Introduction to Markov models for cost-effectiveness analysis

14 February 2024

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The author has no relevant financial or nonfinancial relationships to disclose.

During the development, analysis, and preparation of this presentation, the author was an employee of the Veterans Health Administration, U.S. Department of Veterans Affairs.

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OUTLINE

Limitations of decision trees Markov model description Markov model features Markov chain versus process Discounting and Inflation

LIMITATIONS OF DECISION TREE (1)

Chronic diseases have long time horizons

Can't possibly capture all the re-entry points in a decision tree (becomes repetitive)

Markov re-entry nodes are convenient; decision branches are messy

Markov models are good alternatives to decision trees

LIMITATIONS OF DECISION TREE (2)



LIMITATIONS OF DECISION TREE (3)



This part of the decision tree is a repeat of the Illness node.

When a subject has an illness, they can live or die. If they live and have another illness, they can live or die once again.

This cycle repeats itself over and over.

LIMITATIONS OF DECISION TREE (4)



LIMITATIONS OF DECISION TREE (5)



Well \rightarrow Well Well \rightarrow Illness Well \rightarrow Death

Illness \rightarrow Illness Illness \rightarrow Well Illness \rightarrow Death

Death \rightarrow Death

MARKOV MODEL STRUCTURE



MARKOV MODEL - DESCRIPTION

Markov models are state-transition models Useful when modeling chronic diseases Each state represents a disease stage (or process) Costs and benefits are assigned to each state Can apply discounting Individual subject can only be in one state at any cycle

MARKOV MODEL – DISEASE STATES



Asymptomatic state Disease state Absorbing state

MARKOV MODEL – TRANSITION PROBABILITIES (1)



Death \rightarrow Death tp7

MARKOV MODEL – TRANSITION PROBABILITIES (2)



If you have tp2 and tp3, then tp1 = 1 - tp2 - tp3



Death \rightarrow Death tp7

MARKOV MATRIX



| From / To | Well | lliness | Dead |
|-----------|------------------------|------------------------|------|
| Well | tp1 (1 – tp2 – tp3) | tp2 | tp3 |
| lliness | tp5 | tp4 (1 – tp5 – tp6) | tp6 |
| Dead | 0 | 0 | tp7 |

MARKOV MODEL – FEATURES



One iteration = Cycle X-iterations = Time horizon



Markov chain – static transitions Markov process – dynamic transitions



MARKOV CHAIN VERSUS PROCESS (2)

Markov chain – static transitions

Markov process – dynamic transitions



Transition probabilities remain static If tp1 = 0.90 is cycle 1, then tp1 = 0.90 in cycle 2

Markov chain - static transitions

Markov process – dynamic transitions



Transition probabilities change from cycle to cycle Although tp1 = 0.90 is cycle 1, tp1 = 0.85 in

cycle 2

Markov chain – static transitions

Markov process – dynamic transitions



This is useful when the cohort will have a lower survival over a long period of time

COHORT VERSUS MICROSIMULATIONS (1)

Cohort simulation

Model a group of hypothetical patients at the same time Time horizon is fixed Computationally less intensive Individual or microsimulations (Monte Carlo) Individuals are modeled through the Markov models one at a time Time for each patient can be short or long **Computationally intensive**

COHORT VERSUS MICROSIMULATIONS (1)

Cohort simulation Individual or microsimulations



COHORT VERSUS MICROSIMULATIONS (2)



COHORT VERSUS MICROSIMULATIONS (3)

Cohort simulation



COHORT VERSUS MICROSIMULATIONS (4)

Cohort simulation



COHORT VERSUS MICROSIMULATIONS (5)

Cohort simulation



COHORT VERSUS MICROSIMULATIONS (6)

Cohort simulation

Individual or microsimulations

Tunnel states are used to force the model to consider the previous state



COHORT VERSUS MICROSIMULATIONS (7)



COHORT VERSUS MICROSIMULATIONS (8)

Cohort simulation



COHORT VERSUS MICROSIMULATIONS (9)

Cohort simulation



COHORT VERSUS MICROSIMULATIONS (10)



COHORT VERSUS MICROSIMULATIONS (11)

Cohort simulation



COHORT VERSUS MICROSIMULATIONS (12)

Cohort simulation



Estimating transition probabilities

Using existing studies to estimate probabilities for decision models

ESTIMATING TRANSITION PROBABILITIES (1)

