Simulating Mobile MOUD Clinics and Targeted Overdose Prevention for Opioid Use Disorder in Massachusetts: A Simplified Markov Model Inspired by RESPOND

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Introduction: Background & Challenges

- **U.S. opioid crisis**: major ongoing public health emergency
- **Opioid Use Disorder (OUD)**: chronic, relapsing condition $\rightarrow$ high overdose death risk
  - Overdose deaths rising consistently for over 20 years
- **Medications for OUD (MOUD)** (e.g., buprenorphine, methadone): effective but underused
  - Barriers: provider shortage, stigma, transport, regulation
- **High-risk groups**: homeless, recently incarcerated, rural *"treatment deserts"*
  - High overdose risk post-jail/detox release
  - Gaps in integrated, community-based recovery support

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Introduction: Opportunities & Study Goals

- **Mobile MOUD clinics & telehealth:** promising, low-barrier strategies
  - Deliver person-centered care in underserved areas and treatment deserts
  - Overcome barriers such as stigma, provider shortage, transportation
  - Improve engagement among high-risk groups (e.g., post-incarceration, homeless)
- **Simulation modeling as a decision-support tool**
  - Enables evaluation of intervention impact before large-scale implementation
- **Study goal:** Develop a simplified Markov model inspired by RESPOND
  - Simulate weekly transitions among key OUD states
  - Compare outcomes under status quo vs. mobile MOUD + targeted prevention
  - Inform MOUD expansion strategies and overdose prevention planning

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Methods: RESPOND Model Structure

