (age, sex, HIV stage) for new individuals entering the model were drawn from distributions of characteristics among people newly diagnosed with HIV between 2014-2019 (**Table 1**). Age, sex, and HIV stage distributions for new diagnoses were based on individuals who were recorded in the RWHAP dataset, were ≥18 years old at diagnosis, and diagnosed between 2014-2019. Individuals who had unknown date of birth, unknown HIV status, were HIV-negative, or were HIV-indeterminant were excluded; 1,394 unique individuals were included. The dataset included 3.4% transgender individuals, which were excluded again since

the model did not include parameters for transgender individuals. The resulting incident population was 73.2% male and 26.8% female, reflecting a slightly higher proportion of males in the incident population compared to the prevalent population. It was again assumed that individuals with AIDS status unknown were chronic HIV (non-AIDS) stage. Resulting HIV stages for new diagnoses were 15.5% AIDS and 84.5% chronic HIV.

Due to the annual time step, it was assumed new individuals were distributed to states in the same proportion as observed in the prevalent population since it was assumed new clients would eventually balance out to reflect similar care patterns as the prevalent population over the course of a year. In Minnesota, 87% of new diagnoses link to care within 30 days and 94% link to care within 90 days, indicating that people newly diagnosed link to care and start treatment quickly.[95]

The RWHAP dataset did not include data on CD4 count. Initial CD4 count distributions were derived from a recent study (Lee *et al*., 2021) of the North American AIDS Cohort Collaboration on Research and Design that included 32,013 HIV patients from across the United States and Canada.[96] This study found median CD4 cell count at entry into care in 2018 was 362 cells (IQR: 189-534). Using methods described by *Wan et al*.,[97] a mean and standard deviation were derived from the median and IQR assuming a normal distribution, resulting in a mean CD4 count at care entry of 361.7 cells/µl and standard deviation (sd) of 255.5 cells/µl. To obtain CD4 cell count distributions stratified by AIDS vs. chronic HIV stage, 100,000 CD4 cell counts were simulated using a truncated normal distribution with parameters calculated from Lee *et al.* (minimum=0, maximum=1500, mean=361.7, sd=255.5). The simulated population was then stratified into AIDS stage (CD4≤200) and chronic HIV stage (CD4>200), and the mean and standard deviation of CD4 cell counts for these simulated subpopulations were calculated. The resulting CD4 distribution for clients with chronic HIV was a truncated normal distribution, with minimum=200, maximum=1500, mean=475, and sd=185. For AIDS stage, the CD4 distribution was a truncated normal with minimum=0, maximum=200, mean=113, and sd=56.

Table 1. Model Inputs for Patient Characteristics

Parameter	Prevalent Population	New Diagnoses	Source
Number of individuals	4,000	Average 232/year Poisson dist. (λ=232)	RWHAP MN
Age	Truncated normal dist. (min=18, max=89 mean=44.6, sd=11.6)	Truncated normal dist. (min=18, max=74 mean=35.3, sd=11.9)	RWHAP MN
Sex			
Male	70.7%	73.2%	RWHAP MN
Female	29.3%	26.8%	
HIV Stage			
Chronic HIV	66.2%	84.5%	RWHAP MN
AIDS	33.8%	15.5%	
Model State			
In RWHAP/VS	54%	54%	RWHAP MN; Assumed
In RWHAP/Not VS	10%	10%	
Out of RWHAP/VS	21%	21%	
Out of RWHAP/Not VS	15%	15%	
Initial CD4 Count			
Chronic HIV	Truncated normal dist. (min=200, max=1500, mean=475, sd=185)		Derived from Lee 2021
AIDS	Truncated normal dist. (min=0, max=200, mean=113, sd=56)		

VS: virally suppressed; sd: standard deviation; RWHAP MN: Ryan White HIV/AIDS Program in Minnesota.

1.3 Disease Progression & AIDS-Defining Events

Acute HIV was not included as an HIV stage because its short duration (1-3 months) was considered negligible with an annual time step. Individuals progressed from chronic HIV to AIDS when their CD4 cell count dropped below 200 cells/μl or when they experienced an AIDS-defining event. CD4 cell count increased gradually each month when an individual was virally suppressed and declined gradually when an individual was active in RWHAP but not virally suppressed. CD4 declined more rapidly for individuals not in RWHAP *and* not virally suppressed. Different CD4 declines for unsuppressed individuals in vs. out of RWHAP were used because it was assumed patients active in RWHAP were using at least some antiretroviral treatment (ART) and receiving partial benefit, even if not fully suppressed, while patients not active in RWHAP may not be on any treatment. Model inputs for CD4 cell count increases and decreases were obtained from published literature (**Table 2)**.

Annual increase in CD4 cell count when virally suppressed was derived using values from Trotta *et al.* (2010) .[80] Literature suggests that CD4 cell count increases are highest among ART-naïve patients (patients who have never used HIV treatment) in the first years of treatment, with smaller increases over time. For simplicity in the model, CD4 cell increases were not based on time since initiating treatment. Since the model included newly diagnosed individuals who were ART-naive and individuals who had already been on ART for many years, a study that included both types of patients was selected as the source for CD4 cell count increases. Trotta *et al.* studied CD4 cell count increases among a cohort of 3,537 patients in Italy, not all of whom were ART-naïve.[80] It found an average annual CD4 cell increase of 35 when assuming a constant linear increase over time. When broken down by year, the increase was 98 cells the first year, 45 cells the second year, and 16 cells after the second year. Since the model horizon is long-term, the value of 16 cells was selected as the model parameter value.

Annual decrease in CD4 cell count when out of RWHAP and not virally supressed was derived from Touloumi *et al.* (2013).[81] This study used data from a European cohort of 12,159 patients and provided estimates for mean CD4 cell count loss by HIV-1 subtype based on results from a linear mixed model. Since >90% of infections in the U.S. are HIV-1 subtype B,[98] the difference in estimated mean CD4 cell count from baseline (568 cells) to year 4 (304 cells) for subtype B was divided by 4 to obtain an annual CD4 cell count loss of 66 [(586-304)/4].

Annual decrease in CD4 cell count when in RWHAP and not virally supressed was derived from Schultze *et al.* (2018).[82] The study analyzed CD4 cell count decline in patients maintained on a failing ART regime in a cohort of 5,357 European and UK patients. It found the estimated CD4 decline during episodes of virologic failure was 20 cells per year (95% CI: -22, -17).

