Interfaces

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

Let the Needles Do the Talking! Evaluating the New Haven Needle Exchange

Edward H. Kaplan, Elaine O'Keefe,

To cite this article:
Edward H. Kaplan, Elaine O'Keefe, (1993) Let the Needles Do the Talking! Evaluating the New Haven Needle Exchange. Interfaces 23(1):7-26. http://dx.doi.org/10.1287/inte.23.1.7

Let the Needles Do the Talking! Evaluating the New Haven Needle Exchange

EDWARD H. KAPLAN
Yale School of Organization and Management
Department of Internal Medicine
Yale School of Medicine
Department of Operations Research
Yale University
Box 1A
New Haven, Connecticut 06520-7368

ELAINE O'KEEFE
New Haven Health Department
AIDS Division
540 Ella Grasso Boulevard
New Haven, Connecticut 06519

New Haven, Connecticut implemented a needle exchange program in November 1990 to combat the spread of the AIDS virus. We developed a syringe tracking and testing system that provided data for mathematical models of HIV transmission. The models suggest that needle exchange reduced the HIV infection rate among program clients by 33 percent. In response, the Connecticut legislature continued funding the program, expanded needle exchange services to Bridgeport and Hartford, and decriminalized syringe possession. New needle exchange programs and legislation have also been developed in New York City, California, and Massachusetts partially as a result.

Over 138,000 people have died of acquired immune deficiency syndrome (AIDS) in the United States, while about 214,000 cases of AIDS have been reported to the United States Centers for Disease Control (CDC) as of February 1992 [CDC 1992]. The human immunodeficiency virus (HIV) that causes AIDS may be transmitted via unprotected sexual intercourse, the sharing of contaminated drug injection equipment, vertically from infected mothers to their unborn children, and very rarely via transfusion of blood or blood products. Injecting drug users (IDUs) account directly for about 29 percent of reported AIDS cases among adults and adolescents nationwide, while over half of all heterosexually acquired cases of AIDS can be traced to sex with an IDU. In addition, about 60 percent of all children with AIDS

0091-2102/93/2301/0007$01.25

HEALTH-CARE—EPIDEMIOLOGY
PROBABILITY—APPLICATIONS AIDS EPIDEMIC

INTERFACES **23:** 1 January–February 1993 (pp. 7–26)

can trace their disease to a mother who either injected drugs or was the sexual partner of an IDU. In sum, roughly 69,600 of the 214,000 AIDS cases reported to the CDC involved some aspect of injection drug use; this accounts for just under one third of all AIDS cases nationwide [CDC 1992].

In contrast to the national picture, over 60 percent of the 500 AIDS cases reported in New Haven, Connecticut (population 129,000) can be traced to injecting drug use. That the AIDS epidemic was following a different path in New Haven as compared to national trends was recognized by local health professionals and community activists in the mid-1980s. By 1987, it was clear that the dominant mode of HIV transmission in New Haven was the practice of sharing needles to inject drugs. As a result, the virus spread rapidly among IDUs and their sexual partners. The rate of pediatric AIDS cases also grew, reflecting the foothold HIV had established among female IDUs and the female sex partners of male IDUs. Specific actions had to be taken to prevent the spread of HIV and AIDS throughout the poor and minority communities of New Haven, communities that also suffered from the epidemic of drug abuse.

The behavior of needles must change.

In 1986, the New Haven Mayor's Task Force on AIDS (MTFA) was formed to galvanize the community to develop effective prevention and care services and to formulate rational policy in response to the AIDS epidemic. In 1987, this task force recommended a street outreach program to deliver AIDS information, bleach kits for cleaning needles, and condoms to active IDUs. The recommendation was accepted, and the health department implemented an outreach program. This outreach project included a survey of drug addicts, with the partial intent of determining why IDUs continued to share needles given the threat of HIV infection and AIDS. Survey respondents consistently claimed that IDUs shared needles both because needles were scarce and because they feared arrest for possessing a syringe without prescription (Connecticut was one of a minority of states that made it illegal to possess a hypodermic syringe without a medical prescription). Respondents also noted the difficulties involved in entering drug treatment programs, where long waiting lists, the absence of such supportive services as child care during treatment, and lack of adequate rehabilitative training necessary to sustain a drug-free existence render treatment less accessible and useful than desired. Drug injectors needed a program that would remove the imperative for needle sharing while easing access to drug treatment.

The Road to Needle Exchange

The MTFA recognized that the logical intervention needed was needle exchange, and indeed local activists had already started to distribute clean needles illegally to IDUs. First implemented in Amsterdam in 1984 [Buning et al. 1989], needle exchange is based on a simple idea: active IDUs exchange their used needles for clean ones. This removes infectious drug injection equipment from circulation and also

eases access to clean needles. In addition, the contacts made as a result of needle exchange might lead some active IDUs to consider counseling or even entry into drug treatment.

While the rationale behind such programs seems straightforward, needle exchange was (and is) viewed as controversial. Opponents to needle exchange feared that by allowing drug injectors access to needles, government was signaling defeat in the war on drugs and tacitly condoning and perhaps even encouraging others to initiate drug injection. Also, the public might be placed at risk for accidental infection if IDUs discarded injection equipment carelessly following use. How could one expect a program predicated on IDUs behaving rationally to succeed when the very act of drug injection defies rationality? Finally, needle exchange had not been shown to be effective in reducing the rate of new HIV infections. There was no real proof that such programs actually work.

The MTFA believed that needle exchange could slow the spread of HIV, however, and proceeded to educate the community and lobby for needle exchange at both the state and local level. Although the MTFA included representatives of diverse constituencies in New Haven, it was clear that the task force alone could not change policy at the state level; as it was against state law to possess syringes without prescription, it was largely at the state level that attitudes had to be changed. To achieve this end, the MTFA sponsored meetings for individuals in the criminal justice system, in the drug treatment sector, in the local police force, and from community-based organizations to invite discussion. Simultaneously, local AIDS educators began to weave the notion of needle exchange into presentations that were routinely conducted for community groups. These efforts led to a growth in support among a broad segment of the New Haven community, and in the spring of 1989, members of the MTFA testified before the Connecticut State Public Health Committee calling for the removal of legal impediments to clean needle access. This proposal was not met favorably; state legislators were not yet willing to entertain the prospect of needle exchange.

The year 1989 was an election year in New Haven, and the MTFA took advantage of this to raise AIDS-related issues, including needle exchange, with all of the mayoral candidates. As a result, all candi-

Needles share fewer people.

dates vowed to support syringe decriminalization or the establishment of a needle exchange program in New Haven or both. The outcome of this lobbying was most effective; when John Daniels became New Haven's first African American mayor, he remained committed to his election vow to give needle exchange a fighting chance as part of the city's overall HIV prevention and control effort. Simultaneously, another obstacle to needle exchange in New Haven was overcome when Mayor Daniels appointed Nicholas Pastore, who strongly endorsed and supported the concept of needle exchange, as police chief.