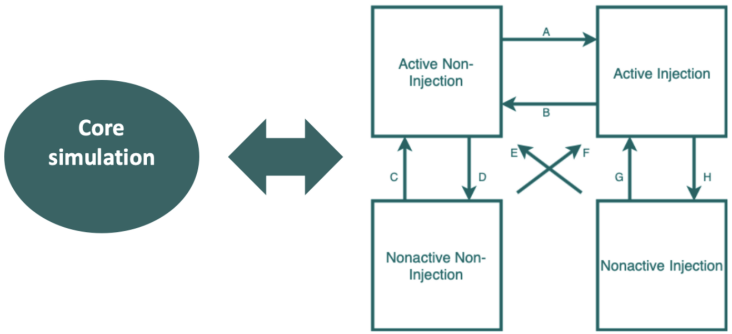

Figure 1: RESPOND Core Simulation Model

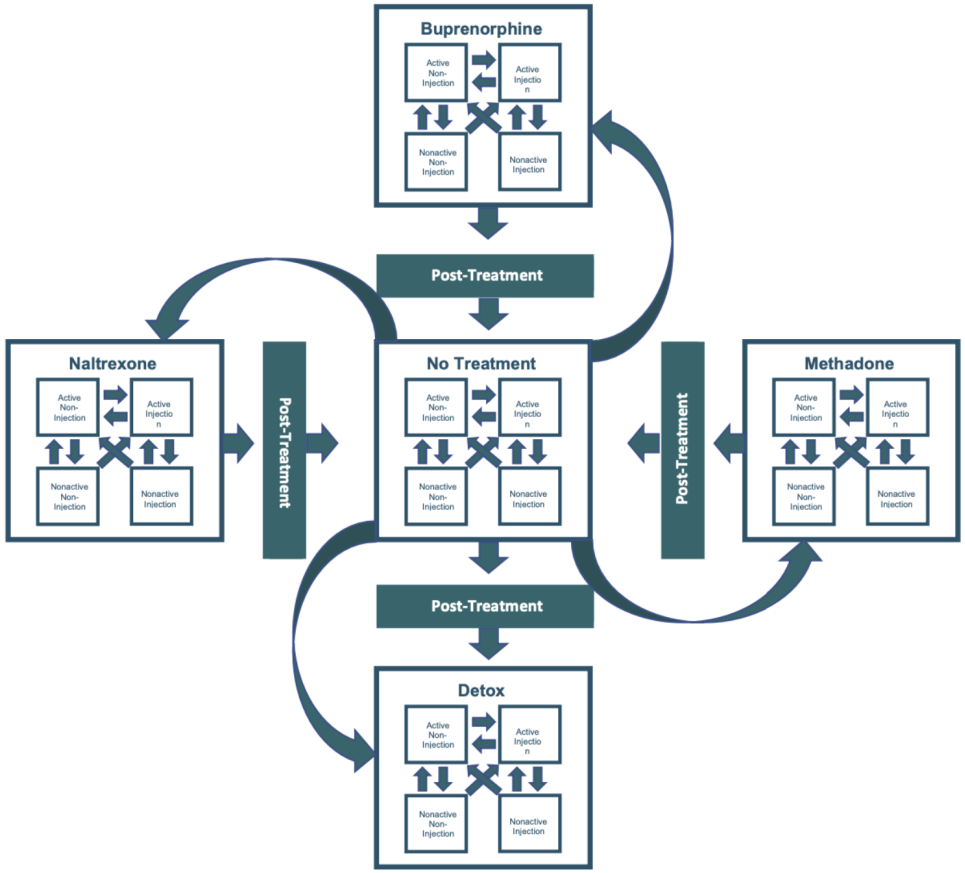

Figure 2: RESPOND's Care Delivery Model

Methods: Simplified Markov Model Structure

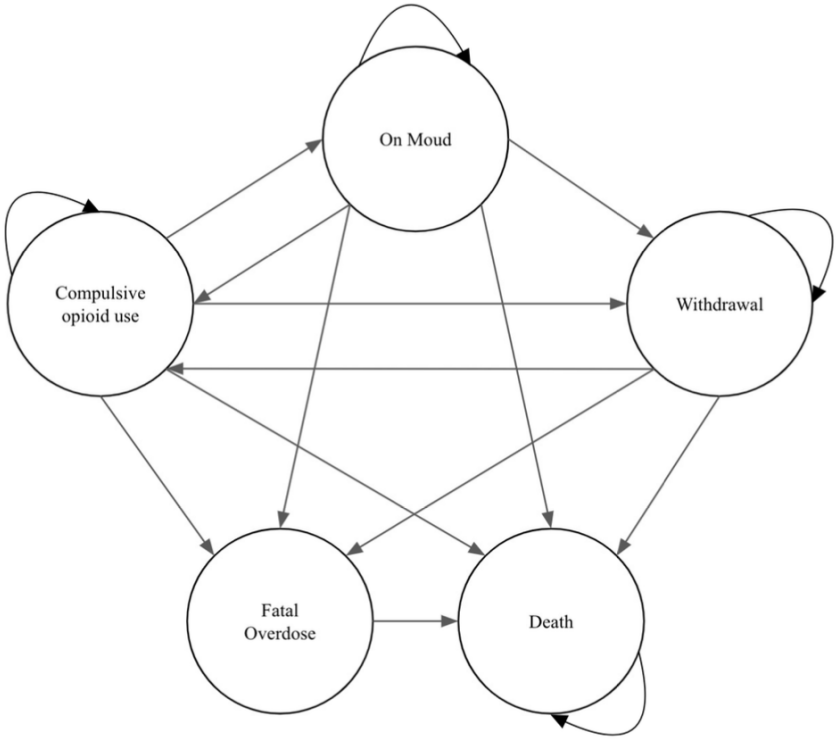

Figure 3: Simplified Markov Model

- **Compulsive Use** – Active opioid use without treatment
- **On MOUD** – Non-active use while on medication (e.g., methadone, buprenorphine, naltrexone)
- **Withdrawal** – Non-active use after stopping treatment or detox
- **Fatal Overdose** – Death from opioid overdose
- **Death** – Death from other causes (absorbing state)

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Methods: Data and Parameter Estimation

