

# Simple 3-state Markov model in R

with dependency for time-since model start AND with state-residency dependency

The DARTH workgroup

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Please cite our publications when using this code:

- Jalal H, Pechlivanoglou P, Krijkamp E, Alarid-Escudero F, Enns E, Hunink MG. An Overview of R in Health Decision Sciences. *Med Decis Making*. 2017; 37(3): 735-746. <https://journals.sagepub.com/doi/abs/10.1177/0272989X16686559>
- Krijkamp EM, Alarid-Escudero F, Enns EA, Jalal HJ, Hunink MGM, Pechlivanoglou P. Microsimulation modeling for health decision sciences using R: A tutorial. *Med Decis Making*. 2018;38(3):400–22. <https://journals.sagepub.com/doi/abs/10.1177/0272989X18754513>
- Krijkamp EM, Alarid-Escudero F, Enns E, Pechlivanoglou P, Hunink MM, Jalal H. A Multidimensional Array Representation of State-Transition Model Dynamics. *Med Decis Making*. 2020 Online first. <https://doi.org/10.1177/0272989X19893973>

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```
rm(list = ls())      # clear memory (removes all the variables from the workspace)
```

## 01 Load packages

```
# no packages required
```

## 02 Load functions

```
# no functions required
```

## 03 Input model parameters

```
# Strategy names
v_names_str <- c("Base Case")

# Number of strategies
n_str <- length(v_names_str)

# Markov model parameters
v_n <- c("Healthy", "Sick", "Dead")      # state names
n_states <- length(v_n)                  # number of states
n_t <- 60                                # number of cycles

# Tunnels
n_tunnel_size <- n_t
# Sick state
v_Sick_tunnels <- paste("Sick_", seq(1, n_tunnel_size), "Yr", sep = "")
# Create variables for time-dependent model
v_n_tunnels <- c("Healthy", v_Sick_tunnels, "Dead") # state names
n_states_tunnels <- length(v_n_tunnels)             # number of states

p_HD <- seq(0.003, 0.01, length.out = n_t) # probability to die when sick (age-dependent) - this is a
p_HS <- 0.05                                # probability to become sick when healthy
p_SD <- 0.1                                  # probability to die when sick

# Weibull parameters
l <- 0.08
g <- 1.1
p_SD <- l*g*(1:n_tunnel_size)^(g-1)         # probability to die when sick (time-dependent)

# Costs and utilities
c_H <- 400                                  # cost of remaining one cycle healthy
c_S <- 1000                                 # cost of remaining one cycle sick
c_D <- 0                                    # cost of remaining one cycle dead
u_H <- 0.8                                  # utility when healthy
u_S <- 0.5                                  # utility when sick
u_D <- 0                                    # utility when dead
d_e <- d_c <- 0.03                          # equal discount of costs and QALYs by 3%

# calculate discount weights for costs for each cycle based on discount rate d_c
```

```
v_dwc <- 1 / (1 + d_e) ^ (0:n_t)
# calculate discount weights for effectiveness for each cycle based on discount rate d_e
v_dwe <- 1 / (1 + d_c) ^ (0:n_t)
```

## 04 Define and initialize matrices and vectors

### 04.1 Cohort trace

```
m_M <- matrix(NA,
              nrow = n_t + 1, # create Markov trace (n_t + 1 because R doesn't understand
                              # Cycle 0)
              ncol = n_states_tunnels,
              dimnames = list(0:n_t, v_n_tunnels))

# The cohort starts as healthy
# initialize first cycle of Markov trace accounting for the tunnels
m_M[1, ] <- c(1, rep(0, n_tunnel_size), 0)
```

### 04.2 Transition probability array

```
# create the transition probability array
a_P <- array(0, # Create 3-D array
            dim = c(n_states_tunnels, n_states_tunnels, n_t),
            dimnames = list(v_n_tunnels, v_n_tunnels, 0:(n_t-1)))
```

Fill in the transition probability array:

```
# from Healthy
a_P["Healthy", "Healthy", ] <- 1 - p_HD - p_HS
a_P["Healthy", "Sick_1Yr", ] <- p_HS
a_P["Healthy", "Dead", ] <- p_HD