Further lobbying followed. The New Haven Board of Health Commissioners officially endorsed the concept of needle ex-

change, as did the statewide Association of Health Directors, the board of the Connecticut Primary Care Association, the Connecticut Latino AIDS Advisory Council, and the statewide AIDS Action Council. In March of 1990, the Public Health Committee again held a hearing focusing on the issue of decriminalizing the sale and possession of drug injection equipment without prescription. It became apparent that while many legislators were comfortable with the notion of implementing a pilot needle exchange program, support for complete decriminalization was not strong. A compromise bill was prepared that funded one demonstration needle exchange program, exempt from existing statutes prohibiting syringe possession without prescription, and mandated that the program be evaluated. In May of 1990, the Connecticut House passed Public Act No. 90-214, *An Act Concerning a Demonstration Needle and Syringe Exchange Program*, by a vote of 99 to 36. The Senate followed suit by a 26 to 10 margin. In June 1990, Governor William O'Neill signed the bill authorizing Connecticut's first legal needle exchange program effective July 1.

Needle Exchange Operations

The design for the needle exchange program was achieved over the summer of 1990. The protocol committee assembled consisted of the director of New Haven's Department of Health, the chair of the MTFA, the chief of police, the director of the AIDS division of the New Haven Department of Health (O'Keefe), the state's chief AIDS epidemiologist, representatives from the mayor's office and from drug treatment programs, community activists, health department outreach workers who would actually provide program services, and a professor from Yale University entrusted with the design and conduct of the program evaluation (Kaplan). The committee decided that IDUs would be treated with understanding and respect. No true identifying information such as name, address, or social security number was requested of program clients. Clients were not tested for HIV infection for fear of scaring away those most in need of needle exchange services. The program began operations on November 13, 1990.

Syringe tracking and testing is a system to "interview" needles.

The needle exchange operates on an outreach basis. A van donated by Yale University visits those neighborhoods with high concentrations of IDUs. Typically, the program operates six hours per day, four days per week. Outreach staff members teach program clients how the AIDS virus is transmitted and specific actions to avoid contracting or passing HIV. They distribute easily understood literature documenting the risks of HIV infection and other infectious diseases transmitted via needle sharing or unsafe sexual practices. Condoms and bleach packets are dispensed as well. The staff provides all clients with information regarding drug treatment services, and informs them that, should they want to enter treatment, a program staff member will be available to help "walk them through" the process. The outreach workers also tell clients where they can receive anonymous HIV counseling and testing.

Clients enrolling in the program are entitled to receive one needle/syringe (nondetachable needle/syringe pairs are distributed) on their first program visit if they do not return used equipment to the van. All future exchanges are made on a one-for-one basis to a maximum of five (so that a client returning three needles would receive three in exchange, while a client returning 10 needles would receive only five in exchange). Clients returning injection equipment place their used needles in canisters which are then sealed, so the program staff never handles used injection equipment.

Of New Haven's estimated 2,300 IDUs [Kaplan and Soloshatz forthcoming], 1,200 have enrolled in the needle exchange. Of those enrolled, about half still participate in the program or have been placed in drug treatment. While it is unknown at present what has happened to apparent dropouts, the possibilities include arrest and incarceration, hospitalization, relocation, voluntary cessation of drug injection, and death in addition to relapse to preprogram behavior. To date, the needle exchange has distributed over 46,000 needles. Sixty-one percent of these have been returned, as have about 18,000 nonprogram needles.

Issues in Evaluating Needle Exchange Programs

The primary goal of needle exchange is to reduce the incidence of new HIV infections among IDUs. Past evaluations of needle exchange in other settings, however, have not shown whether it achieved this goal. Most prior studies have relied on surveys of program participants to determine the frequencies of various risky behaviors (such as drug injection, needle sharing, and failure to clean needles before injecting) both before and during the implementation of needle exchange [Buning 1989; Buning et al. 1988; Hart et al. 1989; Joseph and Des Jarlais 1989; New York City Department of Health 1989; Stimson et al. 1988; Watters et al. 1991]. Self-reported data regarding risky behaviors were collected from the participants in the New Haven needle exchange as well.

While studies have shown consistent self-reported reductions in risky behavior among IDUs participating in needle exchange programs, critics have not found these studies convincing. First, it is not possible to verify self-reported behavior. Second, even if the self-reports are accurate, it is not clear how the changes reported translate to reductions in HIV incidence. Third, an analysis based solely on self-reports does not incorporate the actual operations of needle exchange, yet surely the success or failure of a program depends on the needle distribution and return rates achieved.

In fact, it seems quite clear that whether or not participating clients alter their risky behavior, the mechanics of needle exchange require that the behavior of needles must change [Kaplan 1992]. A circulation theory of needle exchange argues that by making needles available on an exchange basis, it is not the number of needles among program participants that will change, for a law of conservation of needles applies: roughly speaking, the number of needles distributed is balanced by the number of needles returned. However, what will occur is an increase in the turnaround of needles. This is equivalent to re-

ducing the time needles spend circulating in the population. As needles circulate for shorter periods of time, it stands to reason that needles share fewer people. This lowers the number of infected needles in the pool of circulating needles, which in turn lowers the chance that an IDU becomes infected when injecting with a previously used needle. Now, to become infected, an uninfected IDU must inject with a previously used and infected needle, fail to disinfect the needle (for example, with bleach), and HIV must be transmitted. Even if IDUs fail to change their behavior, the rate of new HIV infections will fall in proportion to the lowered level of infection in the needles circulating among needle exchange participants. An analogy to malaria is instructive: needle exchange functions as if infected mosquitos were continuously removed and replaced by newborns free of disease. This circulation theory can be formalized mathematically (appendix). However, to use the theory required the invention of a new data collection system that eventually became the hallmark of the evaluation study.

The Syringe Tracking and Testing System

Syringe tracking and testing is a system developed to "interview" the needles returned to the program. It is our attempt to let the needles do the talking! The system works as follows [Kaplan 1991]: all clients participating in the needle exchange are given unique code names, and every needle distributed receives a tracking code. Any time a client exchanges needles, an outreach worker records the date and location of the exchange on a log sheet. In addition, the outreach worker records the code name of the client receiving the needles alongside the tracking codes of the needles. The client places the returned needles in a cannister, to which the outreach worker affixes a label with the date and location of the exchange, and the code name of the client. All returned needles are brought to a laboratory at Yale University where a technician collates the information on the canister labels with the tracking numbers on the returned needles. For nonprogram (or street) needles returned to the needle exchange, the location, date, and client code are recorded. A sample of the returned needles are tested for HIV using polymerase chain reaction (or PCR). The reliability of this testing procedure is quite good; in controlled laboratory experiments, 0 of 64 HIV negative needles tested positive, while 28 of 30 HIV infected needles tested positive [Heimer et al. 1992]. For all legible program needles returned (86 percent of returned program needles have intact tracking codes), one knows the following:

(1) Who received the syringe;
(2) When the syringe was distributed;
(3) Where the syringe was distributed;
(4) Who returned the syringe;
(5) When the syringe was returned;
(6) Where the syringe was returned.

In addition, for those needles selected for testing, one knows

(7) Whether the needle is HIV positive or HIV negative.