Maximum CD4 cell count was obtained from a U.S. Department of Veterans Affairs webpage about CD4 counts in HIV, which noted that the normal range for CD4 cells is about 500-1,500.[83]

Table 2. Model Inputs for Disease Progression & AIDS-Defining Events

Parameter	Value	Source
CD4 Cell Count (cells/µl)		
Annual increase when VS	16	Trotta 2010
Annual decrease when Out of RWHAP/Not VS	66	Touloumi 2013
Annual decrease when In RWHAP/Not VS	20	Schultze 2018
Maximum count	1500	Veterans Affairs 2019
Annual Probability of AIDS-Defining Event, by CD4 Cell Count		
0-199 cells/µl	0.03262	Buchacz 2016; Mocroft 2013
200-349 cells/µl	0.01053	
350-499 cells/µl	0.00690	

≥500 cells/µl	0.00639	

VS: virally suppressed.

Individuals who were not virally suppressed had a probability of experiencing an AIDS-defining event (i.e., opportunistic infection). The probability of an event increased with lower CD4 counts. An individual with chronic HIV who experienced an event had their HIV stage change to AIDS, regardless of CD4 count. Individuals who were out of RWHAP when they experienced the event re-entered RWHAP in the following time step. Annual probabilities for AIDS-defining events were derived from published literature (**Table 2**).

The annual probability of experiencing an AIDS-defining event was derived from two published sources.[99,100] Buchacz *et al.* (2016) examined the incidence of AIDS-defining events in patients from the United States and Canada between 2000-2010.[99] The appendix reports incidence rate ratios (IRRs) for AIDS events by CD4 cell count: 5.17 for CD4 counts <200, 1.65 for CD4 cell counts between 200-349, and 1.08 for CD4 cell counts between 350-499, with rates for CD4>500 the reference rate. Mocroft *et al.* (2013) examined incidence of AIDS-defining events in European patients with CD4 cell counts>200 between 1998-2010.[100] For patients with CD4 cell counts between 500-749, the rate was 6.4 AIDS events per 1,000 person-years. This rate was then used as the reference value for IRRs from Buchacz *et al*., and rates per 1,000 person-years by CD4 cell count were calculated by multiplying the reference value by the IRR (For example, the rate for CD4 count 200-349 was 6.4*1.65=10.56 AIDS-defining events per 1,000 person-years). Rates were divided by 1,000 to get annual rates for an individual, and then converted to probabilities.

1.4 Engagement in Care & Adherence

The prevalent population and newly diagnosed patients were initially distributed to care states according to proportions observed in the RWHAP dataset, as described in Section 1.2. Individuals then faced an annual probability of changing model states.

Adherence: Individuals *In RWHAP* and *Out of RWHAP* had a probability of achieving viral suppression if not already suppressed or losing viral suppression if already suppressed, while staying in their current RWHAP state (in vs. out). The annual probability of losing viral suppression while in RWHAP care was 4.9% and the annual probability of losing VS while out of RWHAP was 9.9%. These two probabilities were calculated from local RWHAP data based on observed transitions between states between 2018 and 2019 for clients in the dataset. Clients were initially included in calculations if they received RWHAP services or had records of viral load

tests between 2015-2020; this population was then reduced to include only patients with data recorded for years 2018 and 2019. If patients skipped a year (e.g., had data recorded in 2017 and 2019, but not 2018), they were assumed to be *Out of RWHAP/Not VS* for 2018. The annual probability of gaining viral suppression while in RWHAP and the annual probability of gaining viral suppression while out of RWHAP were estimated via model calibration (see Section 2).

Disengagement: Individuals in RWHAP had an annual probability of dropping out of RWHAP. Patients could gain, lose, or maintain their viral suppression state upon dropping out. Disengagement probabilities ranged from 5.4% to 9.7% and were calculated from local RWHAP data on observed changes in patient care states between 2018 and 2019.

Re-Engagement: Individuals not actively engaged in RWHAP had an annual probability of re-entering RWHAP care. Annual probabilities of re-entering the *In RWHAP/VS* state were calculated from local RWHAP data: 18.4% from *Out of RWHAP/VS* and 20.3% from *Out of RWHAP/Not VS*. The annual probabilities of transitioning into the *In RWHAP/Not VS* state from the *Out of RWHAP/VS* state and from the *Out of RWHAP/Not VS* state were estimated via model calibration (see Section 2).

Final parameter values used for all model state transitions is in Section 2.3, Table 7.

1.5 Mortality and Health-Related Quality of Life

Individuals had an annual probability of dying of causes unrelated to HIV. These background mortality rates were based on age- and sex-specific life tables for the state of Minnesota in 2019 published by the U.S. National Vital Statistics System.[101] Individuals in the AIDS stage faced an annual probability of HIV-related death based on their CD4 cell count, with the probability of HIV-related mortality increasing as CD4 cell count decreased. Probabilities of HIV-related death were derived from published literature (**Table 3**).[102] Note that people with AIDS diagnoses could gain CD4 cell counts >200 since AIDS is a permanent diagnosis and HIV-related mortality could still occur in people with CD4 cell counts >200. However, it was assumed that people who had never advanced to AIDS stage do not have a probability of HIV-related mortality, since this would be very unlikely.

Annual probabilities of death unrelated to HIV were directly obtained from age- and sex-specific death probabilities for 2019 in Minnesota published by the U.S. National Vital Statistics System.[101] No modifications were made. Death probabilities from ages 18-100 years were used

because the model does not include individuals younger than 18 years and because the vital statistics reports have a 100% probability of death for individuals 100 and over.

Annual probability of HIV-related death was derived from Young *et al.* (2012), which reported risk of AIDS-defining events and death in a longitudinal cohort of European patients with suppressed viral load prior to 2010.[102] Event rates per 1,000 years virally suppressed for death (all-cause) and death (unrelated to HIV) were reported for CD4 cell count ranges: <50, 50-199, 200-349, 350-499, 500+. HIV-related death rates per person-year were calculating by subtracting deaths unrelated to HIV from all-cause deaths. Rates were divided by 1,000 to obtain HIV-related death rates per person-year. Resulting annual rates were then converted to annual probabilities. For example, for CD4<50 cells, the all-cause death rate was reported to be 64.8 and death rate unrelated to HIV was 25.6. The estimated HIV-related death rate was 39.2 (64.8-25.6), the rate per person-year was 0.0392 (39.2/1,000), and the annual probability was 0.038441 (1-exp(-0.0392)). In the model, it was assumed HIV-related death rates depended on CD4 cell count only and not viral suppression status, since CD4 count is a key indicator of a person's immune system health. Derived deaths rates therefore also applied to individuals in the model who were not virally suppressed; HIV-related deaths may therefore be undercounted in the model since death rates were estimated from a virally suppressed population. HIV-related mortality and background/all-cause mortality rates were tracked separately because they were evaluated in model validation (Section 3).