# from Sick
for(i in 1:(n_tunnel_size - 1)){
  a_P[v_Sick_tunnels[i], v_Sick_tunnels[i + 1], ] <- 1 - p_SD[i]
  a_P[v_Sick_tunnels[i], "Dead", ] <- p_SD[i]
}

a_P[v_Sick_tunnels[n_tunnel_size], v_Sick_tunnels[n_tunnel_size], ] <- 1 - p_SD[n_tunnel_size]
a_P[v_Sick_tunnels[n_tunnel_size], "Dead", ] <- p_SD[n_tunnel_size]

# from Dead
a_P["Dead", "Dead", ] <- 1
```

### 04.3 Check if transition array and probabilities are valid

```
# Check if transition matrix is valid (i.e., each row should add up to 1)
valid <- apply(a_P, 3, function(x) sum(rowSums(x))==n_states_tunnels)
if (!isTRUE(all.equal(as.numeric(sum(valid)), as.numeric(n_t)))) {
  stop("This is not a valid transition Matrix")
}
```

## 05 Run Markov model

```
for (t in 1:n_t) {
  m_M[t + 1, ] <- m_M[t, ] %*% a_P[, , t]
}
head(m_M, n = 30)
```

```
##      Healthy Sick_1Yr Sick_2Yr Sick_3Yr Sick_4Yr Sick_5Yr
## 0  1.0000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000
## 1  0.9470000 0.05000000 0.00000000 0.00000000 0.00000000 0.00000000
## 2  0.8966966 0.04735000 0.04560000 0.00000000 0.00000000 0.00000000
## 3  0.8489589 0.04483483 0.04318320 0.041299187 0.000000000 0.000000000
## 4  0.8036620 0.04244795 0.04088937 0.039110331 0.037242829 0.000000000
## 5  0.7606865 0.04018310 0.03871253 0.037032843 0.035268959 0.033478121
## 6  0.7199188 0.03803432 0.03664698 0.035061315 0.033395520 0.031703780
## 7  0.6812506 0.03599594 0.03468730 0.033190586 0.031617633 0.030019719
## 8  0.6445786 0.03406253 0.03282830 0.031415733 0.029930645 0.028421550
## 9  0.6098041 0.03222893 0.03106503 0.029732063 0.028330116 0.026905092
## 10 0.5768333 0.03049021 0.02939278 0.028135098 0.026811814 0.025466354
## 11 0.5455768 0.02884167 0.02780707 0.026620572 0.025371702 0.024101530
## 12 0.5159492 0.02727884 0.02630360 0.025184414 0.024005930 0.022806992
## 13 0.4878693 0.02579746 0.02487830 0.023822749 0.022710830 0.021579280
## 14 0.4612598 0.02439347 0.02352728 0.022531879 0.021482906 0.020415096
## 15 0.4360468 0.02306299 0.02224684 0.021308283 0.020318824 0.019311296
## 16 0.4121603 0.02180234 0.02103345 0.020148607 0.019215408 0.018264886
## 17 0.3895334 0.02060802 0.01988374 0.019049654 0.018169634 0.017273010
## 18 0.3681025 0.01947667 0.01879451 0.018008380 0.017178619 0.016332948
## 19 0.3478070 0.01840513 0.01776273 0.017021888 0.016239618 0.015442111
## 20 0.3285891 0.01739035 0.01678547 0.016087415 0.015350017 0.014598029
## 21 0.3103942 0.01642946 0.01586000 0.015202334 0.014507328 0.013798354
## 22 0.2931700 0.01551971 0.01498367 0.014364145 0.013709179 0.013040848
## 23 0.2768667 0.01465850 0.01415398 0.013570465 0.012953315 0.012323380
## 24 0.2614373 0.01384334 0.01336855 0.012819029 0.012237589 0.011643923
## 25 0.2468367 0.01307186 0.01262512 0.012107681 0.011559959 0.011000547
## 26 0.2330222 0.01234183 0.01192154 0.011434371 0.010918479 0.010391415
## 27 0.2199532 0.01165111 0.01125575 0.010797147 0.010311301 0.009814780
## 28 0.2075911 0.01099766 0.01062581 0.010194154 0.009736664 0.009268978
## 29 0.1958991 0.01037955 0.01002987 0.009623627 0.009192896 0.008752429
##      Sick_6Yr Sick_7Yr Sick_8Yr Sick_9Yr Sick_10Yr Sick_11Yr
## 0  0.00000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000
## 1  0.00000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000
## 2  0.00000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000
## 3  0.00000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000
## 4  0.00000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000
## 5  0.00000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000
## 6  0.030017606 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000
## 7  0.028426673 0.026857702 0.00000000 0.00000000 0.00000000 0.00000000
## 8  0.026916686 0.025434244 0.023986516 0.00000000 0.00000000 0.00000000
## 9  0.025483715 0.024083211 0.022715231 0.021387800 0.00000000 0.00000000
## 10 0.024124008 0.022801086 0.021508628 0.020254247 0.019043177 0.00000000
## 11 0.022833987 0.021584513 0.020363567 0.019178368 0.018033888 0.016933470
## 12 0.021610240 0.020430291 0.019277050 0.018157364 0.017075953 0.016035996
```

## 13	0.020449513	0.019335365	0.018246218	0.017188561	0.016166875	0.015184186
## 14	0.019348706	0.018296827	0.017268345	0.016269410	0.015304277	0.014375821
## 15	0.018304859	0.017311899	0.016340830	0.015397480	0.014485887	0.013608786
## 16	0.017315156	0.016377937	0.015461194	0.014570453	0.013709542	0.012881062
## 17	0.016376909	0.015492418	0.014627076	0.013786118	0.012973177	0.012190724
## 18	0.015487560	0.014652939	0.013836222	0.013042368	0.012274824	0.011535938
## 19	0.014644669	0.013857210	0.013086487	0.012337196	0.011612608	0.010914952
## 20	0.013845914	0.013103049	0.012375824	0.011668687	0.010984739	0.010326100
## 21	0.013089082	0.012388378	0.011702285	0.011035018	0.010389516	0.009767790
## 22	0.012372067	0.011711216	0.011064015	0.010434452	0.009825312	0.009238508
## 23	0.011692861	0.011069680	0.010459245	0.009865332	0.009290582	0.008736811
## 24	0.011049556	0.010461973	0.009886291	0.009326083	0.008783851	0.008261321
## 25	0.010440332	0.009886387	0.009343550	0.008815203	0.008303717	0.007810729
## 26	0.009863459	0.009341296	0.008829497	0.008331263	0.007848842	0.007383786
## 27	0.009317291	0.008825149	0.008342677	0.007872903	0.007417954	0.006979305
## 28	0.008800261	0.008336475	0.007881709	0.007438826	0.007009841	0.006596153
## 29	0.008310877	0.007873872	0.007445276	0.007027799	0.006623349	0.006233253
##	Sick_12Yr	Sick_13Yr	Sick_14Yr	Sick_15Yr	Sick_16Yr	Sick_17Yr
## 0	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 1	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 2	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 