The initial results from the syringe tracking and testing system were both shocking and decisive. Outreach workers retrieved a large batch of needles from a local shooting gallery (shooting galleries are locations where IDUs buy drugs and rent injection

equipment from the gallery proprietor; often the needles involved have been used previously). Drug injection in shooting galleries is a known high risk factor for acquiring HIV infection [Des Jarlais, Friedman, and Stoneburner 1988; Page 1990]. It was nonetheless horrifying to discover that of 48 needles tested from the shooting gallery, 44 tested HIV positive for a prevalence of 91.7 percent. While this cannot be construed as the risk facing the typical IDU (who typically does not report frequenting shooting galleries), it does represent the disaster that can occur when needle sharing is carried to the extreme.

At the start of the program, IDUs presented whatever needles they had in their possession in exchange for clean needles. These street needles are representative of the risk faced by an IDU prior to the operation of the needle exchange; before the advent of needle exchange, all needles in circulation were street needles! Of 160 street needles tested at the beginning of the program, 108 tested HIV positive, for a prevalence level of 67.5 percent. Though significantly lower than the level of infection in gallery needles, this still represents a very large risk when viewed as the chance of selecting an infected needle from the pool of needles in circulation.

Of 48 needles tested from the shooting gallery, 44 tested HIV positive.

As of the middle of March 1991, 579 program needles had been tested. Of these, 291 (or 50.3 percent) were positive. The drop in the level of infection for program needles is consistent with what the circulation theory suggests. It marks a significant decline in the level of infection relative to the street needles tested at the beginning of the program. These three test results establish a clear risk gradient faced by IDUs in the program. As the statistical significance of the different infection levels reported is beyond question, policy officials found these data alone quite persuasive. Since March 1991, an additional 367 program needles have been tested, of which 147 tested positive (or 40.5 percent), lending further support to the protection offered by the needle exchange program.

While these results are encouraging, they do not link the operations of needle exchange to changes in the rate of new HIV infections. To achieve this very important end required the development of a mathematical model describing HIV transmission among IDUs via needle sharing. The syringe tracking and testing system, in concert with limited observations obtained from surveying program clients, provided the data needed to estimate the parameters for this model. The appendix contains a complete description of the model equations, estimation methods, numerical results obtained, and sensitivity analyses. The model developed was conservative, that is, assumptions arguing against the efficacy of the program were incorporated at several points in the formulation.

In spite of the conservative nature of the model, the results were truly of interest. The model estimated that, in the absence of behavioral changes on the part of the IDUs in the program, the rate of new HIV infections among needle exchange clients would drop from roughly six per 100 IDUs

per year to four per 100 IDUs per year, averting two new HIV infections per 100 IDUs per year. The model thus estimates a 33 percent reduction in the rate of new HIV infections among those IDUs participating in the program. This figure remains the most widely quoted finding of the evaluation study.

Other outcomes of the evaluation study have proven important. First, there was no evidence of any increase in injecting drug use in New Haven as a result of the program. The self-reported demographics of new program enrollees have remained stable over time, and in particular, the distributions of age and duration of drug use have not changed, arguing against the notion that somehow the program has attracted new drug users (the average age among program clients is 34, while the duration of drug use reported averages seven years). Second, roughly one in six IDUs who joined the needle exchange have subsequently entered drug treatment programs. This treatment referral rate is remarkable, as is the fact that the demographics of the needle exchange clients (41 percent African American, 25 percent Latino/a, 34 percent white) differ greatly when compared to the demographics of those currently in local drug treatment programs (27 percent African American, 9 percent Latino/a, 63 percent white). Thus, while over 60 percent of IDUs in area treatment programs are white, over 60 percent of those placed in drug treatment from the needle exchange program are nonwhite, redressing a possible inequity in access to the drug treatment system.

The model estimates a 33 percent reduction in new HIV infections.

The Impact on Public Policy

To understand the impact of this work requires both local and national perspectives. Locally, it is possible to construct a conservative estimate of the actual number of infections averted. As many clients who joined the needle exchange apparently dropped out, we can estimate the impact of the program conservatively by multiplying the cumulative number of person years spent in the program over all clients by the incidence reduction of two HIV infections per 100 client years (the model predicts a drop in the HIV infection rate from six per 100 IDUs per year to four per 100 IDUs per year). This assumes that all those who apparently drop out of the program are truly recidivists, an assumption that is patently false (as roughly one in six clients who joined the program eventually entered drug treatment, where the reduction in risk would be far greater than offered by the needle exchange). As the cumulative number of client days in the program roughly equals $0.688 \cdot a^2$ (where a is the age of the program in days [Kaplan 1992]), this calculation suggests the avoidance of five infections over the first year of the program, rising to 20 over the first two years. With lifetime hospital costs alone amounting to $50,000 to $100,000 per new infection, between $1 million and $2 million in public health care expenditures have been avoided over the first two years of the program.

However, this only hints at the true impact of this work. Needle exchange has

been returned to the menu of legitimate AIDS interventions in major American cities in large part due to the New Haven evaluation. If the New Haven results can be extrapolated elsewhere, then in New York, with an estimated 200,000 IDUs, a network of needle exchanges reaching only 25 percent of the IDU population could avert 1,000 infections in the first year of operations, avoiding between $50 million and $100 million in public health care costs.

A caveat to the calculations above is that they consider only the annual reduction in HIV incidence among needle exchange program clients, as opposed to changes in the lifetime probability of acquiring HIV infection. While the reduction in lifetime risk will be less than the reduction in annual incidence, we have ignored the effect of placing clients in drug treatment via the needle exchange. As one in six clients have been placed in drug treatment, the impact of the needle exchange on the probability of their ever acquiring HIV could be quite substantial.

The derived 33 percent reduction in HIV incidence is cited in the text of a bill currently under debate in the California legislature as part of the rationale for pursuing needle exchange programs in San Francisco and other communities. The state of Connecticut has continued funding for the New Haven program and enacted legislation expanding needle exchange to Bridgeport and Hartford. In addition, Connecticut has finally decriminalized the possession of a syringe without prescription effective July 1, 1992 as a result of this research. The National Commission on AIDS has taken notice of this work, as has the United States Centers for Disease Control and the US Conference of Mayors. Finally, the National Institute on Drug Abuse, the US government agency responsible for research on drug related issues, has awarded a research grant to the first author to continue development of the syringe tracking and testing system—the first federally funded study of needle exchange in the United States. The Robert Wood Johnson Foundation has provided both additional research funding and operating funds for the needle exchange program. Clearly successful intervention programs are of fundamental importance in the face of AIDS. Using management science methods, we have shown that needle exchange is one such intervention.

Acknowledgments

The polymerase chain reaction (PCR) protocol for HIV testing was developed by Robert Heimer of the department of internal medicine, Yale Medical School. The test results reported here are due to his efforts, which were supported by funds from the department of internal medicine. Professor Kaplan acknowledges research support from the Yale School of Organization and Management. This work was also supported in part by Grant #R01-DA07676-01 from the National Institute on Drug Abuse and two complementary grants from the Robert Wood Johnson Foundation. We warmly acknowledge the comments of Stephen Graves, Newton Garber, Fred Murphy, and an anonymous reviewer; their suggestions have served to strengthen this manuscript.

