The Impact of Socio-Demographic Factors on Patterns of Methamphetamine Use in California

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Department of Mathematics

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Overview

• Background
• Dynamic Meth Model
• Analysis
• Parameter Estimation & Uncertainty and Sensitivity Analysis
• Conclusion & Implications
Background

Outcomes to society

- Generated
  - inside homes; back of trucks; backyards
  - pharmaceutical & household chemicals used; poor handling could lead to explosions

- Use
  - violence; STDs; cardiovascular & mental problems
  - highly underreported; no good estimates of prevalence

Greenwood et al., 2011. Mapping the spread of methamphetamine abuse in California.

Scheck, Justin. The Wall Street Journal.
Background
Methamphetamine (meth) use in the United States has been described as an epidemic, particularly, a major public health concern in California.

MONTHLY SWB SEIZURES IN CALIFORNIA

temporal growth

spatial growth

Groeneveldt et al., 2013. Mapping the spread of methamphetamine abuse in California.
Background

Goal: identify critical factors which may be driving the current meth use epidemic

- **Treatment**

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**abuse:** increasing frequency of use to feel same pleasures of earlier use experiences

**dependence:** abuse, in addition to (typically) physical dependence and increasing inability to stop use

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http://ncaddt.org/learn-about-drugs/signs-and-symptoms
# Dynamic Meth Model

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G$</td>
<td>general population</td>
</tr>
<tr>
<td>$S$</td>
<td>susceptible</td>
</tr>
<tr>
<td>$U$</td>
<td>meth users</td>
</tr>
<tr>
<td>$H$</td>
<td>rehab</td>
</tr>
<tr>
<td>$A$</td>
<td>arrested/detained</td>
</tr>
<tr>
<td>$R$</td>
<td>quitters</td>
</tr>
</tbody>
</table>

**General Population**

- $G$ to $A$: $\mu G$
- $A$ to $G$: $\beta_1 \frac{N G}{N} G$
- $S$ to $G$: $\beta_2 \frac{(U + kH) S}{N} S$

**At-Risk Population**

- $H$ to $R$: $\mu H$
- $R$ to $H$: $\theta_H H$
- $U$ to $R$: $\theta_U U$
- $S$ to $U$: $\phi U$
- $A$ to $R$: $(1 - p) v A$
- $U$ to $A$: $p v A$

- $A$ to $A$: $\mu A$
- $A$ to $H$: $\gamma U$
- $U$ to $H$: $\eta R$
Dynamic Meth Model

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General Population

- $\beta_1 \frac{NG}{D}$
- $\mu_G$

At-Risk Population

- $\beta_2 \frac{(U+kH)}{N} S$
- $\mu_S$
- $\theta_H H$
- $\mu_U$
- $(1-p) e A$
- $\eta R$

Additional Processes

- Detainment due to possession
- Social influence into meth user
- Meth rehab
- Relapse
- Quitting due to family/friend pressure
- Efficacy of criminal justice programs
Dynamic Meth Model

Assumptions:
- social influence from meth users ($U$) and individuals in rehab ($H$); however, $H$ influence is extremely small
- detainment is not 100% effective
- relapse possible after long period of abstinence
- demographic factors play a role

\[
\begin{align*}
\frac{dG}{dt} &= N - \beta_1 \frac{N}{O} G - \mu G \\
\frac{dS}{dt} &= \beta_1 \frac{N}{O} G - \beta_2 \frac{|U + kH|}{N} S - \mu S \\
\frac{dU}{dt} &= \beta_2 \frac{|U + kH|}{N} S - \eta R + (1 - \rho) vA + U - \theta_U U - \rho U - \mu U \\
\frac{dH}{dt} &= -U - \theta_H H - \mu H \\
\frac{dA}{dt} &= \rho U - (1 - \rho) vA - \eta A - \rho A - \mu A \\
\frac{dR}{dt} &= \theta_U U + \theta_H H + \rho vA - \eta R - \mu R
\end{align*}
\]

where:

\[
N = S + U + H + A + R \\
O = G + N
\]
Analysis

Remark 1: there exists four equilibria of the system

\[ E_1 = \left( G^{*1}, S^{*1}, U^{*1}, H^{*1}, A^{*1}, R^{*1} \right) \]
\[ E_{01} = \left( \frac{\Lambda}{\mu}, 0, 0, 0, 0, 0 \right) \]
\[ E_2 = \left( G^{*2}, S^{*2}, U^{*2}, H^{*2}, A^{*2}, R^{*2} \right) \]
\[ E_{02} = \left( \frac{\Lambda}{\beta_1}, \frac{\Lambda(\beta_1-\mu)}{\beta_1 \mu}, 0, 0, 0, 0 \right) \]