3	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 4	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 5	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 6	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 7	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 8	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 9	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 10	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 11	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 12	0.015039523	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 13	0.014242428	0.013342706	0.000000000	0.000000000	0.000000000	0.000000000
## 14	0.013485890	0.012635543	0.011825234	0.000000000	0.000000000	0.000000000
## 15	0.012767937	0.011964360	0.011198496	0.010470340	0.000000000	0.000000000
## 16	0.012086692	0.011327410	0.010603647	0.009915412	0.009262380	0.000000000
## 17	0.011440361	0.010723025	0.010039138	0.009388719	0.008771474	0.008186863
## 18	0.010827236	0.010149616	0.009503490	0.008888889	0.008305545	0.007752959
## 19	0.010245685	0.009605666	0.008995295	0.008414614	0.007863380	0.007341132
## 20	0.009694154	0.009089727	0.008513208	0.007964646	0.007443822	0.006950310
## 21	0.009171163	0.008600423	0.008055948	0.007537795	0.007045767	0.006579470
## 22	0.008675298	0.008136437	0.007622292	0.007132926	0.006668162	0.006227636
## 23	0.008205215	0.007696518	0.007211076	0.006748957	0.006310002	0.005893877
## 24	0.007759630	0.007279471	0.006821189	0.006384856	0.005970332	0.005577306
## 25	0.007337322	0.006884159	0.006451573	0.006039641	0.005648237	0.005277076
## 26	0.006937127	0.006509497	0.006101220	0.005712375	0.005342850	0.004992383
## 27	0.006557937	0.006154454	0.005769169	0.005402164	0.005053340	0.004722456
## 28	0.006198695	0.005818045	0.005454505	0.005108158	0.004778918	0.004466562
## 29	0.005858397	0.005499335	0.005156356	0.004829547	0.004518831	0.004224005
##	Sick_18Yr	Sick_19Yr	Sick_20Yr	Sick_21Yr	Sick_22Yr	Sick_23Yr
## 0	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 1	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 2	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 3	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 4	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000

## 5	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 6	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 7	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 8	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 9	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 10	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 11	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 12	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 13	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 14	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 15	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 16	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 17	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 18	0.007230451	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 19	0.006847237	0.006380927	0.000000000	0.000000000	0.000000000	0.000000000
## 20	0.006483521	0.006042738	0.005627152	0.000000000	0.000000000	0.000000000
## 21	0.006138356	0.005721756	0.005328913	0.004959002	0.000000000	0.000000000
## 22	0.005810838	0.005417145	0.005045849	0.004696175	0.004367305	0.000000000
## 23	0.005500106	0.005128109	0.004777221	0.004446720	0.004135838	0.003843779
## 24	0.005205338	0.004853885	0.004522328	0.004209989	0.003916148	0.003640059
## 25	0.004925749	0.004593750	0.004280499	0.003985361	0.003707663	0.003446704
## 26	0.004660594	0.004347011	0.004051093	0.003772245	0.003509837	0.003263211
## 27	0.004409159	0.004113009	0.003833501	0.003570079	0.003322150	0.003089099
## 28	0.004170765	0.003891116	0.003627142	0.003378323	0.003144105	0.002923911
## 29	0.003944766	0.003680732	0.003431461	0.003196466	0.002975230	0.002767209
##	Sick_24Yr	Sick_25Yr	Sick_26Yr	Sick_27Yr	Sick_28Yr	Sick_29Yr
## 0	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 1	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 2	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 3	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 4	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 5	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 6	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 7	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 8	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 9	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 10	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 11	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 12	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 13	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 14	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 15	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 16	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 17	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 18	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 19	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 20	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 21	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 22	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 23	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 24	0.003380957	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
## 25	0.003201766	0.002972127	0.000000000	0.000000000	0.000000000	0.000000000
## 26	0.003031693	0.002814604	0.002611262	0.000000000	0.000000000	0.000000000
## 27	0.002870294	0.002665096	0.002472865	0.002292967	0.000000000	0.000000000