APPENDIX: Needles That Kill Model for Calculating HIV Incidence

This appendix contains the Needles That

Kill (NTK) model the first author (Kaplan) developed to forecast the incidence of new HIV infections and submodels for estimating the necessary parameters. It was the application of this model to preliminary data from the syringe tracking and testing system that produced the well-publicized "33 percent reduction" result (that is, the needle exchange reduced the rate of new HIV infections among program participants by 33 percent). Though the original report of these findings was dated July 31, 1991 [O'Keefe, Kaplan, and Khoshnood 1991], complete syringe tracking and testing data were available only through February 28, 1991.

For notation, let

λ = shared drug injection rate per program client per unit time,
θ = probability of disinfecting (bleaching) a needle before injection,
μ = removal rate per HIV infected program client per unit time,
α = HIV transmission probability per injection with an infected needle,
ρ = needle exchange rate per circulating needle per unit time,
γ = ratio of program clients to needles circulating among clients,
$\beta(t)$ = fraction of circulating needles infected with HIV, and
$\pi(t)$ = prevalence of HIV infection among program clients.

The dynamic variables $\beta(t)$ and $\pi(t)$ are assumed to evolve in accordance with the equations

$$\frac{d\pi(t)}{dt} = [1 - \pi(t)] \cdot \lambda \cdot (1 - \theta) \cdot \beta(t) \cdot \alpha - \pi(t) \cdot \mu \quad (1)$$

$$\frac{d\beta(t)}{dt} = [1 - \beta(t)] \cdot \lambda \cdot \gamma \cdot \pi(t) - \beta(t) \cdot [\rho + \lambda \cdot \gamma \cdot \theta \cdot (1 - \pi(t))]. \quad (2)$$

Equation (1) states that uninfected clients become infected by injecting with a needle that has not been disinfected, is contaminated with HIV, and transmits the infection in a single injection, while infected clients are assumed to depart the injecting population with rate μ per infected client per year. Equation (2) states that clean needles become infected when used by an infected client, while infected needles become uninfectious if they are cleansed prior to use by an uninfected drug injector, or if they are exchanged for clean needles. To interpret this model, imagine that n clients share m needles in common. The aggregate shared injection rate is then given by λn, and as a consequence the shared injection rate per needle equals $\lambda n/m = \lambda\gamma$. Thus, needles share people with rate $\lambda\gamma$, from which equation (2) follows. That drug injectors share groups of needles in the manner described has been documented in the literature (for example, Page [1990]).

The original NTK model assumed that arrivals to and departures from the population exactly cancelled, yielding a constant population size [Kaplan 1989]. However, it is easy to modify this formulation so that the program population grows with time, and equations (1) and (2) are still valid upon normalization by the population size. For a more detailed derivation of the original NTK equations, see Kaplan [1989].

The cumulative incidence of HIV infection per drug injector over some time interval $(0, \tau)$ (where 0 indicates the beginning of the needle exchange), $C(\tau)$, is given by

$$C(\tau) = \int_0^\tau [1-\pi(t)] \cdot \lambda \cdot (1-\theta) \cdot \beta(t) \cdot \alpha \, dt. \quad (3)$$

Thus, if there are D drug injectors in the program on average, the number of HIV infections that occur is estimated by $D \cdot C(\tau)$.

The equations above are, with the exception of the appearance of ρ, reminiscent of models developed to describe the spread

of malaria (see Chapter 14 of Anderson and May [1991] for an excellent review of malaria models). The analogy is clear: with malaria, infection spreads from humans to mosquitos and back to humans, while with HIV, infection spreads from IDUs to needles and back to IDUs.

This model is well-suited to the task of evaluating the needle exchange program. If the required parameters can be assessed, a conservative analysis assuming no behavioral changes can be pursued by comparing the value of $C(\tau)$ for the parameters estimated from available data to the value of $C(\tau)$ that results from setting $\rho=0$ (that is under the assumption of no needle exchange). From equation (3), it is clear that in the short run (where $\pi(t)$ changes little and can roughly be treated as constant), and in the absence of any behavior modification that would lead to changes in λ or θ, the reduction in HIV incidence owing to needle exchange will be roughly proportional to the reduction in the fraction of circulating needles that are infected as induced by the exchange parameter ρ.

Implementing this model required the assignment of numerical values to the various parameters involved. Some of these parameters were directly estimated from surveys of needle exchange clients, while others were themselves the product of simple submodels.

The Frequency of Shared Drug Injections (λ)

This quantity was estimated in two steps. First, self-reported drug injection frequencies were tabulated from the intake surveys of program clients. As of February 28, 1991, the average injection frequency among the clients enrolled in the program was 2.14 injections per client per day. This number has remained roughly constant throughout the program, and is similar to injection frequencies reported among IDUs in San Francisco (2.4 injections per IDU per day [Siegel, Weinstein, and Fineberg 1991, Appendix B]).

Second, it was necessary to produce an estimate of the probability that a given injection was with a shared needle. Clients were asked how often they share their "works" (their injection equipment) in the intake surveys. As of the end of February 1991, their responses averaged 8.4 percent. However, from the syringe tracking data, of all 1,082 program needles returned to the exchange by the end of February 1991, 341 (or 31.5 percent) had been distributed to someone other than the returning client (this fraction of "discordant" needles has remained near 32 percent through the end of December 1991). While one cannot be sure that needles given to one client and returned by another were shared, it seems likely that multiple use of such syringes occurred. It is certainly true (as is clear from equations (1) through (3)) that more sharing leads to more new infections. As a consequence, it is conservative to assume the higher sharing rate in evaluating the needle exchange. Thus, the parameter λ was set equal to $2.14 \times 0.315 = 0.674$ shared injections per client per day (or 246.18 shared injections per client per year). The fraction of shared injections employed here is similar to the 31.5 percent estimated among San Francisco IDUs [Siegel, Weinstein, and Fineberg 1991, Appendix B].

A theoretical objection to the calculation above is that, in effect, we have assumed that acts of drug injection and needle sharing are uncorrelated. Those who inject more often may share relatively more often, implying a positive correlation between the rate of drug injection and the occurrence of sharing. This in turn could lead to a higher shared injection frequency than that calculated. Alternatively, one might conjecture that less frequent injectors are less likely to possess injection equipment and thus are more likely to share when injecting. This argument sug-

gests a negative correlation between injection frequency and the act of sharing. If this were true, the sharing rate calculated above would overstate the case. We intend to be conservative in this analysis; thus we would prefer to overestimate rather than underestimate the amount of sharing. Given the employment of sharing levels 3.75 times higher than self-reported data suggest; it is unlikely that our estimate of λ understates the true shared injection rate, even though we have ignored the possible correlation between injection frequency and sharing. For completeness, we will present a sensitivity analysis later in this appendix to illustrate the possible effects of different shared injection rates.