Rate – Instantaneous likelihood of transition at any point in time (e.g., 5 events per 100 Person Years)

Probability – Proportion of a cohort that experiences the event over a specific period (e.g., 90% of patients had the event)

To get the transition probabilities in a Markov model using an existing study, estimate the rate, then estimate the probability for the time of interest using the rate

Estimating the probability from a study: Probability from study \rightarrow Rate \rightarrow Probability for model

$$Rate = \frac{-\ln(1-p)}{t}$$

 $Probability = 1 - e^{-rt}$

p probability t time r rate

ESTIMATING TRANSITION PROBABILITIES (3)

If the 5-year probability of achieving a cure is 90%, what is the 1-year probability?

You can't divide the 5-year probability by 5 (e.g., 90% / 5 = 18% to get the annual rate)

Probability
from study
$$\implies Rate = \frac{-\ln(1-p)}{t} \implies P(t) = 1 - e^{-rt}$$
$$P(5 \text{ years}) = 90\% \implies Rate = \frac{-\ln(1-0.90)}{5 \text{ years}} = 0.46 \implies P(1 \text{ year}) = 1 - e^{-(0.46)(1 \text{ year})} = 0.37$$

ESTIMATING TRANSITION PROBABILITIES (4)



ESTIMATING TRANSITION PROBABILITIES (5)

Suppose you had data from a meta-analysis where the relative risk of cure is 2.0 with a drug

What is the 1-year probability of cure using an annual rate of cure that is 0.47? (Hint: Is it not 2 x 0.47)

RR * rate $P(t) = 1 - e^{-rt}$ 2.0 X 0.47 = 0.94 $P(1 \text{ year}) = 1 - e^{-(0.94)(1 \text{ year})} = 0.61$

Discounting and inflation

Adjusting costs and outcomes for long time horizons

DISCOUNTING AND INFLATION

Net Present Value: Current purchasing power of currency





What is today's value of \$1 10 years from now using a 3% discount rate?

$$V_0 = \frac{V_t}{(1+r)^t} \qquad \Longrightarrow \quad \$0.74 = \frac{\$1}{(1+0.03)^{10}}$$

 V_0 = Value in today's term V_t = Value at time t in the future r = Discount rate t = Time in the future



What is today's value of \$1 from 10 years ago using the Consumer Price Index?

| CPI Inflation Calculator |
|--|
| \$ 1.00 in January \checkmark 2012 \checkmark has the same buying power as \$1.24 in January \checkmark 2022 \checkmark Calculate |

Use the <u>CPI inflation calculator</u> on the BLS website

Markov models using Excel Tutorial on building Markov models in Excel

FILE LOCATION

You can download the Excel file from the workshop's <u>GitHub</u> site

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Introduction to Markov models in Cost-Effectiveness Analysis

SETTING UP THE MARKOV MODEL

List all the transitions



| Transition states | <u>Variable</u> | Probability | Description |
|-------------------|---|--------------------|-----------------------------------|
| Well> Well | 1 - tp(well_illness) - tp(well_dead) | 0.83 | Remain in the Well state |
| Well> Illness | tp(well_illness) | 0.15 | Transition from Well to Illness |
| Well> Dead | tp(well_dead) | 0.02 | Transition from Well to Death |
| | | | |
| Illness> Illness | 1 - tp(illness_well) - tp(illness_dead) | 0.65 | Remain in the Illness state |
| Illness> Well | tp(illness_well) | 0.30 | Transition from Illness to Well |
| Illness> Dead | tp(illness_dead) | 0.05 | Transition from Illness to Death |
| | | | |
| Dead > Dead | tp(dead) | 1.00 | Remain in Death (Absorbing state) |
| | | | |

MARKOV MATRIX

| From / To | Well | Illness | Dead |
|-----------|------|---------|------|
| Well | 0.83 | 0.15 | 0.02 |
| Illness | 0.30 | 0.65 | 0.05 |
| Dead | 0 | 0 | 1.00 |

ASSIGN COSTS AND UTILITIES TO THE STATES

Since the costs and utilities are specific to each state you can list them in a table

| Transition states | Costs | Utility | <u>Description</u> |
|-------------------|------------|---------|-------------------------------|
| Well | \$500.00 | 1.00 | These parameers are fictional |
| Illness | \$2,000.00 | 0.50 | These parameers are fictional |
| Dead | \$0.00 | 0.00 | These parameers are fictional |