```

## 28 0.002717147 0.002523213 0.002341510 0.002171439 0.002012412 0.000000000
## 29 0.002571848 0.002388585 0.002216854 0.002056096 0.001905755 0.001765288
##      Sick_30Yr Sick_31Yr Sick_32Yr Sick_33Yr Sick_34Yr Sick_35Yr Sick_36Yr
## 0      0      0      0      0      0      0      0
## 1      0      0      0      0      0      0      0
## 2      0      0      0      0      0      0      0
## 3      0      0      0      0      0      0      0
## 4      0      0      0      0      0      0      0
## 5      0      0      0      0      0      0      0
## 6      0      0      0      0      0      0      0
## 7      0      0      0      0      0      0      0
## 8      0      0      0      0      0      0      0
## 9      0      0      0      0      0      0      0
## 10     0      0      0      0      0      0      0
## 11     0      0      0      0      0      0      0
## 12     0      0      0      0      0      0      0
## 13     0      0      0      0      0      0      0
## 14     0      0      0      0      0      0      0
## 15     0      0      0      0      0      0      0
## 16     0      0      0      0      0      0      0
## 17     0      0      0      0      0      0      0
## 18     0      0      0      0      0      0      0
## 19     0      0      0      0      0      0      0
## 20     0      0      0      0      0      0      0
## 21     0      0      0      0      0      0      0
## 22     0      0      0      0      0      0      0
## 23     0      0      0      0      0      0      0
## 24     0      0      0      0      0      0      0
## 25     0      0      0      0      0      0      0
## 26     0      0      0      0      0      0      0
## 27     0      0      0      0      0      0      0
## 28     0      0      0      0      0      0      0
## 29     0      0      0      0      0      0      0
##      Sick_37Yr Sick_38Yr Sick_39Yr Sick_40Yr Sick_41Yr Sick_42Yr Sick_43Yr
## 0      0      0      0      0      0      0      0
## 1      0      0      0      0      0      0      0
## 2      0      0      0      0      0      0      0
## 3      0      0      0      0      0      0      0
## 4      0      0      0      0      0      0      0
## 5      0      0      0      0      0      0      0
## 6      0      0      0      0      0      0      0
## 7      0      0      0      0      0      0      0
## 8      0      0      0      0      0      0      0
## 9      0      0      0      0      0      0      0
## 10     0      0      0      0      0      0      0
## 11     0      0      0      0      0      0      0
## 12     0      0      0      0      0      0      0
## 13     0      0      0      0      0      0      0
## 14     0      0      0      0      0      0      0
## 15     0      0      0      0      0      0      0
## 16     0      0      0      0      0      0      0
## 17     0      0      0      0      0      0      0
## 18     0      0      0      0      0      0      0
## 19     0      0      0      0      0      0      0

```