The Probability of Needle Cleaning (θ)

The New Haven Mayor's Task Force on AIDS launched a bleach outreach program in 1987. By the beginning of the needle exchange in November 1990, IDUs in New Haven were aware of the benefits of sterilizing needles with bleach and were able to obtain regular supplies of bleach from health department outreach staff. The needle exchange continued to provide bleach kits to IDUs, and these kits are in constant high demand. Although one might be suspicious of the intake survey results suggesting that as of the end of February 1991, IDUs used bleach to clean needles when sharing 84 percent of the time on average, this figure was employed in assigning θ the value of 0.84. Again, given the 3+ year history of bleach outreach among New Haven's IDUs, augmented by the observed high demand for bleach on the part of program clients, such a high value for θ does not seem unreasonable. Recognizing that this parameter is not subject to independent verification, however, a sensitivity analysis relating the main results to θ will be reported later in this appendix.

The Departure Rate (μ)

A standard assumption in AIDS epidemic models is that progression to full-blown AIDS coincides with departure from the population in question. This is not precise. Some IDUs continue to inject even after the manifestation of AIDS symptoms. Others cease injecting prior to developing clinical AIDS. In fact, because IDUs leave the population for other reasons (such as entry into drug treatment, arrest and imprisonment, hospitalization for non-AIDS reasons, relocation, cessation of drug injection, or death), it is again conservative to assume that the remaining time spent injecting drugs by a newly HIV-infected drug injector equals the AIDS incubation time. However, because such an assumption argues against the program, it is employed. A number of studies now peg the mean (or median) AIDS incubation time in the neighborhood of 10 years [Bacchetti and Moss 1989; Brookmeyer and Goedert 1989; Lui, Darrow, and Rutherford 1988]. Accordingly, the departure rate μ was set equal to 0.1 departure per infected client per year.

The Infectivity per Injection (α)

There are no direct data by which one can estimate the probability that HIV will be transmitted following injection with an HIV-contaminated needle. There have, however, been studies of health care workers who suffered needlestick injuries while treating known AIDS or HIV positive patients. The empirical transmission probability (as measured by the number of health care workers who became infected, divided by the number of known needlestick exposures to HIV) falls roughly between 1/300 and 1/200 [Friedland and Klein 1987; Leentvaar-Kuijpers et al. 1990; Marcus 1988]. This range probably captures the order of magnitude of the infectivity per injection. It seems logical, however, that the probability of transmitting the infection via an injection should exceed the probability of transmission via a needlestick because an injection transfers a larger volume of

blood.

The NTK model provides an alternative method for estimating α that is consistent with the theory espoused in equations (1) and (2) and expanded upon in Kaplan and Heimer [forthcoming]. As documented in several papers, the spread of HIV among drug users has been rapid, and apparent equilibrium levels of infection have been reached in a number of locations around the world (for example, see Des Jarlais, Friedman, and Stoneburner [1988]). Such an equilibrium has been observed in New York City for several years now, and it is reasonable to assume that, prior to the introduction of the needle exchange in New Haven, the level of infection had also reached steady state.

In the absence of needle exchange ($\rho = 0$), the quantities $\pi(t)$ and $\beta(t)$ reach equilibrium levels whose values are found by setting equations (1) and (2) equal to zero. The equilibrium prevalence of infection among the needles, β, is given by

$$\beta = 1 - \mu \cdot \theta / [\lambda \cdot \alpha \cdot (1-\theta)] \quad (4)$$

providing $\lambda\alpha(1-\theta)$ exceeds $\mu\theta$. Rearranging equation (4) yields

$$\alpha = \mu \cdot \theta / [\lambda \cdot (1-\theta) \cdot (1-\beta)]. \quad (5)$$

Now, at the beginning of the needle exchange, clients turned in whatever needles they had in their possession in exchange for new program syringes. As there is no incentive for clients to selectively return one set of needles over another (for any needle is acceptable for exchange), it is reasonable to treat these "street needles" as representative of the injection equipment clients had at their disposal at the start of the program, and the level of infection in these needles is thus an estimate of the level of infection among circulating syringes (that is, β). Of 160 street needles tested for HIV infection via polymerase chain reaction [Heimer et al. 1992], 108 tested positive suggesting that $\beta = 0.675$. Combined with our previous estimates of μ, θ, and λ, equation (5) estimates $\alpha = 0.0066$. In light of the needlestick studies, this infectivity seems quite reasonable, and demonstrates the use of simple models to estimate a significant epidemiological parameter.

The Per Syringe Exchange Rate (ρ)

The parameter ρ represents the per syringe exchange rate (so if there are N needles in circulation among program clients, the number of needles exchanged in a time interval of length Δt is given by $N \cdot \rho \cdot \Delta t$). This parameter can be estimated from the circulation times of returned needles and the observed number of needles returned. To do so, a simple needle circulation model was constructed. In addition to ρ, let

- δ = the per syringe loss rate (so if there are N needles in circulation among program clients, the number of needles lost, destroyed, or removed from use by any means other than needle exchange in a time interval of length Δt is given by $N \cdot \delta \cdot \Delta t$),
- ℓ = the fraction of returned needles that are legible (or decodeable; a small number of syringes have had their tracking codes smudged or otherwise rendered unreadable),
- t_i = the observed circulation time for the i^{th} syringe (which equals the date a syringe is returned minus the date that syringe was distributed for observed returned syringes, or the most recent date minus the date that syringe was distributed for syringes not yet observed to have returned),
- x_i = 1 if the i^{th} syringe has been observed to have returned, and 0 if not.

From the syringe tracking and testing system, direct observations of t_i and x_i for all syringes distributed are available. Also, one can directly estimate ℓ, for even if a syringe has lost its tracking code, it can still be determined that the syringe was ini-

tially distributed by the legal needle exchange (for all needles distributed by the program have European markings not available on syringes distributed in the United States). Assuming that n syringes have been distributed by the program, the unknown parameters ρ and δ can be estimated by maximizing the following likelihood function:

$$\mathcal{L} = \prod_{i=1}^{n} \{\rho \ell e^{-(\rho+\delta)t_i}\}^{x_i} \left\{\frac{\delta + \rho(1-\ell)}{\rho+\delta} + \frac{\rho\ell}{\rho+\delta} e^{-(\rho+\delta)t_i}\right\}^{1-x_i}. \quad (6)$$

The first term of this function reflects the likelihood of receiving a decodeable syringe exactly t_i time units following distribution. The second term reflects the probability that a syringe circulating for t_i time units has not been observed to have returned; this could arise because the syringe has been lost (with probability $\delta/(\rho + \delta)$), has been or will be returned but cannot be decoded (with probability $\rho(1-\ell)/(\rho+\delta)$), or will be returned and decoded at some future date (with probability $\rho\ell/(\rho+\delta)\cdot\exp(-(\rho+\delta)t_i)$).