Remark 2: the model has two threshold quantities \( R_{01} \) and \( R_{02} \) (referred to as basic reproduction numbers)

\[ R_{01} = \frac{\beta_1}{\mu} \]
\[ R_{02} = \frac{\beta_2}{(\gamma+\theta_U+\phi+\mu)} + \frac{\beta_2 k \gamma}{(\theta_H+\mu)(\gamma+\theta_U+\phi+\mu)} \]
\( (R_{02} \text{ also referred to as } R_{use}) \)
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</tr>
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- Social influence into meth user
- Meth rehab
- Recruitment into at-risk
- Relapse
- Quitting due to family/friend pressure
- Detainment due to possession
- Efficacy of criminal justice programs
Analysis

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\[ E_1 = (G^1, S^1, U^1, H^1, A^1, R^1) \]
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(\( R_{02} \) also referred to as \( R_{use} \))
Analysis
Remark 3: stability
- if $R_{01} < 1$ then $E_{01}$ is asymptotically stable (unstable otherwise)
- if $R_{02} < 1$ then $E_{02}$ is asymptotically stable (unstable otherwise)

Given a susceptible (and at-risk population), the basic reproduction number $R_{use}$ ($R_{02}$) is the expected number of meth users generated from one (typical) individual infected by meth use
- $R_{use} > 1$: meth use persists
- $R_{use} < 1$: meth use declines to extinction
## Parameter Estimation

Socio-economic-demographic factors related to at-risk population

American Journal of Public Health and U.S. Census Bureau

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
<th>Statistic</th>
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<tbody>
<tr>
<td>2012</td>
<td>Hispanic</td>
<td>38.2%</td>
</tr>
<tr>
<td>2012</td>
<td>White</td>
<td>39.4%</td>
</tr>
<tr>
<td>2008-2012</td>
<td>below poverty</td>
<td>15.3%</td>
</tr>
<tr>
<td>2010</td>
<td>1-person household</td>
<td>23.3%</td>
</tr>
<tr>
<td>2010</td>
<td>rural</td>
<td>6.3%</td>
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</table>
Parameter Estimation

arrests (possession & sale)
State of CA Department of Justice
(Attorney General, Criminal Justice Info Serv, CJSC Stats)

<table>
<thead>
<tr>
<th>Year</th>
<th>Arrests</th>
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<tbody>
<tr>
<td>2003</td>
<td>163,656</td>
</tr>
<tr>
<td>2004</td>
<td>177,992</td>
</tr>
<tr>
<td>2005</td>
<td>194,516</td>
</tr>
<tr>
<td>2006</td>
<td>180,916</td>
</tr>
<tr>
<td>2007</td>
<td>164,144</td>
</tr>
<tr>
<td>2008</td>
<td>138,677</td>
</tr>
<tr>
<td>2009</td>
<td>131,174</td>
</tr>
<tr>
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<td>139,472</td>
</tr>
<tr>
<td>2011</td>
<td>133,322</td>
</tr>
<tr>
<td>2012</td>
<td>142,489</td>
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</table>

release

CA Department of Corrections and Rehabilitation

<table>
<thead>
<tr>
<th>Year</th>
<th>Earliest Weekly Report</th>
<th>Parole Percentage</th>
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<tr>
<td>2001</td>
<td>November 7</td>
<td>16.4</td>
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<tr>
<td>2002</td>
<td>January 2</td>
<td>15.5</td>
</tr>
<tr>
<td>2003</td>
<td>January 1</td>
<td>16.0</td>
</tr>
<tr>
<td>2004</td>
<td>January 7</td>
<td>14.0</td>
</tr>
<tr>
<td>2005</td>
<td>January 5</td>
<td>12.4</td>
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## Parameter Estimation