Each cycle is 1 year Simulate for 100 years (or 100 cycles) Apply an annual discount rate of 3% on costs and outcomes

MATHEMATICAL MODEL

Cohort size

1

We start at cell E12

| 1 | . cycle = 1 year | Expected pro | babilities | | |
|---|------------------|--------------|------------|--------|-------|
| | Cycle | Well | Illness | Dead | Total |
| | 0 | 1.0000 | 0.0000 | 0.0000 | 1 |
| | 1 | 0.8300 | 0.1500 | 0.0200 | 1 |
| | 2 | 0.7339 | 0.2220 | 0.0441 | 1 |
| | 3 | 0.6757 | 0.2544 | 0.0699 | 1 |
| | 4 | 0.6372 | 0.2667 | 0.0961 | 1 |
| | 5 | 0.6089 | 0.2689 | 0.1222 | 1 |
| | 6 | 0.5860 | 0.2661 | 0.1478 | 1 |
| | 7 | 0.5663 | 0.2609 | 0.1728 | 1 |
| | 8 | 0.5483 | 0.2545 | 0.1972 | 1 |
| | 9 | 0.5314 | 0.2477 | 0.2209 | 1 |
| | 10 | 0.5154 | 0.2407 | 0.2439 | 1 |

MATHEMATICAL MODEL

At cycle 0, all subjects will start at the "Well" state. In the cell, the formula is: =\$G\$6 * 1 The "\$" denotes that the column / row does not change. Cohort size 1

The size of the cohort. We'll set this at 1. The cell is G6.

| Cycle Well Illness Dead Total 0 1.0000 0.0000 0.0000 1 1 0.8300 0.1500 0.0200 1 2 0.7339 0.2220 0.0441 1 3 0.6757 0.2544 0.0699 1 4 0.6372 0.2667 0.0961 1 | 1 cycle = 1 | year | Expected pro | babilities | | |
|--|--------------------|------|--------------|------------|--------|-------|
| 0 1.0000 0.0000 0.0000 1 1 0.8300 0.1500 0.0200 1 2 0.7339 0.2220 0.0441 1 3 0.6757 0.2544 0.0699 1 4 0.6372 0.2667 0.0961 1 | Cvcle | | Well | Illness | Dead | Total |
| 1 0.8300 0.1500 0.0200 1 2 0.7339 0.2220 0.0441 1 3 0.6757 0.2544 0.0699 1 4 0.6372 0.2667 0.0961 1 | | 0 | 1.0000 | 0.0000 | 0.0000 | |
| 2 0.7339 0.2220 0.0441 1 3 0.6757 0.2544 0.0699 1 4 0.6372 0.2667 0.0961 1 | | 1 | 0.8300 | 0.1500 | 0.0200 | 1 |
| 3 0.6757 0.2544 0.0699 1 4 0.6372 0.2667 0.0961 1 | | 2 | 0.7339 | 0.2220 | 0.0441 | 1 |
| 4 0.6372 0.2667 0.0961 1 | | 3 | 0.6757 | 0.2544 | 0.0699 | 1 |
| 0.0072 0.2007 0.0001 | | 4 | 0.6372 | 0.2667 | 0.0961 | 1 |
| 5 0.6089 0.2689 0.1222 1 | | 5 | 0.6089 | 0.2689 | 0.1222 | 1 |
| 6 0.5860 0.2661 0.1478 1 | | 6 | 0.5860 | 0.2661 | 0.1478 | 1 |
| 7 0.5663 0.2609 0.1728 1 | | 7 | 0.5663 | 0.2609 | 0.1728 | 1 |
| 8 0.5483 0.2545 0.1972 1 | | 8 | 0.5483 | 0.2545 | 0.1972 | 1 |
| 9 0.5314 0.2477 0.2209 1 | | 9 | 0.5314 | 0.2477 | 0.2209 | 1 |
| 10 0.5154 0.2407 0.2439 1 | | 10 | 0.5154 | 0.2407 | 0.2439 | 1 |

At cycle 0, zero subjects will start at the "Illness" and "Dead" states. In these cells, the formulas are: =\$G\$6 * 0

Based on probability theory the sum of the expected number of subjects should be equal to cell G6. In this case, that will be 1.

