Enhancing Public Health: Leveraging Multi-Armed Bandit for Vaccination Outreach

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ABOUT OUR COMPANY

CVS Health is a leading American healthcare company with a wide network of pharmacies and clinics, providing vital access to medications and healthcare services for millions.

Embracing technology, CVS is driving positive change by leveraging innovative solutions to enhance its services.
Problem Statement

BACKGROUND

- Extremely low current vaccination rate via SMS outreach
- Large volume of messages via traditional A/B testing
- Traditional A/B testing lacks the contextual and interpretability

SOLUTION

- Create personalized SMS campaign with different verbiages by developing multi-armed bandits (MAB) models
- Measure the uplift in performance to enhance efficiency and cost-effectiveness in experimentation
- To utilize the effectiveness of contextual MAB in incorporating different factors to derive actionable interoperable insights
## Dataset Overview

1000+ features

100M patients

7 types of vaccines

### Type of Data Used

- 2022 Vaccine Measurement Data
- Prescription Pickup Record Table
- Patient Data like Age, Gender, Income
- 10 Verbiages: Value, Cost, Safety, etc

## Data Preprocessing

**Exploratory Data Analysis**

- Helped in determining the focused vaccine for MAB

**Clustering Techniques**

- Identified the right features for the contextual MAB

**Synthetic Data Creation**

- Created synthetic response data for new verbiages
MODEL 1: SEGMENTED MAB

01. Put eligible patients into pre-defined clusters

02. ACTION: Initialize and subsequently send a verbiage to patients per cluster
   - Age Group: 35-65
   - 10 Rounds
   - Explore for knowledge from earlier rounds and exploit using the current feedback

03. REWARD: Update rewards for that verbiage based on patient's vaccination response

Cluster selected

Synthetic Response Data

Epsilon-Greedy Algo

Thompson Sampling

Time Distribution
Thompson Sampling with Time Distribution

We update the beta distribution weekly for a faster signal change for the MAB.

Day 0
- Round 1: 4k Messages, 1k messages for VI
  - No of + rewards = 200
  - No of - rewards = 800

Day 7
- Round 1: No of + rewards = 350
  - No of - rewards = 650

Day 14
- Round 1: No of + rewards = 450
  - No of - rewards = 550

Day 21
- Round 2: 4k Messages, 1k messages for VI
  - No of + rewards = 200
  - No of - rewards = 800

- Round 3: 4k Messages, 1k messages for VI
  - No of + rewards = 350
  - No of - rewards = 650

Beta Update
- No of + rewards = 200
  - No of - rewards = 800

- No of + rewards = 550
  - No of - rewards = 1450

- No of + rewards = 1000
  - No of - rewards = 2000
PERFORMANCE METRICS - PROPORTION WINS

Model: Segmented MAB-Thompson Sampling
Features: Age 35 - 65

All verbiages initialized with uniform distribution

Best Verbiage - 1
Proportion Wins: 0.251
at 95.0% confidence level:
Confidence Interval: [0.249, 0.254]

Rounds tell how fast the model converges

9 Rounds later

Verbiage 1 with highest beta value

Confidence interval tells how well the model converges

The Proportion Wins is computed as the proportion of times where the best arm outperforms other arms using Monte Carlo simulations.
# PERFORMANCE METRICS - A/B TESTING vs MAB

Case of Segmented MAB based on Age

% Increase in Vaccination rates compared to A/B testing

<table>
<thead>
<tr>
<th>Feature: Age</th>
<th>Epsilon-Greedy Algo</th>
<th>Thompson Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;65</td>
<td>1.33%</td>
<td>3.68%</td>
</tr>
<tr>
<td>35-65</td>
<td>2.42%</td>
<td>6.71%</td>
</tr>
<tr>
<td>&lt;35</td>
<td>0.38%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Overall</td>
<td>1.78%</td>
<td>4.39%</td>
</tr>
</tbody>
</table>

Thompson Sampling is performing better in more cases.
MODEL 2: CONTEXTUAL BANDIT

VISION

Explore for knowledge and exploit current knowledge simultaneously

Contextual Bandits

Given a Context → Choose an Action → Observe reward

update models

Goal: To maximize the rewards (Flu vaccination rate)

Context: Patient features

AGE

INCOME

Action/Arm: Text messages with different verbiages

Model: Thompson Sampling
PERFORMANCE METRICS

Model: Contextual MAB
Features: Age, Income

4.61% Improvement in vaccination rate across all features

Proportion Wins:
Features: Age 35 - 65, Income Above 70k

All Verbiages initialized with uniform distribution

Round 0

Best Verbiage - 1
Proportion Wins: 0.251
at 95.0% confidence level:
Confidence Interval: [0.249, 0.254]

14 Rounds later

Round 14

Best Verbiage - 2
Proportion Wins: 0.951
at 95.0% confidence level:
Confidence Interval: [0.950, 0.952]
ADAPTIVITY OF MAB

Unlike A/B testing, MAB efficiently leverages peak periods of flu campaigns, leading to escalated vaccination rates. Faster convergence with less volume of messages.

Effect of increase in vaccination rate
Leading to increase in millions of people vaccinated

The number of people vaccinated

Peak Period of Flu

Months
RESULTS & IMPACT

$1M \rightarrow $12M
Projected Cost savings per campaign  Projected Cost savings per annum

85%
Decrease in message overload

Better Adaptivity & Interpretable
Results using contextual MAB

5%
Increase in flu vaccination rates across all features

Millions of patients
Get vaccinated with boosted engagements & enhanced loyalty
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Thank You

"Empowering Health, One Arm at a Time"