## 20	0	0	0	0	0	0	0
## 21	0	0	0	0	0	0	0
## 22	0	0	0	0	0	0	0
## 23	0	0	0	0	0	0	0
## 24	0	0	0	0	0	0	0
## 25	0	0	0	0	0	0	0
## 26	0	0	0	0	0	0	0
## 27	0	0	0	0	0	0	0
## 28	0	0	0	0	0	0	0
## 29	0	0	0	0	0	0	0
##	Sick_44Yr	Sick_45Yr	Sick_46Yr	Sick_47Yr	Sick_48Yr	Sick_49Yr	Sick_50Yr
## 0	0	0	0	0	0	0	0
## 1	0	0	0	0	0	0	0
## 2	0	0	0	0	0	0	0
## 3	0	0	0	0	0	0	0
## 4	0	0	0	0	0	0	0
## 5	0	0	0	0	0	0	0
## 6	0	0	0	0	0	0	0
## 7	0	0	0	0	0	0	0
## 8	0	0	0	0	0	0	0
## 9	0	0	0	0	0	0	0
## 10	0	0	0	0	0	0	0
## 11	0	0	0	0	0	0	0
## 12	0	0	0	0	0	0	0
## 13	0	0	0	0	0	0	0
## 14	0	0	0	0	0	0	0
## 15	0	0	0	0	0	0	0
## 16	0	0	0	0	0	0	0
## 17	0	0	0	0	0	0	0
## 18	0	0	0	0	0	0	0
## 19	0	0	0	0	0	0	0
## 20	0	0	0	0	0	0	0
## 21	0	0	0	0	0	0	0
## 22	0	0	0	0	0	0	0
## 23	0	0	0	0	0	0	0
## 24	0	0	0	0	0	0	0
## 25	0	0	0	0	0	0	0
## 26	0	0	0	0	0	0	0
## 27	0	0	0	0	0	0	0
## 28	0	0	0	0	0	0	0
## 29	0	0	0	0	0	0	0
##	Sick_51Yr	Sick_52Yr	Sick_53Yr	Sick_54Yr	Sick_55Yr	Sick_56Yr	Sick_57Yr
## 0	0	0	0	0	0	0	0
## 1	0	0	0	0	0	0	0
## 2	0	0	0	0	0	0	0
## 3	0	0	0	0	0	0	0
## 4	0	0	0	0	0	0	0
## 5	0	0	0	0	0	0	0
## 6	0	0	0	0	0	0	0
## 7	0	0	0	0	0	0	0
## 8	0	0	0	0	0	0	0
## 9	0	0	0	0	0	0	0
## 10	0	0	0	0	0	0	0
## 11	0	0	0	0	0	0	0



## 12	0	0	0	0	0	0	0
## 13	0	0	0	0	0	0	0
## 14	0	0	0	0	0	0	0
## 15	0	0	0	0	0	0	0
## 16	0	0	0	0	0	0	0
## 17	0	0	0	0	0	0	0
## 18	0	0	0	0	0	0	0
## 19	0	0	0	0	0	0	0
## 20	0	0	0	0	0	0	0
## 21	0	0	0	0	0	0	0
## 22	0	0	0	0	0	0	0
## 23	0	0	0	0	0	0	0
## 24	0	0	0	0	0	0	0
## 25	0	0	0	0	0	0	0
## 26	0	0	0	0	0	0	0
## 27	0	0	0	0	0	0	0
## 28	0	0	0	0	0	0	0
## 29	0	0	0	0	0	0	0
##	Sick_58Yr	Sick_59Yr	Sick_60Yr	Dead			
## 0	0	0	0	0.00000000			
## 1	0	0	0	0.00300000			
## 2	0	0	0	0.01035336			
## 3	0	0	0	0.02172383			
## 4	0	0	0	0.03664758			
## 5	0	0	0	0.05463798			
## 6	0	0	0	0.07522164			
## 7	0	0	0	0.09795380			
## 8	0	0	0	0.12242522			
## 9	0	0	0	0.14826470			
## 10	0	0	0	0.17513925			
## 11	0	0	0	0.20275287			
## 12	0	0	0	0.23084460			
## 13	0	0	0	0.25918620			
## 14	0	0	0	0.28757954			
## 15	0	0	0	0.31585404			
## 16	0	0	0	0.34386408			
## 17	0	0	0	0.37148650			
## 18	0	0	0	0.39861833			
## 19	0	0	0	0.42517452			
## 20	0	0	0	0.45108598			
## 21	0	0	0	0.47629765			
## 22	0	0	0	0.50076685			
## 23	0	0	0	0.52446170			
## 24	0	0	0	0.54735973			
## 25	0	0	0	0.56944660			
## 26	0	0	0	0.59071503			
## 27	0	0	0	0.61116370			
## 28	0	0	0	0.63079642			
## 29	0	0	0	0.64962131			

Create aggregated trace.