CALCULATING EXPECTED PROBABILITIES (1)



LIMITATIONS OF DECISION TREES (2)



CALCULATING EXPECTED PROBABILITIES (1)



CALCULATING EXPECTED PROBABILITIES (2)



CALCULATING EXPECTED PROBABILITIES (3)



CALCULATING EXPECTED PROBABILITIES (4)



sum to 1

1 cycle = 1 yearExpected probabilities Cycle Well Dead Total Illness 1.0000 0.0000 0.0000 0 1 0.8300 0.1500 0.0200 1 0.7339 1 2 0.2220 0.0441 1 3 0.6757 0.2544 0.0699 0.6372 0.2667 0.0961 1 4 5 0.6089 0.2689 0.1222 1 6 0.5860 0.2661 0.1478 0 1729 7 0 2609 0.5663 1 0.5483 8 0.2545 0.1972 1 1 9 0.5314 0.2477 0.2209 10 0.5154 1 0.2407 0.2439

CALCULATING EXPECTED COSTS AND UTILITIES (1)

| 1 cycle = 1 year | Expected p | obabilities | | | Total Expected | l Costs | = | \$31,128.64 | Total Expected | I QALYs | = | 27. |
|------------------|------------|-------------|--------|-------|----------------|----------|--------|-------------|----------------|---------|--------|-----|
| Cycle | Well | Illness | Dead | Total | Well | Illness | Dead | Total | Well | Illness | Dead | T |
| 0 | 1 0000 | 0.0000 | 0.0000 | 1 | \$500.00 | \$0.00 | \$0.00 | \$500.00 | 1.0000 | 0.0000 | 0.0000 | |
| 1 | 0.8300 | 0.1500 | 0.0200 | 1 | \$415.00 | \$300.00 | \$0.00 | \$715.00 | 0.8300 | 0.0750 | 0.0000 | |
| 2 | 0.7 39 | 0.2220 | 0.0441 | 1 | \$ 6.95 | \$444.00 | \$0.00 | \$810.95 | 0.7339 | 0.1110 | 0.0000 | (|
| 3 | 0.675. | 0.2544 | 0.0699 | 1 | \$337.87 | \$508.77 | \$0.00 | \$846.64 | 0.6757 | 0.1272 | 0.0000 | (|
| 4 | 0.6372 | 0.2667 | 0.0961 | 1 | \$318.59 | \$533.42 | \$0.00 | \$852.01 | 0.6372 | 0.1334 | 0.0000 | (|
| 5 | 0.6089 | 0.2689 | 0.1222 | 1 | \$304.44 | \$537.88 | \$0.00 | \$842.31 | 0.6089 | 0.1345 | 0.0000 | (|

Expected costs at cycle 1 is 0.83 * \$500 = \$415

CALCULATING EXPECTED COSTS AND UTILITIES (2)

| 1 cycle = 1 year | Expected p | robabilities | | | Total Expected | d Costs | = | \$31,128.64 | Total Expected | d QALYs | - | 27.909 |
|------------------|------------|--------------|--------|-------|----------------|----------|--------|-------------|----------------|---------|--------|--------|
| Cycle | Well | Illness | Dead | Total | Well | Illness | Dead | Total | Well | Illness | Dead | Total |
| 0 | 1.0000 | 0.0000 | 0.0000 | 1 | \$500.00 | \$0.00 | \$0.00 | \$500.00 | 1.0000 | 0.0000 | 0.0000 | 1.00 |
| 1 | 0.8300 | 0.1500 | 0.0200 | 1 | \$415.00 | \$300.00 | \$0.00 | \$715.00 | 0.8300 | 0.0750 | 0.0000 | 0.9 |
| 2 | 0.7339 | 0.2220 | 0.0441 | 1 | \$366.95 | \$444.00 | \$0.00 | \$810.95 | 0.7339 | 0.1110 | 0.0000 | 0.84 |
| 3 | 0.6 57 | 0.2544 | 0.0699 | 1 | 5 7.87 | \$508.77 | \$0.00 | \$846.64 | 0.6757 | 0.1272 | 0.0000 | 0.80 |
| 4 | 0.6372 | 0.2667 | 0.0961 | 1 | \$318.59 | \$533.42 | \$0.00 | \$852.01 | 0.6372 | 0.1334 | 0.0000 | 0.7 |
| 5 | 0.6089 | 0.2689 | 0.1222 | 1 | \$304.44 | \$537.88 | \$0.00 | \$842.31 | 0.6089 | 0.1345 | 0.0000 | 0.74 |