Table 1: Weekly Transition Probabilities

From State	To State	Value	Source
Compulsive Use	On MOUD	0.002675905	MA DPH
Compulsive Use	Withdrawal	0.00058	10
Compulsive Use	Fatal Overdose	0.0001253437	7, MA DPH
Compulsive Use	Death	0.0001683808	MA DPH
Compulsive Use	Compulsive Use	0.9964504	-
On MOUD	Withdrawal	0.0567	7, N-SSATS
On MOUD	Compulsive Use	0.002448776	7, N-SSATS
On MOUD	Death	0.000162375	MA DPH
On MOUD	On MOUD	0.9406888	-
Withdrawal	Compulsive Use	0.00329	11, 12
Withdrawal	Death	0.000162375	MA DPH
Withdrawal	Withdrawal	0.9965476	-
Fatal Overdose	Death	1	-
Death	Death	1	-

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Methods: Data and Parameter Estimation

Table 2: Probability of Fatal Overdose Within One Week Following Relapse

Relapse From State	Value	Source
On MOUD	0.0000713976	13, 14
Withdrawal	0.0002506874	13, 14

```
# Fill in transition probabilities for the status quo scenario
P_statusquo["Compulsive Use", ] <- c(0.9964504, 0.002675905, 0.00058, 0.0001253437, 0.0001683808)
P_statusquo["On MOUD", ] <- c(0.002448776*(1-0.0000713976), 0.9406888, 0.0567, 0.002448776*0.0000713976, 0.000162375)
P_statusquo["Withdrawal", ] <- c(0.00329*(1-0.0002506874), 0, 0.9965476, 0.00329*0.0002506874, 0.000162375)
P_statusquo["Fatal Overdose", ] <- c(0, 0, 0, 0, 1)
P_statusquo["Death", ] <- c(0, 0, 0, 0, 1)
```

Table 3: Final Weekly Transition Probability (Status Quo)

From State	Compulsive Use	On MOUD	Withdrawal	Fatal Overdose	Death
Compulsive Use	0.996450400	0.002675905	0.000580000	0.0001253437	0.0001683808
On MOUD	0.002448601	0.940688800	0.056700000	0.0000001748	0.0001623750
Withdrawal	0.003289175	0.000000000	0.996547600	0.0000008248	0.0001623750
Fatal Overdose	0.000000000	0.000000000	0.000000000	0.0000000000	1.0000000000
Death	0.000000000	0.000000000	0.000000000	0.0000000000	1.0000000000

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Methods: Intervention Design

- Simulated a simplified Markov model with weekly cycles over 5 years (260 weeks)
- Initial cohort: 300,000 individuals in **Compulsive Use** state
- Compared two scenarios:
  - **Status Quo**: baseline treatment engagement and relapse risk
  - **Enhanced Intervention:**
    - ↑ Probability of initiating MOUD (simulating mobile clinic outreach)
    - ↓ Overdose risk during relapse (reflecting naloxone & peer support)
- Outputs: weekly population distribution, cumulative overdose deaths

Table 4: Final Weekly Transition Probability (Intervention Status)

From State	Compulsive Use	On MOUD	Withdrawal	Fatal Overdose	Death
Compulsive Use	0.989132692	0.010000000	0.0005757406	0.0001244232	0.0001671442
On MOUD	0.002448759	0.940688800	0.0567000000	0.0000000171	0.0001623750
Withdrawal	0.003289342	0.000000000	0.9965476000	0.0000006580	0.0001623750
Fatal Overdose	0.000000000	0.000000000	0.0000000000	0.0000000000	1.0000000000
Death	0.000000000	0.000000000	0.0000000000	0.0000000000	1.0000000000

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Methods: Sensitivity Analysis

Goal: Assess robustness of model outcomes under uncertainty in key parameters.