```
m_M_tunnels <- cbind(Healthy = m_M[, "Healthy"],
  Sick = rowSums(m_M[, 2:(n_tunnel_size + 1)]),
  Dead = m_M[, "Dead"])
```

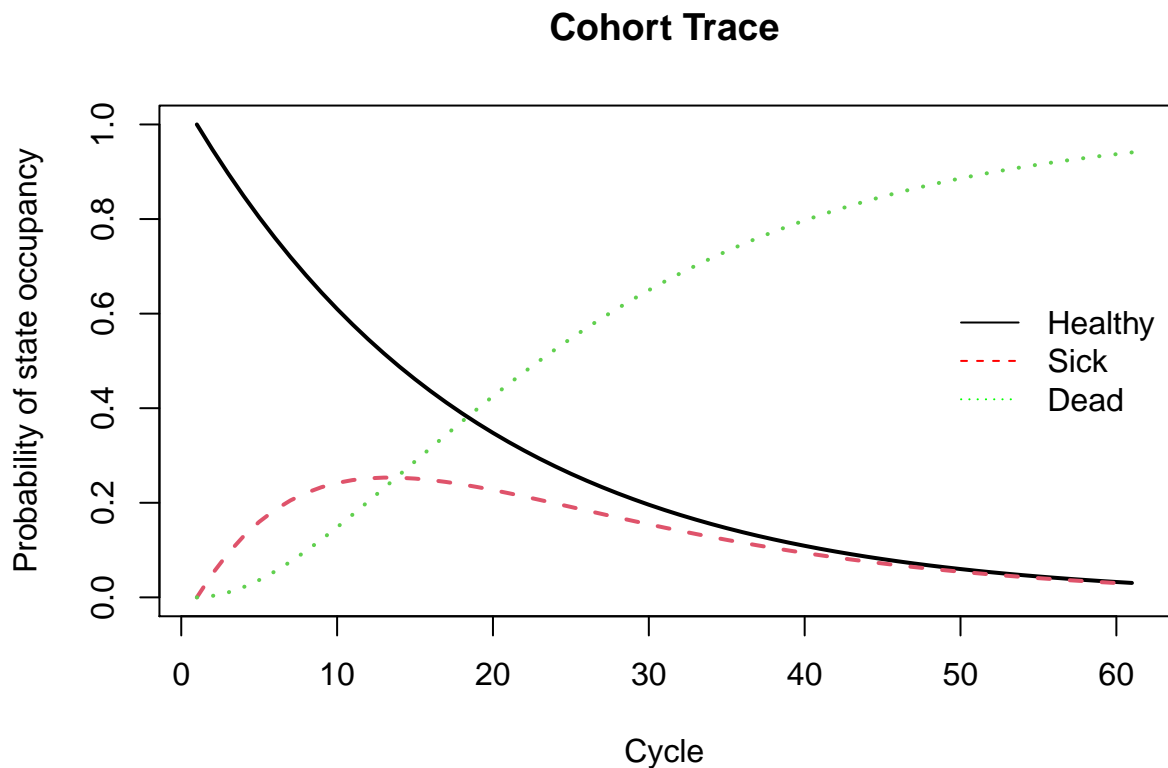
```
head(m_M_tunnels) # show the first rows of the aggregated Markov trace
```