Expected costs at cycle 2 is 0.7339 * \$500 = \$366.95

CALCULATING EXPECTED COSTS AND UTILITIES (3)

| cycle = 1 year | Expected p | robabilities | | | Total Expecte | d Costs | = | \$31,128.64 | Tota | I Expected | QALYs | = | 27 |
|----------------|------------|--------------|--------|-------|---------------|----------|--------|-------------|------|------------|---------|--------|----|
| Cycle | Well | Illness | Dead | Total | Well | Illness | Dead | Total | | Well | Illness | Dead | 1 |
| 0 | 1 0000 | 0.0000 | 0.0000 | 1 | \$500.00 | \$0.00 | \$0.00 | \$500.00 | | 1.0000 | 0.0000 | 0.0000 | |
| 1 | 0.8300 | 0.1500 | 0.0200 | 1 | \$415.00 | \$300.00 | \$0.00 | \$715.00 | | 0.8300 | 0.0750 | 0.0000 | |
| 2 | 0.79 | 0.2220 | 0.0441 | 1 | \$366.95 | \$444.00 | \$0.00 | \$810.95 | | | 0.1110 | 0.0000 | |
| 3 | 0.6757 | 9.2544 | 0.0699 | 1 | \$337.87 | \$508.77 | \$0.00 | \$846.64 | | 0.6757 | 0.1272 | 0.0000 | |
| 4 | 0.6372 | 0.2667 | 0.0961 | 1 | \$318.59 | \$533.42 | \$0.00 | \$852.01 | | 0.6372 | 0.1334 | 0.0000 | |
| 5 | 0.6089 | 0.2689 | 0.1222 | 1 | \$304.44 | \$537.88 | \$0.00 | \$842.31 | | 0.6089 | 0.1345 | 0.0000 | |

Expected utility at cycle 1 is 0.83 * 1 = 0.83 QALYs

CALCULATING EXPECTED COSTS AND UTILITIES (4)

| 1 | cycle = 1 year | Expected p | robabilities | | |
|---|----------------|------------|--------------|--------|-------|
| | Cycle | Well | Illness | Dead | Total |
| | 0 | 1.0000 | 0.0000 | 0.0000 | 1 |
| | 1 | 0.8300 | 0.1500 | 0.0200 | 1 |
| | 2 | 0.7339 | 0.2220 | 0.0441 | 1 |
| | 3 | 0.67 | 0.2544 | 0.0699 | 1 |
| | 4 | 0.6372 | 0 2667 | 0.0961 | 1 |
| | 5 | 0.6089 | 0.2689 | 0.1222 | 1 |

| Total Expected | d Costs | = | \$31,128.64 |
|----------------|----------|--------|-------------|
| Well | Illness | Dead | Total |
| \$500.00 | \$0.00 | \$0.00 | \$500.00 |
| \$415.00 | \$300.00 | \$0.00 | \$715.00 |
| \$366.95 | \$444.00 | \$0.00 | \$810.95 |
| \$337.87 | \$508.77 | \$0.00 | \$846.64 |
| \$318.59 | \$533.42 | \$0.00 | \$852.01 |
| \$304.44 | \$537.88 | \$0.00 | \$842.31 |

| Т | otal Expected | I QALYs | = | 27.9098 |
|---|---------------|---------|--------|---------|
| | Well | Illness | Dead | Total |
| | 1.0000 | 0.0000 | 0.0000 | 1.0000 |
| | 0.8300 | 0.0750 | 0.0000 | 0.9050 |
| | 0.7339 | 0.1110 | 0.0000 | 0.8449 |
| | . 6757 | 0.1272 | 0.0000 | 0.8029 |
| | 0.6372 | 0.1334 | 0.0000 | 0.7705 |
| | 0.6089 | 0.1345 | 0.0000 | 0.7433 |

Expected utility at cycle 2 is 0.7339 * 1 = 0.73 QALYs

CALCULATING EXPECTED COSTS AND UTILITIES (5)