Deterministic Sensitivity Analysis

- Varied one parameter at a time; others held constant
- Key parameters:
  - Weekly MOUD initiation probability from *Compulsive Use*
  - Overdose risk during relapse from *On MOUD* and *Withdrawal*
- Parameters ≥ 0.001: $\pm 50\%$ range
- Extremely small probabilities: fixed alternative values based on published estimates

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Methods: Sensitivity Analysis

Probabilistic Sensitivity Analysis

- 1,000 Monte Carlo simulations per intervention scenario
- Transition probabilities sampled from beta distributions
- Parameters calibrated using means and standard errors from:
  - Administrative records
  - Prior modeling studies
- Generated 95% uncertainty intervals for:
  - Cumulative overdose deaths
  - State distribution averages
  - Relative benefit of enhanced intervention

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Results

Table 5: Outcomes of Enhanced Intervention vs Status Quo

Outcome	Status Quo, mean value (95% UI)	Intervention, mean value
Overdose Deaths (Year 1)	1794.946 (1749.351-1834.708)	1508.608
Overdose Deaths (Year 5)	6994.380 (6405.431-7546.728)	4180.659
Alive (Year 1)	295604.5 (295560.8-295654.5)	295918.1
Alive (Year 5)	280435.0 (279857.5-281050.4)	283369.3
Compulsive Use (Year 1)	252519.8 (240089.6-263492.1)	178212.5
Compulsive Use (Year 5)	164694.8 (141521.0-187601.2)	71525.27
On MOUD (Year 1)	11463.40 (7930.144-15402.55)	33306.45
On MOUD (Year 5)	7540.603 (5799.246-9153.694)	12388.40
Withdrawal (Year 1)	31621.30 (24138.62-40162.31)	84399.09
Withdrawal (Year 5)	108199.6 (86457.00-130375.7)	199455.7

Table 6: One-way Deterministic Sensitivity Analysis

Parameter	Value	Overdose Deaths	Compulsive Use	On MOUD	Withdrawal
CU_to_MOUD	0.001338	7874.85	201619.6	4627.94	73267.09
CU_to_MOUD	0.004014	6282.79	136275.7	9479.42	135424.4
OD_OnMOUD	0.000001	7005.97	164361.4	7591.18	108471.2
OD_OnMOUD	0.000100	7006.54	164361.0	7591.16	108471.1
OD_Withdrawal	0.000001	6992.40	164372.0	7591.62	108473.5
OD_Withdrawal	0.000100	6997.94	164367.7	7591.44	108472.6

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Key Findings: Impact of Intervention

- Mobile MOUD clinics and overdose prevention strategies can **substantially reduce fatal overdoses**.
- The intervention promotes shifts into **more stable, recovery-oriented states**, reducing time spent in compulsive use.
- Even modest improvements in MOUD access and reduced relapse risk generate **large population-level benefits**.
- Supports **statewide policy planning** to expand low-barrier treatment access and recovery services.

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Key Findings: Population-Level Outcomes

- **2,800 lives saved** over 5 years (40% reduction in cumulative overdose deaths).
- Significant redistribution of population:
  - $\downarrow$ **Compulsive Use**
  - $\uparrow$ **Withdrawal and On MOUD**
- Reflects improved MOUD **initiation**, **retention**, and longer periods of abstinence.
- Consistent with **clinical goals** of long-term stabilization and relapse prevention.

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Key Findings: Time Trends and Cumulative Effects

- Overdose death reduction was modest at first:
  - Year 1: $\downarrow$ 0.01 percentage points
  - Year 5: $\downarrow$ 0.94 percentage points
- Benefits **compound over time** as more people engage in treatment.
- Shrinking high-risk population $\rightarrow$ **progressively larger impact** on mortality.
- Highlights importance of **early and sustained intervention** for long-term gains.