Table 3. Model Inputs for Mortality and Health-Related Quality of Life

Parameter	Value	Source
Annual probability of death unrelated to HIV	Age- and sex- specific for Minnesota	National Vital Statistics Reports 2022
Annual Probability of HIV-Related Death, by CD4 Cell Count (cells/mm^3)		
0-50	0.038442	Young 2012
51-199	0.005883	
200-349	0.001699	
350-499	0.000900	
≥500	0.000500	
Health-Related Quality of Life Utility Values		
In or Out of RWHAP, VS, CD4<200	0.87	Miners 2014
In or Out of RWHAP, VS, CD4>200	0.89	
In RWHAP, Not VS, CD4<200	0.85	
In RWHAP, Not VS, CD4>200	0.89	
Out of RWHAP, Not VS, CD4<200	0.82	
Out of RWHAP, Not VS, CD4>200	0.87	
Age-Adjustment*	-0.003	

VS: virally suppressed; RWHAP: Ryan White HIV/AIDS Program.
* Overall HRQoL decreases by 0.003 per year of life. For example, a perfectly healthy 20 year old would have a HRQoL of 1-(0.003*20) = 0.94. A virally suppressed 20-year old with CD4<200 would have HRQoL of 0.87-(0.003*20) = 0.81

Each year, individuals accrued quality-adjusted life years (QALYs) based on their age, viral suppression, and RWHAP engagement state. QALYs were calculated from health-related quality of life (HRQoL) utility values obtained from published literature (**Table 3**).[84] HRQoL was typically higher with CD4 cell counts >200 and when virally suppressed. It was lowest when out of RWHAP, not virally suppressed, and CD4 cell counts <200. HRQoL also decreased by a small amount (-0.003) each year as individuals aged.

HRQoL utility values were obtained from a UK-based study that included HRQoL data from the EQ-5D-3L for over 10,000 HIV-infected individuals collected between 2011-2012.[84] HRQoL values reported in the paper were adjusted for smoking status, age, ethnic origin, sex, children, and education (Table 4/Model 4 in original publication). No modifications were made to values reported in the paper.

1.6 Costs

Individuals incurred medical costs each year based on their viral suppression status, CD4 cell count, and status in/out of RWHAP (**Table 4**). It was assumed all people who were virally suppressed (regardless of whether they were in or out of RWHAP) and all people who are in RWHAP (regardless of viral suppression status) incurred costs associated with HIV treatment (ART). Only clients out of RWHAP and not virally suppressed incurred no ART costs. Clients in RWHAP also incurred costs of RWHAP services, which varied based on whether a person was suppressed or not suppressed with the assumption that patients who were not suppressed incurred higher costs through more service use as RWHAP providers worked to get the patient suppressed.

All costs were converted to 2018 U.S. dollars. As needed, costs were inflated using the consumer price index inflator for medical care published by the U.S. Bureau of Labor Statistics.[103]

Table 4. Annual Medical and RWHAP Costs

Parameter	Value (2018 USD)	Source
Medical Costs for Patients In RWHAP/VS, In RWHAP/NotVS, and Out of RWHAP/VS		
CD4<500	$45,714	Enns 2019
CD4 200-499	$46,419	
CD4 <200	$49,695	
Medical Costs for Patients Out of RWHAP/Not VS		
CD4<500	$5,242	Enns 2019
CD4 200-499	$6,319	
CD4 <200	$13,455	
Ryan White HIV/AIDS Program Service Costs		
Virally Suppressed	$5,545	Goyal 2020
Not Virally Suppressed	$10,374	

VS: Virally suppressed; USD: U.S. dollars.

Medical costs were derived from costs reported in Enns *et al.* (2019).[85] This study examined costs for 40,022 HIV-infected patients from 17 U.S. sites that used healthcare between 2010 and 2015. Costs included inpatient, outpatient, emergency room, lab tests, ART, and non-ART prescription drugs. Predicted mean quarterly medical costs were reported by CD4 count, patient risk group, region (Northeast, South, West), and ART status. To derive costs for the model, costs by CD4 count and ART status for men-who-have-sex-with-men, heterosexual females, and heterosexual males were combined using a weighted average with weights reflecting the proportion of MSM, heterosexual females, and heterosexual male clients in Minnesota's Ryan White Program in 2019. Since there was no Midwest region reported, costs across the Northeast, South, and West regions were weighted equally. These three risk groups were selected because they represented the risk groups for the majority of individuals served by RWHAP in Minnesota. Female injection drug users, male injection drug users, and MSM who inject drugs were excluded since they each made up less than 5% of the RWHAP population in Minnesota in 2019.[8] Weights used for MSM, heterosexual females, and heterosexual male clients were 51.6%, 30.2%, and 18.1%, respectively. Quarterly costs were multiplied by 4 to obtain annual costs.

RWHAP service costs were obtained from a study on the cost-effectiveness of RWHAP published by Goyal *et al.* (2020).[45] In this study, per-person monthly costs in 2016 USD for RWHAP services were estimated to be $120 for outpatient ambulatory health services, $224 for medical case management, $385 for mental health and/or substance abuse treatment, and $98 for other support services. These costs were inflated to 2018 USD. It was assumed patients who were *In RWAHP/VS* receive outpatient health services, medical case management, and support services since these are core services. It was assumed patients who were *In RWAHP/Not VS* required more services than those who are virally suppressed, so they also incurred costs in addition to the three other services. Since mental health/substance abuse treatment was the only other service cost category published, this cost was used as the additional service cost for patients *In RWHAP/Not VS*. It should be noted that it is not assumed that all people who were not virally suppressed required mental health and substance abuse treatment services, but rather that mental health/substance abuse treatment was a stand-in cost for the wide range of additional services that RWHAP clients might benefit from when working towards suppression, such as adherence support, medical nutrition therapy, and financial aid, to name a few. Patients *Out of RWHAP* do not incur RWHAP service costs.