For 3,007 syringes distributed between November 13, 1990 and February 28, 1991, the likelihood function shown above was maximized (having previously observed that ℓ = (1,090 legible returns)/(1,269 total program returns) = 86 percent), resulting in maximum likelihood estimates of ρ = 20.5 exchanges per circulating syringe per year, and δ = 23.1 lost syringes per circulating syringe per year. Note that δ does not appear in equation (2); implicitly, the NTK model assumes perfect cancellation of lost needles, that is, infected needles that are lost to the system are replaced by infected street needles, while uninfected needles lost to the system are replaced by uninfected street needles. This assumption seems reasonable. Some street needles undoubtably are introduced unused to program clients. Others are obtained from dealers, shooting galleries, or friends, having already been used and possibly infected.

The Ratio of Drug Injectors to Needles (γ)

Finally, it remains to estimate γ, the ratio of IDUs to needles in the program population. The needle exchange program operates as a 1-for-1 exchange (though needles turned in need not be program needles). As a consequence, the "law of conservation of needles" states that the total number of needles distributed by the program must equal the total number of needles returned to the program.

What is the rate with which needles are distributed from the program? If there are D IDUs in the program, and ν is the needle distribution rate per drug injector per unit time, then $D\nu$ is the aggregate rate with which needles are distributed to program clients. Similarly, if N needles are in circulation among program participants, and ρ is the needle exchange rate per needle per unit time, then $N\rho$ is the aggregate rate with which needles are returned by clients to the needle exchange. Equating these two aggregate rates yields the law of conservation of needles, that is

$$N\rho = D\nu \quad (7)$$

from which the ratio of IDUs in the program to needles circulating among those IDUs, γ (= D/N), is easily seen to equal ρ/ν. We have already estimated ρ (ρ=20.5 exchanges per circulating syringe per year). From the *STT*, we can easily determine τ_i, the amount of time spent by the i^{th} drug injector in the program thus far, as well as the total number of needles distributed. The per drug injector needle distribution rate, then, is given simply by

$$\nu = (\text{TOTAL NUMBER OF NEEDLES DISTRIBUTED})/\sum_i \tau_i \quad (8)$$

where $\sum_i \tau_i$ represents the total "exposure time" of IDUs to the program. Applying these methods to the *STT* data for New Haven's legal needle exchange yields $\nu = 122.4$ needles distributed per drug injector per year, and as a consequence, the ratio of IDUs to needles in the population is given by $\gamma = \rho/\nu = 20.5/122.4 = 0.1675$. Because the needle exchange operates on a one-for-one basis, one would not expect this ratio to differ from its preprogram level (though the amount of time each needle spends in circulation must have changed).

Initial Conditions

Implementing the model requires initial conditions. Again, it was assumed that prior to the needle exchange, HIV infection had reached steady state in the populations of both IDUs and their needles. The initial value for the level of infection in needles, $\beta(0)$, was set equal to the observed value of 67.5 percent among the 160 street needles tested at the start of the program. The initial prevalence, $\pi(0)$, was then estimated directly by setting equation (2) (and ρ) equal to zero and solving to yield

$$\pi(0) = \theta \cdot \beta/[1-(1-\theta)\cdot\beta] = 0.636. \quad (9)$$

Prevalence estimates among New Haven IDUs from other sources vary from 13 percent among drug injectors visiting counseling and testing sites [MTFA 1991], through 36 percent reported among IDUs visiting a sexually transmitted disease (STD) clinic [CDC 1990], through 67 percent among African American men entering drug treatment programs [Dr. Patrick O'Connor, personal communication]. HIV prevalence among early needle exchange clients has also been estimated as falling in the neighborhood of 60 percent, though this estimate derives from models linked to syringe testing data [Kaplan and Heimer 1992]. No HIV prevalence studies have been conducted among "street samples" of drug injectors in New Haven, but given the relative ease of access to the needle exchange van versus the motivation and effort required to enter drug treatment or visit a counseling and testing site, as well as the fact that the demographics of needle exchange clients (predominantly nonwhite) differ from the demographics of those in drug treatment programs (predominantly white), needle exchange clients represent a different snapshot of New Haven's drug injectors than other samples of drug injectors studied previously.

Alternatively, as is clear from equation (9), the modeled baseline prevalence is highly dependent upon the assumed value of θ (the bleaching probability); lower values of θ correspond to lower values of $\pi(0)$. As θ was determined solely from self-reported data, it is important to conduct sensitivity analyses of our main results with respect to θ.

The 33 Percent Result

Having estimated all of the necessary parameters, it was possible to apply the model using equations (1) through (3). In the base case (no needle exchange and $\rho = 0$), equation (3) predicted a cumulative incidence of 6.4 HIV infections per 100 IDUs per year over a one-year time horizon. The application of equations (1) through (3) incorporating the needle exchange ($\rho = 20.5$ exchanges per circulating syringe per year) resulted in a one-year cumulative incidence of 4.3 HIV infections per 100 IDUs per year. Thus, the absolute reduction in new HIV infections is roughly two per 100 IDUs per year, while the percentage reduction is given by $(6.4-4.3)/6.4 \approx 33$ percent. This figure remains the most widely quoted finding of the evaluation study.

Sensitivity Analyses

The incidence reduction result is dependent upon the numerical values of the parameters employed in the model. While some of the parameter values were endogenously derived ($\pi(0)$, α, and γ), the pa-

rameters λ, θ, μ, $\beta(0)$, and ρ were estimated exogenously. It therefore is reasonable to assess the impact of variations in these exogenous parameters on the main results while allowing the endogenous parameters to vary in accordance with their various submodels.

Instead of recomputing equations (1) through (3) for various parameter combinations, however, an excellent analytical approximation to the HIV incidence rate reduction will now be derived. The resulting closed form expression makes clear the effects different parameters have on the conclusions of this study.

The HIV incidence rate prior to the implementation of the needle exchange is given by

$$\iota_0 = [1 - \pi(0)] \cdot \lambda \cdot (1-\theta) \cdot \beta(0) \cdot \alpha \qquad (10)$$

infections per client per year, as is clear from (1). In the short run, the prevalence of infection among needle exchange clients will not change, but the level of infection in their needles will be reduced owing to the replacement of infected needles by clean ones. Keeping $\pi(t)$ equal to $\pi(0)$ allows estimation of the "short run equilibrium" level of infection in needles following the implementation of the needle exchange. This is achieved by setting equation (2) to zero, and solving for β. Denoting this new equilibrium by β^*, one obtains

$$\beta^* = \lambda\gamma\pi(0)/(\lambda\gamma\pi(0) + \lambda\gamma[1-\pi(0)]\theta + \rho), \qquad (11)$$

as well as the new HIV incidence rate

$$\iota^* = [1-\pi(0)] \cdot \lambda \cdot (1-\theta) \cdot \beta^* \cdot \alpha. \qquad (12)$$

The incidence reduction owing to needle exchange, $\Delta\iota$, equals $\iota_0 - \iota^*$.