```
##      Healthy      Sick      Dead
## 0 1.0000000 0.0000000 0.0000000
## 1 0.9470000 0.0500000 0.0030000
## 2 0.8966966 0.0929500 0.0103536
## 3 0.8489589 0.1293172 0.02172383
## 4 0.8036620 0.1596905 0.03664758
## 5 0.7606865 0.1846755 0.05463798
```

## 06 Compute and Plot Epidemiological Outcomes

### 06.1 Cohort trace

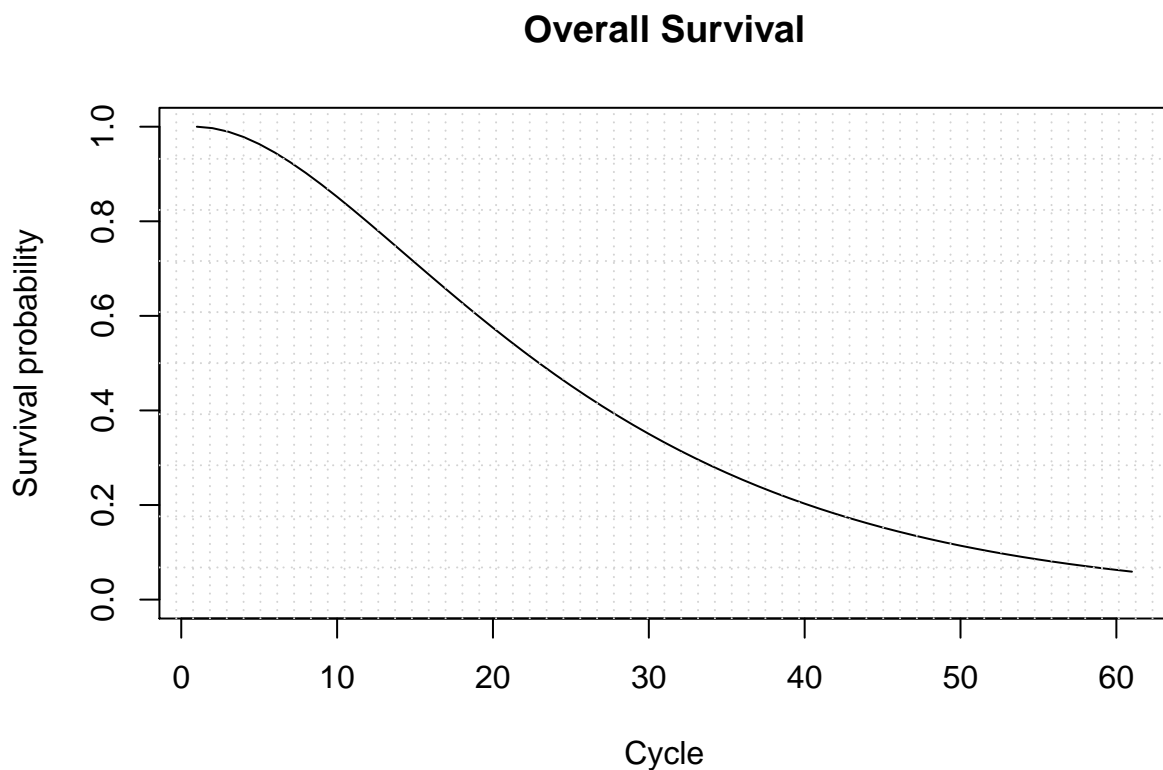
```
# create a plot of the data
matplot(m_M_tunnels, type = 'l',
        ylab = "Probability of state occupancy",
        xlab = "Cycle",
        main = "Cohort Trace", lwd = 2)
# add a legend to the graph
legend("right", v_n, col = c("black", "red", "green"), lty = 1:3, bty = "n")
```



## 06.2 Overall Survival (OS)

```
v_os <- 1 - m_M_tunnels[, "Dead"]      # calculate the overall survival (OS) probability
v_os <- rowSums(m_M_tunnels[, 1:2])    # alternative way of calculating the OS probability