Sum the costs to get the total expected costs

Sum the QALYs to get the total expected QALYs

| 1 c | ycle = 1 year | Expected p | robabilities | | |
|------------|---------------|------------|--------------|--------|-------|
| | Cycle | Well | Illness | Dead | Total |
| | 0 | 1.0000 | 0.0000 | 0.0000 | 1 |
| | 1 | 0.8300 | 0.1500 | 0.0200 | 1 |
| | 2 | 0.7339 | 0.2220 | 0.0441 | 1 |
| | 3 | 0.6757 | 0.2544 | 0.0699 | 1 |
| | 4 | 0.6372 | 0.2667 | 0.0961 | 1 |
| | 5 | 0.6089 | 0.2689 | 0.1222 | 1 |

APPLYING DISCOUNTING

| 1 | cycle = 1 year | E | Expected p | robabilities | | |
|---|----------------|---|------------|--------------|--------|-------|
| | Cycle | | Well | Illness | Dead | Total |
| | 0 | | 1.0000 | 0.0000 | 0.0000 | 1 |
| | 1 | | 0.8300 | 0.1500 | 0.0200 | 1 |
| | 2 | | 0.7339 | 0.2220 | 0.0441 | 1 |
| | 3 | | 0.6757 | 0.2544 | 0.0699 | 1 |
| | 4 | | 0.6372 | 0.2667 | 0.0961 | 1 |
| | 5 | | 0.6089 | 0.2689 | 0.1222 | 1 |

 V_0



r is the annual discount rate at 3%

DISCOUNT EXPECTED COSTS AND UTILITIES (1)

| 1 cycle = 1 year Expected probabilities | | | | | | | | |
|---|--------|---------|--------|-------|--|--|--|--|
| Cycle | Well | Illness | Dead | Total | | | | |
| 0 | 1.0000 | 0.0000 | 0.0000 | 1 | | | | |
| 1 | 0.8300 |).1500 | 0.0200 | 1 | | | | |
| 2 | 0.73 9 | 0.2220 | 0.0441 | 1 | | | | |
| 3 | 0.6757 | 0.2544 | 0.0699 | 1 | | | | |
| 4 | 0.6372 | 0.2667 | 0.0961 | 1 | | | | |
| 5 | 0.6089 | 0.2689 | 0.1222 | 1 | | | | |

| Т | otal Expected | Costs | = | \$16,238.55 |
|---|-----------------------|----------|--------|-------------|
| | Well | Illness | Dead | Total |
| | \$500.00 | \$0.00 | \$0.00 | \$500.00 |
| | \$402.91 | 291.26 | \$0.00 | \$694.17 |
| | Ş₹ <mark>5.8</mark> 9 | \$418.51 | \$0.00 | \$764.40 |
| | 309.20 | \$465.60 | \$0.00 | \$774.79 |
| | \$283.06 | \$473.94 | \$0.00 | \$757.00 |
| | \$262.61 | \$463.98 | \$0.00 | \$726.59 |

| Total Expe | ted QALYs | = | 15.0816 |
|------------|-----------|--------|---------|
| Well | Illness | Dead | Total |
| 1.0000 | 0.0000 | 0.0000 | 1.0000 |
| 0.8058 | 0.0728 | 0.0000 | 0.8786 |
| 0.6918 | 0.1046 | 0.0000 | 0.7964 |
| 0.6184 | 0.1164 | 0.0000 | 0.7348 |
| 0.5661 | 0.1185 | 0.0000 | 0.6846 |
| 0.5252 | 0.1160 | 0.0000 | 0.6412 |

Expected costs at cycle 1 with discounting is $402.91 = (0.83 * 500) / (1 + 0.03)^{1}$



MARKOV MODEL RESULTS (1)

| Strategy | <u>Total Cost</u> | Total QALYs | Incremental Costs | Incremental QALYs | <u>ICER</u> |
|---------------------|-------------------|-------------|-------------------|-------------------|-------------|
| Without Discounting | \$31,128.64 | 27.9098 | \$14,890.09 | 12.8282 | \$1,160.73 |
| With Discounting | \$16,238.55 | 15.0816 | | | |