2. Calibration

2.1 Targets

There were five calibration targets. Four targets were proportions of the population in each of the four model states in 2019:

- 54% in RWHAP and virally suppressed (*In RWHAP/VS*),
- 10% in RWHAP and not virally suppressed (*In RWHAP/Not VS*),
- 21% out of RWHAP and virally suppressed (*Out of RWHAP/VS*), and
- 15% out of RWHAP and not virally suppressed (*Out of RWHAP/Not VS*).

These targets were calculated from local RWHAP data (as described in Section 1.1) using the same threshold of engagement for *In RWHAP* (≥6 months of services) as used in the model structure. Viral suppression was defined as sustained suppression, meaning all viral load tests in a year were suppressed. It was assumed that service engagement and viral suppression status of the RWHAP population was in equilibrium, with these estimates remaining stable over the 10-year time horizon in the status quo scenario.

The fifth calibration target was the difference in viral suppression rates when food needs are met (food secure) compared to when food needs are not met (food insecure) for clients *In RWHAP*. This risk difference (3%) was estimated from local RWHAP data using a propensity score adjusted logistic regression analysis that predicted sustained viral suppression rates among people who used food vouchers vs. didn't use vouchers between 2015-2019.[68] Propensity scores were calculated using data on client demographics, socioeconomic information, and use of other RWHAP services. A logistic regression using generalized estimating equations and an independent correlation structure was used to predict sustained viral suppression with propensity scores adjusting for the probability of using food vouchers. We predicted potential outcomes, estimated the risk difference, and bootstrapped standard errors from 250 samples. The analysis found a risk difference of 3.05% (95% CI: 1.41%-4.70%). The average probability of sustained viral suppression among clients who used food vouchers was 80.85% compared to 77.8% among clients who did not use food vouchers when adjusting for propensity to use vouchers.

Each of the five calibration targets was assessed over a 10-year horizon, resulting in 50 total calibration targets. As noted above, it was assumed each target remained constant over the 10-year period.

2.2 Methods

The food insecurity multiplier was selected for calibration because there were no data to inform this parameter and a multiplier was needed to achieve the risk difference of 3% calculated from local RWHAP data (as described in Section 2.1).

Annual transition probability parameters were selected for calibration in order of parameter uncertainty accounting for limitations of RWHAP data (e.g., limitations of how data was collected, what was adequately captured in available data, and which transitions probabilities calculated from the data were implausibly large or small based on knowledge of patient care dynamics in RWHAP). For example, transitions from out of care states were highly uncertain since data would be missing for individuals who were fully out of care, making transitions calculated directly from data unreliable. Probability of gaining viral suppression while in RWHAP was also uncertain because the transition probability calculated from the annual-level data was much lower than expected based on analyses of more granular data on all viral load test results collected.

For calibration, all transition parameters were initially set to the values calculated directly from RWHAP data. The calibration was then run with a single parameter (probability of gaining VS Out of RWHAP), with additional parameters being added in sequentially in order of uncertainty from most to least uncertain. Parameters stopped being added to the calibration when no further meaningful gains in goodness-of-fit were achieved. In cases of uncertain parameters involving opposing flows from the same state (e.g., gaining VS and losing VS while in RWHAP), including both opposing parameters in the calibration was avoided by including only the most uncertain of the opposing parameters. This was done so that best fitting calibrated values could converge, rather than be a wide range of values that balanced each other out. Minimum and maximum values parameters were selected based on estimates calculated from local data, parameter definitions (i.e., probabilities must sum to 1), or set intentionally wide when little information was available to guide search space size (**Table 5**).

Table 5. Calculated Values, Uncertainty Level, and Search Spaces for Transition Probability Parameters

Annual Transition Probability					**Opposing Annual Transition Probability**	
Parameter	**Value from Local Data**	**Uncertainty Level**	**Search Space**		**Opposing Parameter**	**Value from Local Data**
			Min	**Max**		
Gain VS <u>out</u> of RWHAP	19.1%	1 (highest)	0	20%	Lose VS <u>out</u> of RWHAP	9.9%
Enter RWHAP, Stay Not VS	5.7%	2	0	70%	Leave RWHAP, Stay Not VS	9.7%
Gain VS <u>in</u> RWHAP	37.9%	3	30%	85%	Lose VS <u>in</u> RWHAP	4.9%

Enter RWHAP, Lose VS	1.6%	4	0	30%	Leave RWHAP, Gain VS	5.4%
Enter RWHAP, Gain VS	20.3%	5	10%	50%	Leave RWHAP, Lose VS	5.6%
Enter RWHAP, Stay VS	18.4%	6 (lowest)	10%	50%	Leave RWHAP, Stay VS	9.0%

2,500 combinations of input values were randomly generated with Latin hypercube random sampling to ensure sufficient coverage over the search space. The model was run 50 times for each of these 2,500 parameter sets. 50 samples were deemed sufficient because variation in model results due to stochasticity was not meaningfully large enough to warrant a larger sample size; the average standard deviation of model results across 50 samples was less than 1 percentage point (~0.5-0.6%). Goodness-of-fit of model results to target values was measured using sum of squared differences based on the mean model result over the 50 samples. All calibration targets were weighted equally when calculating an overall goodness-of-fit metric.

2.3 Results

Calibration targets were achieved by including the top four most uncertain transition parameters in the calibration. Adding in the fifth and sixth most uncertain transition parameters did not make a substantial difference in goodness-of-fit, so the values calculated from local data were used for these parameters.

The model reached an equilibrium by Year 2 so the final overall goodness-of-fit metric was calculated with Year 1 excluded. Excluding Year 1 improved overall goodness-of-fit from a top-10 average of 0.00049 to 0.00023. The top ten best-fitting values for the four calibrated transition probabilities are depicted in **Figure 2**. Goodness-of-fit results for these parameter sets were between 0.00017-0.00026.