*rehab*

Substance Use & Misuse and American Journal of Public Health

<table>
<thead>
<tr>
<th>Year</th>
<th>ICD-9-304.4</th>
<th>ICD-9-305.7</th>
<th>Sum</th>
<th>Rate of Change</th>
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<tbody>
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<td>1983</td>
<td>0.33</td>
<td>0.33</td>
<td>0.66</td>
<td>0.55</td>
</tr>
<tr>
<td>1984</td>
<td>0.55</td>
<td>0.47</td>
<td>1.02</td>
<td>0.33</td>
</tr>
<tr>
<td>1985</td>
<td>0.71</td>
<td>0.65</td>
<td>1.36</td>
<td>-0.33</td>
</tr>
<tr>
<td>1986</td>
<td>1.59</td>
<td>1.14</td>
<td>2.73</td>
<td>1.01</td>
</tr>
<tr>
<td>1987</td>
<td>1</td>
<td>0.8</td>
<td>1.8</td>
<td>-0.34</td>
</tr>
<tr>
<td>1988</td>
<td>1.99</td>
<td>1.45</td>
<td>3.44</td>
<td>0.91</td>
</tr>
<tr>
<td>1989</td>
<td>2.13</td>
<td>1.51</td>
<td>3.64</td>
<td>0.06</td>
</tr>
<tr>
<td>1990</td>
<td>1.52</td>
<td>1.28</td>
<td>2.8</td>
<td>-0.23</td>
</tr>
<tr>
<td>1991</td>
<td>1.2</td>
<td>1.1</td>
<td>2.3</td>
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</tr>
<tr>
<td>1992</td>
<td>1.51</td>
<td>1.84</td>
<td>3.35</td>
<td>0.46</td>
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<tr>
<td>1993</td>
<td>1.64</td>
<td>2.39</td>
<td>4.03</td>
<td>0.20</td>
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<tr>
<td>1994</td>
<td>2.46</td>
<td>3.98</td>
<td>6.44</td>
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<tr>
<td>1995</td>
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<td>4.3</td>
<td>6.69</td>
<td>0.04</td>
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<td>1996</td>
<td>1.86</td>
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</tr>
<tr>
<td>1997</td>
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<td>4.42</td>
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<td>1998</td>
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<td>3.58</td>
<td>5.22</td>
<td>-0.22</td>
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<td>4.71</td>
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</tr>
<tr>
<td>2000</td>
<td>1.5</td>
<td>3.59</td>
<td>5.09</td>
<td>0.08</td>
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<tr>
<td>2001</td>
<td>1.66</td>
<td>4.37</td>
<td>6.03</td>
<td>0.18</td>
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<tr>
<td>2002</td>
<td>1.97</td>
<td>5.37</td>
<td>7.34</td>
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<tr>
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<td>7.87</td>
<td>10.37</td>
<td>0.15</td>
</tr>
<tr>
<td>2005</td>
<td>2.57</td>
<td>9.43</td>
<td>12</td>
<td>0.16</td>
</tr>
</tbody>
</table>
Parameter Estimation

quitting (successful rehab)
CA Dept of Alcohol and Drug Programs
“...longer treatment stays are associated with positive outcomes”

\[
\frac{(0.1)90 + (0.1)180 + (0.2)270 + (0.6)360}{90 + 180 + 270 + 360} = 0.3300
\]

relapse
Journal of Psychoactive Drugs
“36% return to use within 6 months”
“15% return to use within 7 to 19 months”

\[
\frac{(0.36)6 + (0.15)(7+19)}{6+7+19} = 0.1894
\]
Uncertainty and Sensitivity Analysis

- Although the meth control and use model is deterministic, the use of data to estimate parameters introduces stochasticity.
- Data - based on observations - contain measurement error.
- UA - better identification of uncertainty in parameters and model outputs.
- SA - measures impact of parameter uncertainty on uncertainty of output(s) (i.e. basic reproduction number).
Uncertainty Analysis
UA related to $R_{use}$ ($R_{02}$):

- Based on current parameter estimates, $R_{use}$ is roughly normal, but skewed, with a mean of 1.945 and a standard deviation of 1.285.
- $P(R_{use} > 1) = 0.7642$
- $P(R_{use} < 1) = 0.2358$
Sensitivity

- Sensitivities to $R_{use}$: social influence (0.96); transmission intensity from $H$ (0.55); rehab (-0.74); self-quit (-0.71)
- Social influence will have more impact on controlling the growth of meth use than rehab
- As expected, an increase in rehab will decrease $R_{use}$ estimates; whereas, increased social interactions lead to increases
Sensitivity Analysis
Meth users

- Social interaction, rehab, and self-quitting parameters are most significant to meth use patterns over time.
- Initially, social interaction plays a more significant role influencing patterns than rehab programs. However, over a long period of time their impact becomes almost similar and prominent.
Sensitivity Analysis
Detainees

- Impact of arrest rate decreases but becomes similar to social interaction and release rate impacts in the long run.
- In contrast to the user class, arrest and release rates become significantly correlated with patterns of meth incarceration; however, arrest is positively related, while release is negative.
Conclusion

- To reduce meth users in the population, programs which decrease social influence, will have larger impacts than other programs.
- The data and analysis suggests a methamphetamine outbreak with a mean $R_{\text{use}} = 1.945$.
- If the goal is to control the population of meth users, then rehab and social influence reduction programs are better than incarceration programs.
- If the goal is to control incarceration of meth users, then social interaction programs have significant impact over time.
References


Acknowledgements

- Dr. Anuj Mubayi of Northeastern Illinois University and Arizona State State University
- Dr. Paul J. Gruenewald for data and subject matter
- Dr. Carlos Castillo-Chavez for model development
- Rasheed Hameed and Ridouan Bani