Substituting equations (5) and (9) into (10) yields

$$\iota_0 = \mu \cdot \theta\beta(0)/(\theta\beta(0) + 1-\beta(0)). \qquad (13)$$

These same substitutions applied to (11) and (12) along with the identity

$$\rho = \nu\gamma \qquad (14)$$

(which follows from $\gamma = \rho/\nu$ as derived from equation (7); ν is the needle distribution rate per client) results in a new expression for the needle exchange HIV incidence,

$$\iota^* = \iota_0 \cdot \lambda\theta/(\lambda\theta + \nu[\theta\beta(0) + 1 - \beta(0)]). \qquad (15)$$

As a consequence, the reduction in HIV incidence, $\Delta\iota$, is given by

$$\Delta\iota = \mu \cdot \nu\theta\beta(0)/(\lambda\theta + \nu[\theta\beta(0) + 1 - \beta(0)]). \qquad (16)$$

How accurate is equation (16)? The application of (3) to the parameters estimated previously resulted in a one-year incidence reduction from 0.064 to 0.043, or about two fewer infections per 100 IDUs per year. Applying the same parameter estimates used previously to (16) (that is, μ = 0.1; ν=122.4; θ=0.84; $\beta(0)$ = 0.675; and λ=246.18) results in an estimated annual incidence reduction of 0.022, in excellent agreement with the earlier result.

Equation (16) makes clear a number of possible concerns. First, as claimed earlier, it is conservative to employ overestimates of the shared injection rate λ, for (16) decreases with λ. In the model, it was assumed that 31.5 percent of injections were shared (even though drug injectors self-reported sharing only 8.4 percent of the time). Holding all other exogenous parameters constant, if 50 percent of injections were shared, $\Delta\iota$ would equal 0.016. Even if 75 percent of injections were shared, $\Delta\iota$ would still equal 0.012. Thus, the needle exchange yields a tangible reduction in incidence even if clients underestimate their sharing rates by a factor of nine!

Second, the main result is robust with respect to the bleaching parameter θ. As this parameter was estimated solely from

self-reported data, it is the most questionable of those obtained. Holding all other exogenous parameters constant, reducing θ by a factor of two from its estimated value of 0.84 yields an incidence reduction of 0.0195 via equation (16); a factor of four reduction in θ to 0.21 still yields an incidence reduction of 0.016. The robustness of $\Delta\iota$ to θ over this range is both comforting and clear.

Third, it is conservative to assume infected drug injectors remain in the program until they develop AIDS. As $\Delta\iota$ is directly proportional to μ, reducing the length of time infected IDUs spend in the program increases μ and hence increases $\Delta\iota$. In particular, the analysis has not considered the placement of program clients in drug treatment programs (as has occurred for roughly one-sixth of those clients who entered the needle exchange), thus fixing μ=0.1 greatly understates the impact of the needle exchange.

Finally, one can see the impact of program operations on the reduction in HIV incidence directly by examining the dependence of $\Delta\iota$ on ν, the needle distribution rate. As ν approaches 0, so does $\Delta\iota$, indicating that programs with low distribution rates (and by implication low exchange rates) are not effective. Alternatively, as ν becomes large, $\Delta\iota$ approaches ι_0 as expected, illustrating the "circulation theory" of needle exchange (that the turnaround of needles becomes so rapid that all needles are replaced before they can be shared). Given the syringe tracking and testing system, the estimate of ν=122.4 needles per client per year is quite accurate.

Equation (16) clarifies the impact of alternative parameter values on the incidence reduction obtained via our model. With the exception of the bleaching level θ, the parameter values employed have resulted in a conservative estimate of the impact of needle exchange. Also, even if clients overstated their use of bleach by a factor of four, the needle exchange would still result in an incidence reduction of roughly two HIV infections per 100 clients per year. In addition, as this analysis has ignored both the placement of clients in drug treatment programs (which clearly reduces their risk of infection beyond that derived by the model) and any behavioral changes induced by the program (such as reductions in needle sharing), the benefits of needle exchange argued above have surfaced from a truly conservative analysis.

References

Anderson, R. M. and May, R. M. 1991, *Infectious Diseases of Humans: Dynamics and Control*, Oxford University Press, Oxford, England.

Bacchetti, P. and Moss, A. R. 1989, "Incubation period of AIDS in San Francisco," *Nature*, Vol. 338, No. 6212, pp. 251–253.

Brookmeyer, R. and Goedert, J. J. 1989, "Censoring in an epidemic with application to hemophilia associated AIDS," *Biometrics*, Vol. 45, No. 1, pp. 325–335.

Buning, E. C. 1989, *Effects of Amsterdam Needle and Syringe Exchange*, Drug Department of the Municipal Public Health Service, Amsterdam, The Netherlands.

Buning, E. C.; Hartgers, C.; van Santen, G.; Verster, A.; and Coutinho, R. A. 1988, "A first evaluation of the needle/syringe exchange in Amsterdam, Holland," in *The Global Impact of AIDS*, eds. A. F. Fleming, M. Carballo, D. W. FitzSimons, M. R. Bailey, and J. Mann, Alan R. Liss, Inc., New York.

CDC 1990, *National HIV Seroprevalence Surveys*, United States Department of Health and Human Services, Centers for Disease Control, Atlanta, Georgia.

CDC 1992, *HIV/AIDS Surveillance Report*, United States Department of Health and Human Services, Centers for Disease Control, Atlanta, Georgia.

Des Jarlais, D. C.; Friedman, S. R ; and Stoneburner, R. L. 1988, "HIV infection and intravenous drug use: Critical issues in transmission dynamics, infection outcomes, and prevention," *Review of Infectious Diseases*, Vol. 10, No. 1, pp. 151–158.

Friedland, G. H. and Klein, R. S. 1987, "Transmission of the human immunodeficiency virus," *New England Journal of Medicine*, Vol. 317, No. 18, pp. 1125–1135.

Hart, G. J.; Carvell, A. L. M.; Woodward, N.; Johnson, A. M.; Williams, P.; and Parry, J. V. 1989, "Evaluation of needle exchange in central London: Behaviour change and anti-HIV status over one year," *AIDS*, Vol. 3, No. 5, pp. 261–265.

Heimer, R.; Myers, S. S.; Cadman, E. C.; and Kaplan, E. H. 1992, "Detection by polymerase chain reaction of human immunodeficiency virus type 1 proviral DNA sequences in needles of injecting drug users," *Journal of Infectious Diseases*, Vol. 165, No. 4, pp. 781–782.

Joseph, S. C. and Des Jarlais, D. C. 1989, "Needle and syringe exchange as a method of AIDS epidemic control," *AIDS Updates*, Vol. 2, No. 5, pp. 1–8.

Kaplan, E. H. 1989, "Needles that kill: Modeling human immunodeficiency virus transmission via shared drug injection equipment in shooting galleries," *Reviews of Infectious Diseases*, Vol. 11, No. 2, pp. 289–298 (*Erratum*, Vol. 11, No. 4, p. 672).

Kaplan, E. H. 1991, "Evaluating needle exchange programs via syringe tracking and testing (STT)," *AIDS and Public Policy Journal*, Vol. 6, No. 3, pp. 109–115.

Kaplan, E. H. 1992, "Needle exchange or needless exchange? The state of the debate," *Infectious Agents and Disease*, Vol. 1, No. 2, pp. 92–98.