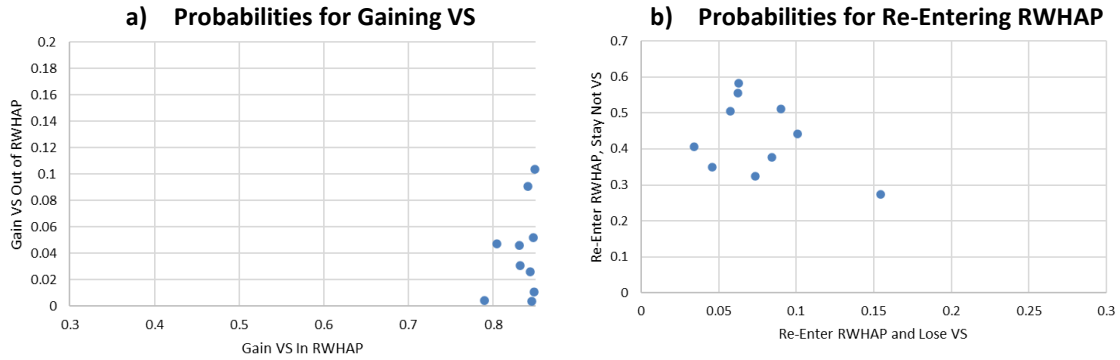
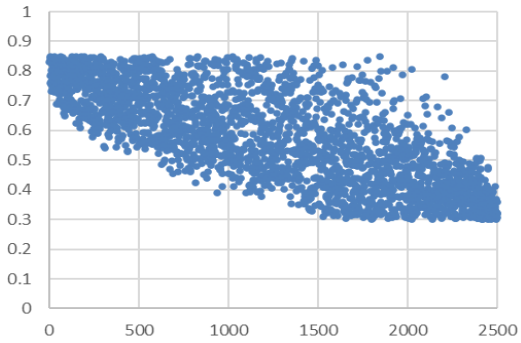


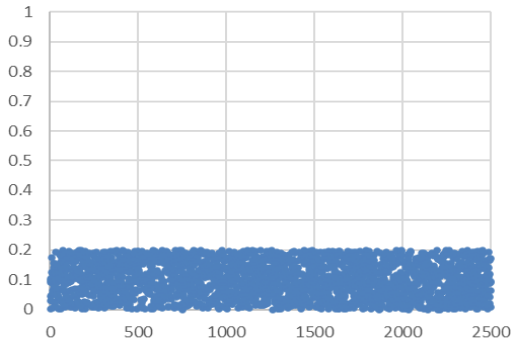
Figure 2. Top 10 Best-Fitting Values Over Search Space. a) Best fitting values for gaining VS in RWHAP converged between 0.8-0.85 (x-axis). Best fitting values for gaining VS out of RWHAP ranged between 0-0.1. **b)** Best fitting values for re-entering RWHAP and losing VS converged to values less than 0.1 (x-axis). Best fitting values for re-entering RWHAP and staying not VS converged between 0.3-0.6 (y-axis).

The probability of gaining viral suppression in RWHAP had the strongest pattern of convergence to a best fitting value with best fitting values above 0.8 (**Figure 3a, Figure 2a**). The probability of gaining VS out of RWHAP converged to values between 0-0.1 (**Figure 3b, Figure 2a**). Best fitting values for probabilities of re-entering RWHAP had a wider range: re-entering RWHAP/staying not VS converged to values between 0.3-0.6, and re-entering RWHAP/losing VS typically converged to values less than 0.1 (**Figure 3c-d, Figure 2b**).

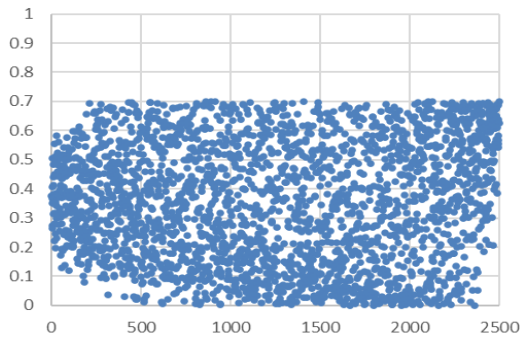
a) Gain VS in RWHAP



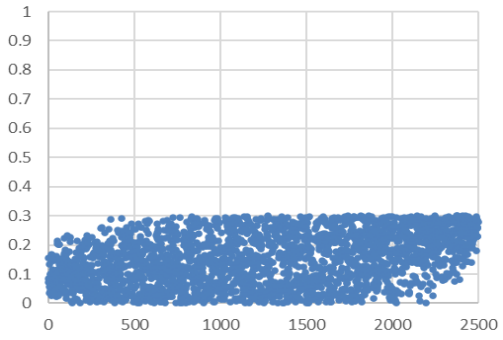
b) Gain VS Out of RWHAP



c) Enter RWHAP and Stay Not VS



d) Enter RWHAP and Lose VS



e) Food Insecurity Multiplier

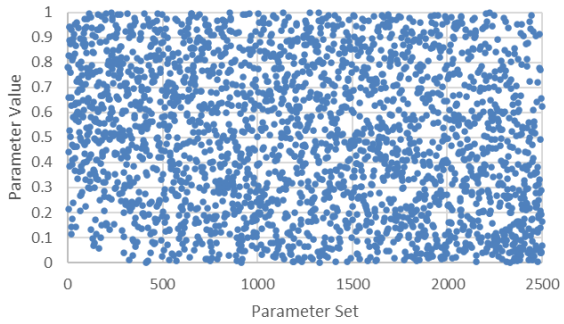


Figure 3. Search Space, Ordered by Overall Goodness-of-Fit, for Five Calibrated Parameters. Each dot represents one of 2,500 parameter values across the defined search space for each calibrated parameter. Parameter values are ordered by overall goodness-of-fit, with better fitting parameter values to the left (towards 0 on the x-axis) and poorly fitting parameter values to the right (towards 2,500).

The food insecurity multiplier did not have clear convergence to a value when goodness-of-fit was equally weighted across all 50 calibration targets (**Figure 3e**). This was likely due to calibration targets being on different scales (i.e., deviations from the target of 0.03 would be small compared to deviations from the target of 0.54 when equally weighted). Two options to address this in the calibration process could be 1) using a weighted goodness-of-fit metric that more heavily weights the 0.03 risk difference target or 2) to divide each goodness-of-fit value by the target such that the goodness-of-fit reflects a percentage deviation. However, in this project to avoid the computational burden of re-running the entire calibration, the top 100 best fitting parameter sets overall were examined. Goodness-of-fit specifically for the food voucher target in this set of top 100 was best (minimized) when the food voucher multiplier was between 0.4-0.5 (**Figure 4**). To ensure good fit for the food voucher risk difference, the final best-fitting parameter set selected was one that had a food voucher multiplier between 0.4-0.5.