MARKOV MODEL RESULTS (2)

| | File Home In | ert Draw Page Layout | Formulas Data | Review View Auto | nate Developer | Help | | | |
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| | 4 5 6 7 | Cohort size | | | Bubble Use it of | cheet type to: or at least two sets of values or data. hars | ounting | | Scatter and the Scatter with |
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| | 12 14 15 16 | 1 0.000 1 0.6300 2 0.7339 3 0.6757 4 0.6372 | 0.0000 0.0000 0.1500 0.0200 0.2220 0.0441 0.2544 0.0009 0.2967 0.0961 | 1 500 1 541 1 530 1 533 1 533 | 5.00 \$200.00 5.00 \$200.00 5.55 \$444.00 7.87 \$508.77 5.59 \$513.42 | 90.00 500.00 90.00 \$715.00 90.00 \$810.95 90.00 \$846.64 \$0.00 \$852.01 | 1,0000 0, 0,8300 0, 0,7339 0, 0,6757 0, 0,6372 0, | 0000 0.0000 1.0000 0750 0.0000 0.9050 1110 0.0000 0.8449 1272 0.0000 0.8029 1334 0.0000 0.7705 | |
| | 17 18 19 20 | 5 0.009 6 0.500 7 0.560 8 0.560 | 0.2609 0.1222 0.2661 0.3478 0.2609 0.1728 0.2545 0.3972 | 1 530 1 529 1 528 1 527 | L44 5517.88 L02 5532.28 L33 5521.80 L33 5509.05 | \$8.00 \$842.11 \$8.00 \$825.30 | 0.6099 0. 0.3090 0. Chart Title | 1345 0.0000 0.7433 1331 0.0000 0.7291 167 2755 | |
| Step 1: Select the | 22 22 23 | 5 0.5154 10 0.5154 11 0.5000 12 0.4051 13 0.4207 | 0.2677 0.2209 0.2407 0.2439 0.2338 0.2003 0.2209 0.2879 0.2209 0.3090 | 1 5,55 1 525 1 524 1 524 1 524 | 5.71 9405.36 7.69 \$481.41 3.99 \$407.53 2.55 \$453.89 5.36 \$440.56 | | | 157 | Step 3: A chart will |
| data from cycle 0 - to 100 | 77 28 29 | 14 0.4568 15 0.4433 16 0.4302 17 0.4174 | 0.2138 0.3294 0.2075 0.3493 0.2034 0.3665 0.1934 0.3672 | 1 522 1 522 1 521 1 523 | 1.39 5427.38 1.60 5434.96 5.08 5402.71 1.72 5390.81 | \times | | 9 87 870 908 151 | appear; make changes to match |
| | 10 31 32 32 | 18 0.4051 19 0.3931 20 0.3835 21 0.3702 | 0.1896 0.4053 0.1840 0.4229 0.1756 0.4399 0.1733 0.4565 | 1 520 1 519 1 519 | 2.35 \$779.25 6.36 \$368.64 0.75 \$357.36 5.11 \$346.60 | 2 4 | 40 80 Well Briess | 100 120 150 Send 700 | the figure |
| | 10 10 10 10 10 10 10 10 10 10 10 10 10 1 | 22 0.3593 23 0.3486 24 0.3383 25 0.3283 | 0.1682 0.4726 0.1612 0.4881 0.1584 0.5033 0.1537 0.5180 | 1 513 1 513 1 516 1 516 | Add 5336.36 4.32 \$326.41 4.37 \$336.76 4.37 \$307.40 | 58.00 5515.99 58.00 5508.79 58.00 5475.50 58.00 5471.56 | 0.3593 0. 0.3488 0. 0.3383 0. 0.3283 0. | 0841 0.0000 0.4434 0835 0.0000 0.4302 0792 0.0000 0.4175 0768 0.0000 0.4052 | |
| | 79 40 | 27 0.3092 28 0.3001 | 0.3407 0.3409 0.3405 0.3595 | 1 \$15 1 \$15 1 \$15 | 1.60 \$289.49 1.60 \$289.49 1.60 \$280.90 | \$6.00 \$444.09 \$6.00 \$430.96 | 0.3092 0. 0.3091 0. | 0724 0.0000 0.3636 0702 0.0000 0.3703 | |

MARKOV MODEL RESULTS (2)



Questions

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REFERENCES

Briggs and Sculpher - Introduction to Markov Models

GitHub site for Markov model

Online Markov model tutorial (link)