# create a simple plot showing the OS
plot(v_os, type = 'l',
     ylim = c(0, 1),
     ylab = "Survival probability",
     xlab = "Cycle",
     main = "Overall Survival")
# add grid
grid(nx = n_t, ny = 10, col = "lightgray", lty = "dotted", lwd = par("lwd"), equilogs = TRUE)
```



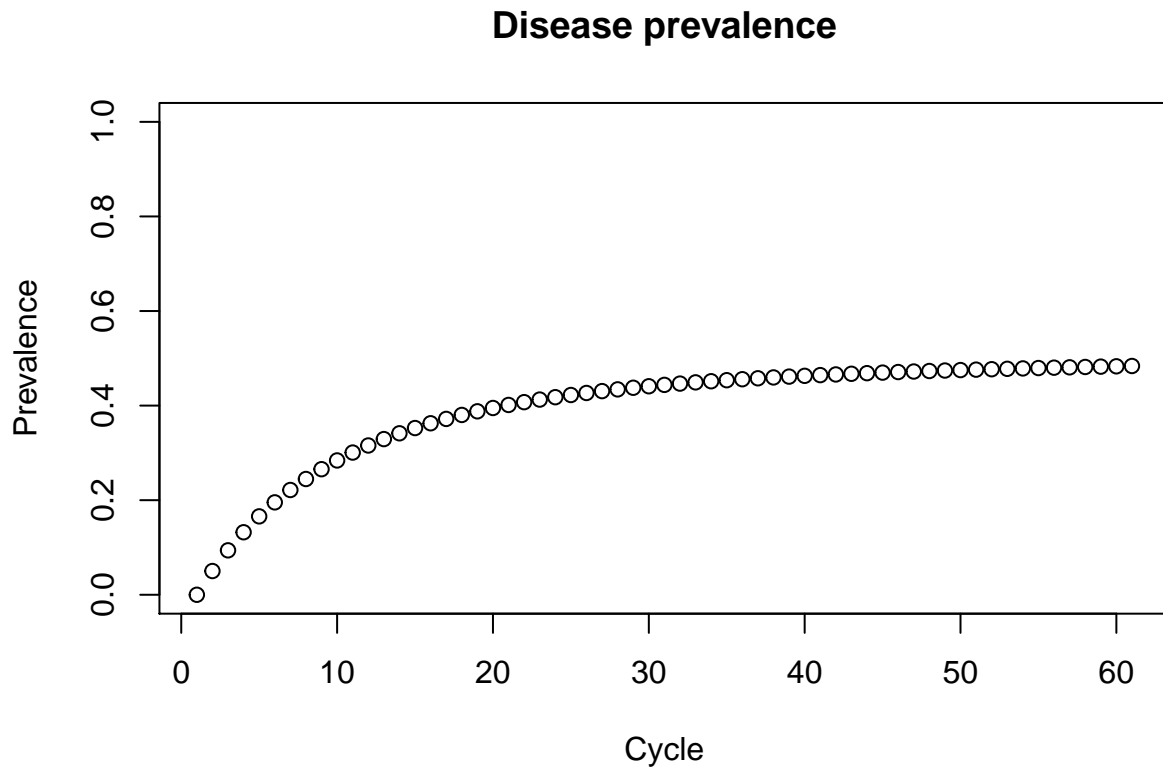
### 06.2.1 Life Expectancy (LE)

```
v_le <- sum(v_os)      # summing probability of OS over time (i.e. life expectancy)
```

## 06.3 Disease prevalence

```
v_prev <- m_M_tunnels[, "Sick"] / v_os
plot(v_prev,
     ylim = c(0, 1),
     ylab = "Prevalence",
     xlab = "Cycle",
```

```
main = "Disease prevalence")
```



## 07 Compute Cost-Effectiveness Outcomes

### 07.1 Mean Costs and QALYs

```
# per cycle
# calculate expected costs by multiplying m_M with the cost vector for the different
# health states
v_tc <- m_M_tunnels %*% c(c_H, c_S, c_D)
# calculate expected QALYs by multiplying m_M with the utilities for the different
# health states
v_tu <- m_M_tunnels %*% c(u_H, u_S, u_D)
```

### 07.2 Discounted Mean Costs and QALYs

```
# Discount costs by multiplying the cost vector with discount weights (v_dw)
v_tc_d <- t(v_tc) %*% v_dwc
# Discount QALYs by multiplying the QALYs vector with discount weights (v_dw)
v_te_d <- t(v_tu) %*% v_dwe
```

## 07.3 Results

```
results <- data.frame( "Total Discounted Cost" = v_tc_d,  
                      "Life Expectancy" = v_le,  
                      "Total Discounted QALYs" = v_te_d,  
                      check.names = F)
```

```
results
```

```
##   Total Discounted Cost Life Expectancy Total Discounted QALYs  
## 1           9382.938         25.89709           11.98968
```