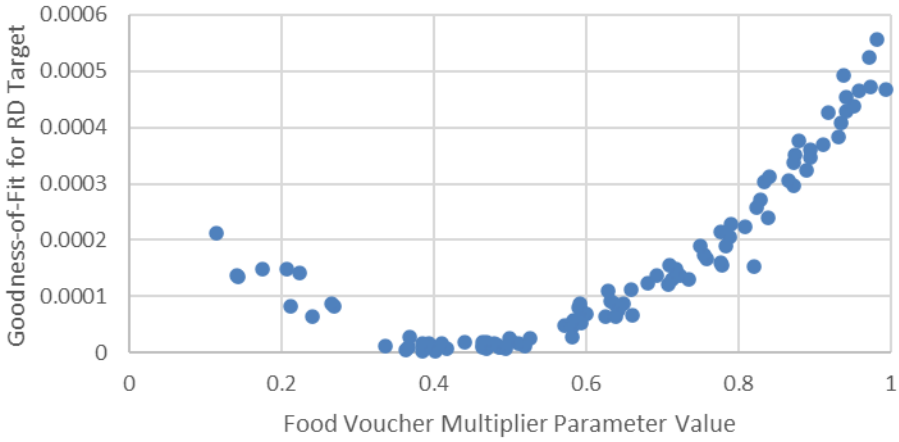


Figure 4. Distribution of Food Voucher Multiplier Values and Goodness-of-Fit for Food Voucher Risk Difference Target Among the Top 100 Best Fitting Parameter Sets Overall. Best fitting values specifically for the food voucher multiplier converged to between 0.4-0.5.

The parameter values from the best fitting set are listed in **Table 6** and the final annual transition matrix is in **Table 7**.

Table 6. Parameter Values from Best Fitting Set Compared to Values Calculated from Local Data

Parameter	Value from Best Fitting Set
Probability of gaining VS while out of RWHAP	9.1%
Probability of gaining VS while in RWHAP	84.1%
Probability of re-entering RWHAP while staying not VS	37.6%
Probability of re-entering RWHAP and losing VS	8.4%
Food insecurity multiplier on probability of gaining VS in RWHAP	0.44

Table 7. Annual Transition Probability Matrix

	Transition to:			
Transition from:	**In RWHAP VS**	**In RWHAP Not VS**	**Out of RWHAP VS**	**Out of RWHAP Not VS**
In RWHAP, VS	80.5%	4.9%	9.0%	5.6%
In RWHAP, Not VS	84.1%*	0.8%	5.4%	9.7%
Out of RWHAP, VS	18.4%	8.4%*	63.3%	9.9%
Out of RWHAP, Not VS	20.3%	37.6%*	9.1%*	33.0%

*Calibrated values. All rows sum to one and values on the diagonal were calculated by subtracting the other values in the row from 1. RWHAP: Ryan White HIV/AIDS Program. VS: Virally suppressed.

The best-fitting parameter value set achieved stability for the four model states over the 10-year period (**Figure 5**). Across 150 runs, there was not strong variability or deviance from the mean. The best fitting values also achieved stability in the fifth calibration target, which was the risk difference in viral suppression rates between individuals who experience food insecurity versus those who don't (**Figure 6**). There was wider variability in risk difference outcomes across the 150 runs, however the mean was stable and centered at the target of 0.03.

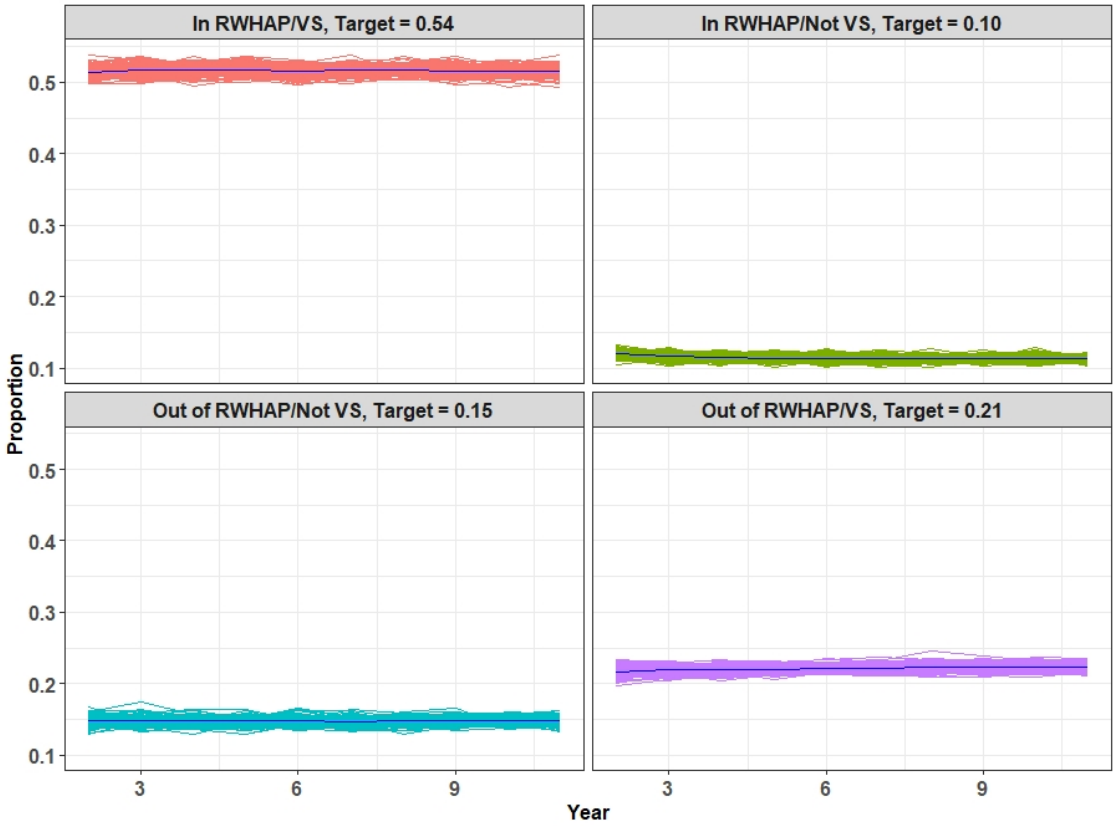


Figure 5. Proportion of population in each model state over 10 years from best-fitting calibrated value set. States are stable over the 10-year period and closely match the desired target values. Colored lines represent results from 150 different simulation runs using the best-fitting parameter set. The center blue line indicates the mean outcomes from the 150 runs.