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Key Findings: Impact of Intervention

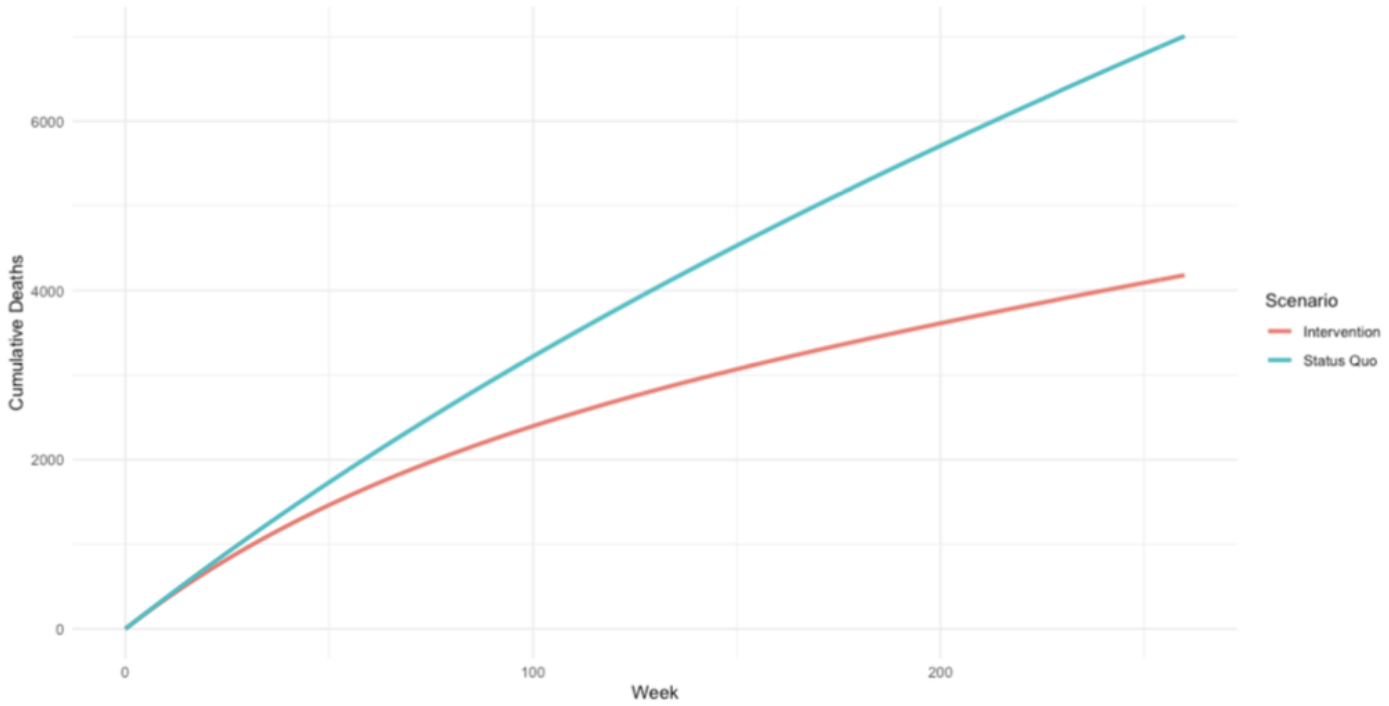

Figure 4: Cumulative Overdose Deaths: Intervention vs. Status Quo

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Discussion: Model Structure & Limitations

- **Strengths:**
  - Captures key OUD behaviors: relapse, dropout, reengagement
  - Weekly cycles allow for fine-grained transition tracking
  - Transparent, interpretable structure for policy use
- **Limitations:**
  - Closed cohort; no incident OUD cases included
  - Parameters derived from literature and may not reflect local heterogeneity
  - Does not model:
    - Mixed adherence (MOUD + opioid use)
    - Comorbidities or social networks
    - Economic costs and resource use