Kaplan, E. H. and Heimer, R. 1992, "HIV prevalence among intravenous drug users: Model-based estimates from New Haven's legal needle exchange," *Journal of Acquired Immune Deficiency Syndromes*, Volume 5, No. 2, pp. 163–169.

Kaplan, E. H. and Heimer, R. forthcoming, "A model-based estimate of HIV infectivity via needle sharing," *Journal of Acquired Immune Deficiency Syndromes*.

Kaplan, E. H. and Soloshatz, D. forthcoming, "How many drug injectors are there in New Haven? Answers from AIDS data," *Mathematical and Computer Modelling*.

Leentvaar-Kuijpers, A.; Dekker, M. M.; Coutinho, R. A.; Dekker, E. E.; Keeman, J. N.; and Ansink-Schipper M. C. 1990, "Needle-stick injuries, surgeons, and HIV risks," *The Lancet*, Vol. 335, No. 8688, pp. 546–547.

Lui, K-J.; Darrow, W. W.; and Rutherford, G. W. 1988, "A model-based estimate of the mean incubation period for AIDS in homosexual men," *Science*, Vol. 240, No. 4857, pp. 1333–1335.

Marcus, R. 1988, "Surveillance of health care workers exposed to blood from patients infected with the human immunodeficiency virus," *New England Journal of Medicine*, Vol. 319, No. 17, pp. 1118–1123.

MTFA 1991, *The New Haven County HIV Health Care Plan*, New Haven Mayor's Task Force on AIDS, New Haven, Connecticut.

New York City Department of Health 1989, *The Pilot Needle Exchange Study in New York City: A Bridge to Treatment*, New York City Department of Health, New York.

O'Keefe, E.; Kaplan, E. H.; and Khoshnood, K. 1991, *Preliminary Report: City of New Haven Needle Exchange Program*, New Haven Health Department, AIDS Division, New Haven, Connecticut.

Page, J. B 1990, "Shooting scenarios and risk of HIV-1 infection," *American Behavioral Scientist*, Vol. 33, No. 4, pp. 478–490.

Siegel, J. E.; Weinstein, M. C.; and Fineberg, H. V. 1991, "Bleach programs for preventing AIDS among IV drug users: Modeling the impact of HIV prevalence," *American Journal of Public Health*, Vol. 81, No. 10, pp. 1273–1279.

Stimson, G. V.; Aldritt, L. J.; Dolan, K. A.; Donoghoe, M. C.; and Lart, R. A. 1988, *Injecting Equipment Exchange Schemes: Final Report*, Monitoring Research Group, Sociology Department, Goldsmiths' College, New Cross London, London, England.

Watters, J.; Cheng, Yu-Teh; and Prevention Point Research Group 1991, "Syringe exchange (SE) in San Francisco: Preliminary findings," *Seventh International Conference on AIDS*, Vol. 2, Abstract ThC 99, p. 81, Florence, Italy.

Elaine O'Keefe accepted the Edelman Award on behalf of the New Haven Health Department. She said in part, . . . Those of us who work with injection drug

users and understand the exigencies of addiction have always believed that needle exchange is a practical and viable means of slowing the spread of HIV in this population. Yet we had no way of proving its efficacy. Through Ed Kaplan's brilliant use of management science we can now say with confidence that these programs can reduce the incidence of HIV infection. . . .

I cannot overstress how significant Ed's work is to the national and even global struggle to curb the deadly course of the AIDS epidemic. Given the moral and political controversy surrounding needle exchange, I believe that we would be facing an impasse today were it not for the breakthrough achieved through his unique evaluation design and compelling findings. We have convinced not only Connecticut policy makers of the imperative to continue and expand this critical intervention, but many others as well from states around the country. National policy makers have also taken notice and are beginning to re-examine the potential of this measure in the fight against AIDS. The fact that the National Institute on Drug Abuse awarded a major grant to Ed and the Yale evaluation team, the first time government money has been allocated to needle exchange research, indicates a willingness to at least consider the arguments.

In closing, I must say that working with Ed has been both an inspiration and a constant challenge. His motivation comes from the heart; he has not received a single penny for the countless hours devoted to this project. Beyond Ed's efforts, Yale University must be thanked for its tremendous contribution; the university has provided the entire evaluation of the needle exchange pro bono. We could not possibly have done it without their magnanimous support. I must also thank my colleagues from the original Mayor's Task Force on AIDS in New Haven, Sher Horosko and Al Novick, for their relentless effort and compassion in moving hearts and minds in Connecticut on the issue of needle exchange. In addition, as I receive this award on behalf of the City of New Haven, I wish to acknowledge the enduring support of our mayor, John Daniels, our health director, William Quinn, our police chief, Nicholas Pastore, and state representative William Dyson. Their belief in the program has never wavered in spite of the political risk associated with endorsing a measure as controversial as needle exchange. Finally, the outreach workers who do the difficult work of providing these critical services, under most difficult circumstances, must be recognized for their outstanding efforts.

Needle exchange is about saving lives. Your vote of confidence in our efforts will surely help to open other hearts and minds. Again, I thank the Institute of Management Science for this honor. Please know that the money that comes with this award will go toward AIDS services.

In his acceptance speech, Edward Kaplan said . . . there is no doubt that Elaine and her staff care deeply for the people they serve. My reward has been the privilege of documenting the success of the needle exchange; this has been the most exciting work I have ever undertaken, as well as the most meaningful.

Numerous colleagues in biology, epidemiology, and internal medicine at Yale de-

serve praise for their participation in this project; this was not a solo effort. Dr. Alvin Novick, professor of biology and former chair of the New Haven Mayor's Task Force on AIDS, introduced me to the health department; this eventually led to my role as the evaluator of the needle exchange. With no external funding, the Yale Medical School stepped to the rescue in the persona of Dr. Edwin Cadman, Chair of Internal Medicine, and allowed Dr. Robert Heimer to devote his full time attention to the development and implementation of our testing protocols. The Yale School of Organization and Management provided summer support for my activities, and a warm home base for my work.

As I may never get a chance like this again, I want to acknowledge some people in the management science community who have helped without necessarily being aware of their roles. Fifteen years ago, I was a confused graduate student searching for the meaning of life by serving time at MIT. For reasons unknown, Dick Larson made me his personal project. He taught me that theory and practice need not be adversarial; true synergy is not only possible, it's optimal! He convinced me that careful operational analysis of serious policy problems really can make a difference. Well, I have to say today that I'm all Dick Larson's fault! Other colleagues like Arnie Barnett, Jon Bartholdi, Oded Berman, Al Blumstein, Margaret Brandeau, Jon Caulkins, Don Morrison, David Paltiel, and Bill Pierskalla have always shown interest in my excursions into AIDS research. Such collegiality is of tremendous import in an arena where others have told me I'm crazy. . . .

Finally, some thoughts about AIDS. It is a horrible disease that is spreading needlessly in our country and around the world. AIDS is killing people; it is killing our friends. Unlike cancer and heart disease, however, the spread of AIDS can be stopped if we have the will to do so. I invite any of you so moved to think about ways to better manage this epidemic. Management science and you can make a difference.