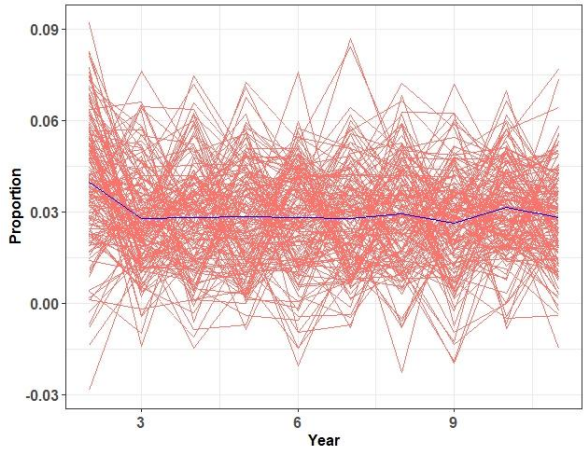


Figure 6. Risk difference in viral suppression rates between individuals who experience food insecurity compared to those who do not. Red lines represent results from 150 different simulation runs using the best-fitting parameter set. The center blue line indicates the mean risk difference from the 150 runs, which is centered around the target of 0.03.

3. Validation

3.1 Targets

Two targets were chosen for model validation based on data availability and appropriateness of targets for validation.

Percent of people living with HIV (PLWH) who die from all causes each year. Target = 0.7-1.2%

A target value of 0.7-1.2% was based on mortality rates over a five year period from both public Minnesota Department of Health data for the entire state[104] and internal RWHAP data. In Minnesota, the percent of PLWH who died ranged from 1.12% in 2015 to 0.83% in 2019 **(Table 8).** In the RWHAP dataset, the percent of PLWH who died ranged from 1.23% in 2015 to 0.82% in 2019. There was a slight decreasing trend over time in the proportion of PLWH who died between 2015-2019 in both datasets, however this trend was insignificant when evaluated in a linear regression (p=0.23 in DOH data, p=0.16 in RWHAP data).

Percent of PLWH who die from HIV-related causes. Target = 0.2-0.4%

A target value of 0.2-0.4% was based on public Minnesota Department of Health data for the entire state between 2015 and 2019;[104] the RWHAP dataset did not differentiate between HIV-related vs. non-HIV-related deaths. The percent of deaths due to underlying HIV disease ranged from 0.38% in 2015 to 0.23% in 2019, with a maximum of 0.41% in 2016/2017 and average of 0.34% over the 5-year period (**Table 8**). There was again a slight decreasing trend, however it was insignificant when evaluated in a linear regression (p=0.08).

Table 8. Validation Data and Target Value Estimates

Data Point	2015	2016	2017	2018	2019	5-Year Avg.	Source
Total PLWH in MN	8,215	8,554	8,789	8,981	9,193	-	Minnesota Department of Health
No. of Deaths in MN (All-Cause)	92	69	85	81	76	-	
No. of Deaths Due to HIV in MN	31	35	36	26	21	-	
% of PLWH Died (All-Cause)	1.12% (92/8,215)	0.81%	0.97%	0.90%	0.83%	0.92%	Calculated from MN data above
% of PLWH Died (HIV-Related)	0.38% (31/8,215)	0.41%	0.41%	0.29%	0.23%	0.34%	
Avg. No. PLWH in RWHAP Dataset	3,995	4,276	4,418	4,325	4,385	-	Internal RWHAP data
No. of Deaths in RWHAP	49	40	31	36	36	-	
% of PLWH Who Died (All-Cause)	1.23% (49/3,995)	0.94%	0.70%	0.83%	0.82%	0.90%	Calculated from RWHAP data above

PLWH: People living with HIV; MN: Minnesota; RWHAP: Ryan White HIV/AIDS Program.

3.2 Methods

Using the model values described in Section 1 and the best-fitting parameter value set from the calibration (Section 2), the model was run for 150 stochastic simulations over a 20-year time horizon. The mean across all 150 simulations was used to visually assess fit with validation targets.

3.3 Results

The model achieved alignment with validation targets (**Figure 7**).

Percent of PLWH who die each year. Target = 0.7-1.2% | Model = 0.6-1.2%

Across 150 simulations, the mean percentage of PLWH who died each year ranged from 0.64-1.17%, which was mostly within range of the validation target range 0.7-1.2% (**Figure 8**). Of note, the model had an increasing trend in the all-cause death rate over the 20-year time horizon, which likely is reflective of aging within the population.

Percent who die from HIV-related causes. Target =0.2-0.4% | Model = 0.3%-0.4%

Across 150 simulations, the mean percentage of PLWH who died of HIV-related costs was relatively steady between 0.3-0.4%, which was within the validation target range. (**Figure 8**).

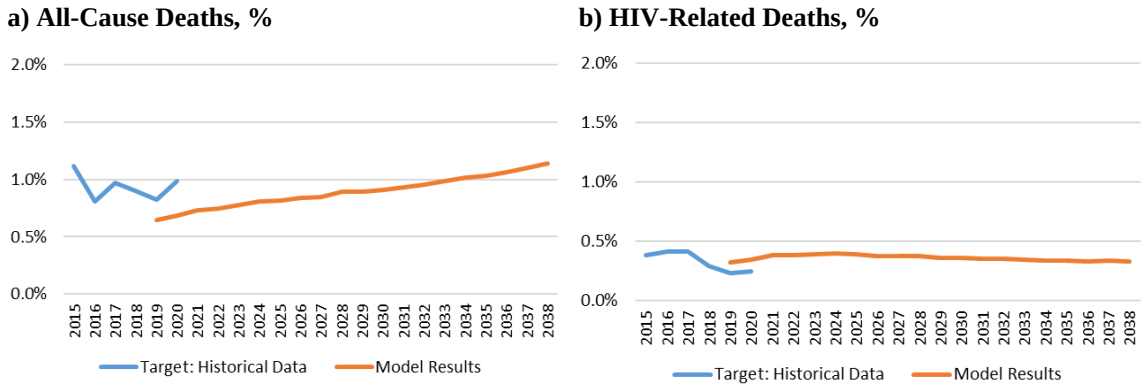


Figure 7. Validation results: Comparison of historical data with model results. Historic data is in blue and the mean model result across 150 simulations is in orange.

Figure 8. Validation results: Percent of people dying each year from all-causes and HIV-related causes. Colored lines represent results from 150 different simulation runs using the best-fitting parameter set. The center blue line indicates the mean outcomes from the 150 runs.