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Improved Model Structure

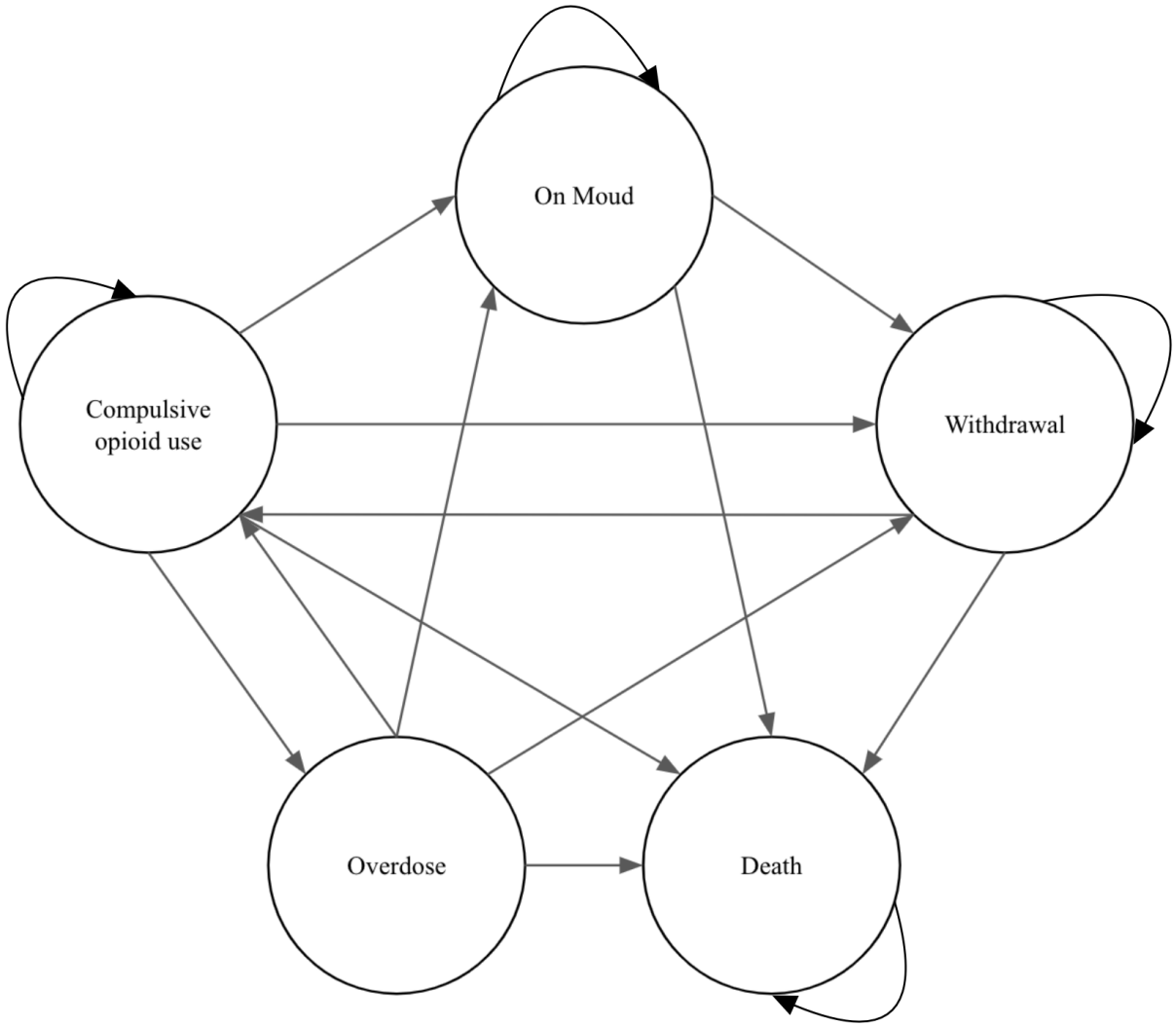

Figure 4: Improved Simplified Markov Model

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