4. Food Voucher Intervention Strategy

4.1 Background

As part of support services for clients, RWHAP funds various food aid services, including on-site meals, home-delivered meals, food shelf, and food vouchers. Food vouchers was selected as the intervention for this analysis because it had a positive impact on sustained viral suppression in data analyses[68] and because it was a relatively low barrier intervention to expand compared to other food aid service that would require larger investments in staff and physical space. Barriers and opportunities for service expansion were assessed in interviews with service providers in Minneapolis-St. Paul who receive RWHAP funding to provide these services.[90]

4.2 Intervention Structure

In the model, each individual was assigned an indicator for whether or not they needed food aid. It was assumed that need for food aid did not change over time for individuals. Individuals who needed food aid had a probability of receiving food aid each year and the amount of food aid they received could vary year-to-year. Individuals who needed food aid, but didn't receive it, experienced a health-related quality of life (HRQoL) decrement since studies have shown that food insecurity has a negative impact of quality of life.[74]

The intervention under consideration was expanding food vouchers to fill unmet need among RWHAP clients. It was assumed that only patients in RWHAP (using ≥6 months of services) were eligible to receive food vouchers because local data showed that only 2.6% of individuals receiving <6 months of services used food vouchers. Receipt of food vouchers had a positive impact on the probability of gaining viral suppression and also eliminated the HRQoL decrement from food insecurity. Intervention costs consisted of costs of the food vouchers themselves and the costs associated with outreach and operations (e.g., reaching clients who need food aid and distributing food vouchers). It was assumed that outreach costs would be highest in the first year of the intervention because a larger, more intensive effort would be needed to fill unmet need in the first year. Outreach costs were then lower in subsequent years, assuming that most people on food vouchers in one year will remain on vouchers for subsequent years and that outreach will mainly be focused on new individuals entering RWHAP or those that dropped out of RWHAP services.

4.3 Parameterization

Intervention-related inputs were parameterized using a combination of local data analysis, local RWHAP reports, published literature, and calibration (**Table 9**).

Table 9. Base Case Intervention-Related Parameters

Input	Value	Source
Proportion of RWHAP clients who need food aid	50%	RWHAP 2020 Needs Assessment
Proportion of RWHAP clients who receive food aid among those who need it	60%	RWHAP 2020 Needs Assessment
Mean number of food vouchers received in a year, per-person	3.8 (sd 2.2)	Local data analysis
HRQoL decrement when experiencing food insecurity	0.11	Hanmer 2021
Multiplier on probability of gaining VS in RWHAP if experiencing food insecurity	0.44	Local data analysis; calibration
Costs		
Average cost per food voucher received	$60	Local data analysis
Upfront outreach and operational cost to reach clients with unmet need (incurred in year 1 of intervention period)	$6,240	Personal email correspondence (5/10/2022)
Annual outreach and operational cost to (incurred in years 2-10 of intervention period)	$960	

RWHAP: Ryan White HIV/AIDS Program; SD: standard deviation; HRQoL: health-related quality of life; VS: viral suppression.

In the base case, the proportion of people needing and receiving food aid was based on a survey-based needs assessment conducted by Hennepin County RWHAP in 2020.[79] The survey found approximately 50% of individuals did not need food vouchers, 30% needed and received vouchers, and 20% needed but did not receive vouchers (i.e., 20% unmet need). The intervention

under consideration fills unmet need, providing food vouchers to the 20% of people who needed but did not receive vouchers. In other words, the proportion of clients who received food aid among those who needed it in the base case was 60% (30%/50%); the intervention increased this proportion to 100%.

The HRQoL decrement associated with food insecurity was assumed to be 0.11. This estimate came from a nationally-representative survey on the association between food insecurity and HRQoL in the U.S. (Hanmer 2021).[74] This study assessed food insecurity from data reported in the USDA Household Food Security Survey Module and measured HRQoL using five different quality of life assessments: PROMIS-Preference (PROPr), self-rated health (SRH), Euroqol-5D-5L (EQ-5D), Health Utilities Index (HUI), and Short Form-6D (SF-6D). The study found differences in HRQoL for food secure vs. food insecure individuals to be both significant and large, with differences associated with food insecurity ranging from -0.11 to -0.21, depending on the QoL assessment used. To be conservative, the lowest difference (-0.11) was used as the quality of life decrement associated with food insecurity in this cost-effectiveness analysis.

The mean number of food vouchers received in a year was 3.8 vouchers. A RWHAP data analysis on local food voucher use found that among clients who used food vouchers, the distribution of number of vouchers received per year was a mean of 3.8, standard deviation of 2.2, median of 4, minimum of 1, and maximum of 12. It was assumed the number food vouchers received by new clients reached by the intervention followed this distribution. A scenario analysis was conducted that increased the number of food vouchers received to a mean of 12, standard deviation of 2.2, minimum of 1, and maximum of 12. This is because local RWHAP food voucher policy changed in 2020 such that all food voucher requests should be honored each month. With this change, the community-based organization that distributed RWHAP-funded food vouchers reported that most clients were now receiving food vouchers every month (personal email correspondence, 5/10/2022).

The impact of experiencing food insecurity (i.e., needing food vouchers but not receiving them) was assumed to decrease the probability of achieving viral suppression by a multiplier of 0.44 This multiplier was estimated through calibration to match differences in sustained viral suppression rates among people who used vouchers vs. didn't use vouchers from a propensity score adjusted logistic regression analysis on local RWHAP data, as described in Section 2.[68]

The estimated cost of a single food voucher was $60. From interviews with local service providers, it was determined that the maximum food voucher amount an individual could receive

in a month was $60 and the maximum that an individual with a family could receive was $100. An assessment of total annual spending by local RWHAP Part A and Part B on food vouchers and local service encounter data analysis on food voucher use found that $60 was the approximate average amount received per person per food voucher. This suggests the majority of food voucher users were individuals rather than families.

The upfront outreach cost was $6,240 based on estimates provided by a program director at a community-based non-profit organization in Minneapolis-St. Paul that provides the majority of food vouchers to RWHAP clients in Minnesota. The director estimated that reaching the initial population of individuals with unmet need for vouchers would require one staff member doing 4-6 hours per week of outreach for 52 weeks, for a total of 208-312 hours. At a pay rate of $20.00 per hour, this comes to $4,160-$6,240. To be conservative, the upper bound on this cost was used in base case.

The same program director estimated annual outreach costs after the first year of program expansion to be $960. This was based on 2-4 hours a month of outreach work, for a total of 24-48 hours. At a pay rate of $20.00 per hour, this comes to $480-$960. To be conservative, the upper bound on this cost was used in base case.

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