Report for the Markov model (cohort state-transition model)

Data and parameters

```
rate_data <- read_csv("../data/ghdx_data.csv")
print(xtable(data.frame(rate_data),digits=c(0,0,0,6,6,6),
      caption = "Data from Global Health Data Exchange"),
      caption.placement="top",comment=FALSE)
```

Table 1: Data from Global Health Data Exchange

	index	sex	incidence	death_CVD	death_nonCVD
1	40	male	0.003888	0.000819	0.002494
2	45	male	0.006729	0.001340	0.003399
3	50	male	0.010564	0.002302	0.004951
4	55	male	0.015291	0.003665	0.007282
5	60	male	0.022078	0.006404	0.011159
6	65	male	0.030980	0.011155	0.016946
7	70	male	0.043589	0.019978	0.026305
8	40	female	0.004545	0.000351	0.001137
9	45	female	0.007094	0.000643	0.001620
10	50	female	0.010133	0.001206	0.002475
11	55	female	0.013734	0.002014	0.003705
12	60	female	0.018272	0.003872	0.005850
13	65	female	0.023744	0.006996	0.009060
14	70	female	0.033907	0.013398	0.014907

```
noStrategy_data <- read_csv("../data/Normal_data.csv")
print(xtable(data.frame(noStrategy_data),digits=c(0,0,0,0),
      caption = "Distribution of the population"),
      caption.placement="top",comment=FALSE)
```

```
population_data <- read_csv("../data/Normal3Stra_data.csv")
population_data <- data.frame(population_data)
print(xtable(data.frame(population_data),digits=c(0,0,0,0,0,0,0,0),
      caption = "Distribution of the population under different strategies"),caption.placement="top",co
```

Table 2: Distribution of the population

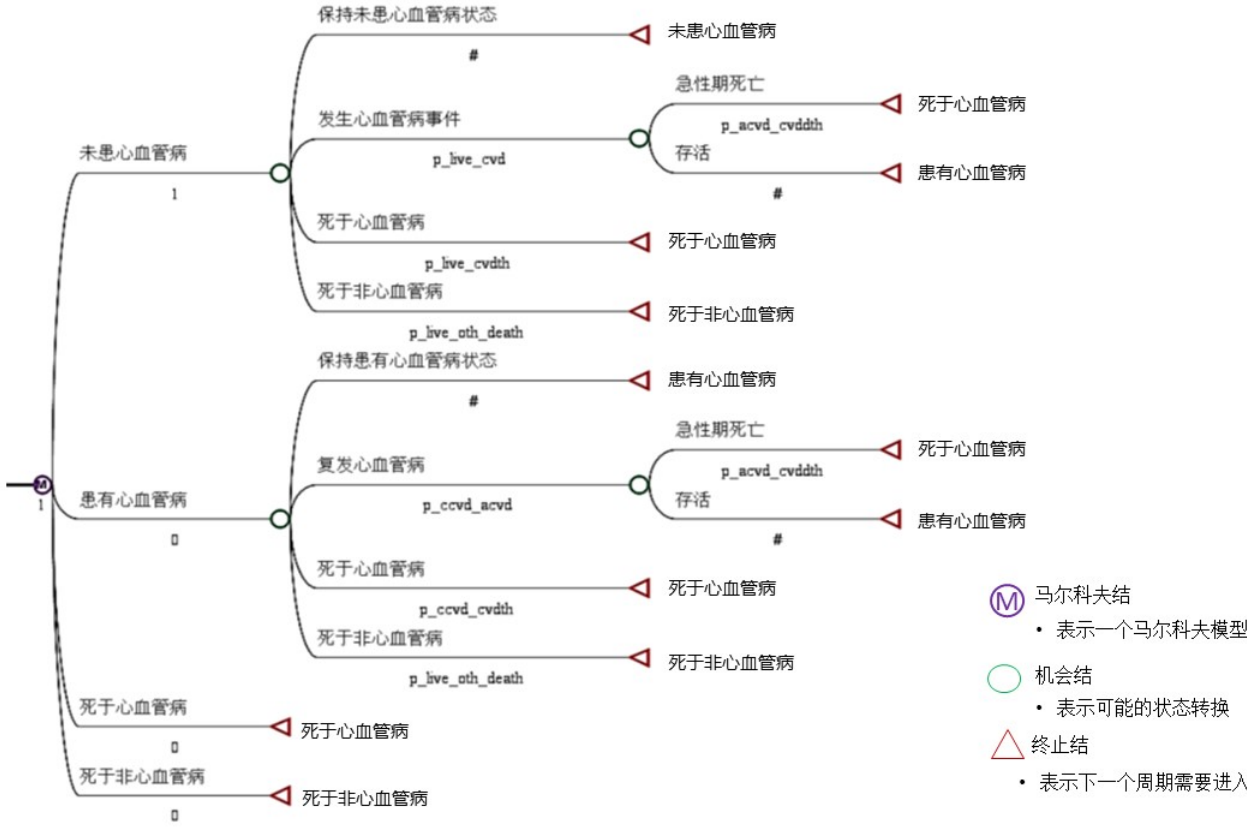
	index	sex	num
1	40	male	229
2	45	male	444
3	50	male	422
4	55	male	410
5	60	male	322
6	65	male	160
7	70	male	116
8	40	female	498
9	45	female	856
10	50	female	822
11	55	female	842
12	60	female	519
13	65	female	394
14	70	female	187

Table 3: Distribution of the population under different strategies

	index	sex	strategy	low	medium	high
1	40	male	strategy1	159	8	62
2	45	male	strategy1	173	64	207
3	50	male	strategy1	188	63	171
4	55	male	strategy1	200	89	121
5	60	male	strategy1	129	89	104
6	65	male	strategy1	71	42	47
7	70	male	strategy1	48	28	40
8	40	female	strategy1	444	6	48
9	45	female	strategy1	738	18	100
10	50	female	strategy1	677	20	125
11	55	female	strategy1	440	217	185
12	60	female	strategy1	216	164	139
13	65	female	strategy1	128	136	130
14	70	female	strategy1	65	55	67
15	40	male	strategy2	163	50	16
16	45	male	strategy2	212	168	64
17	50	male	strategy2	106	231	85
18	55	male	strategy2	35	210	165
19	60	male	strategy2	5	81	236
20	65	male	strategy2	1	15	144
21	70	male	strategy2	0	3	113
22	40	female	strategy2	478	17	3
23	45	female	strategy2	734	108	14
24	50	female	strategy2	537	238	47
25	55	female	strategy2	277	433	132
26	60	female	strategy2	44	282	193
27	65	female	strategy2	4	104	286
28	70	female	strategy2	0	23	164
29	40	male	strategy3	0	0	0
30	45	male	strategy3	0	0	0
31	50	male	strategy3	106	231	85
32	55	male	strategy3	35	210	165
33	60	male	strategy3	5	81	236
34	65	male	strategy3	1	15	144
35	70	male	strategy3	0	3	113
36	40	female	strategy3	0	0	0
37	45	female	strategy3	0	0	0
38	50	female	strategy3	537	238	47
39	55	female	strategy3	277	433	132
40	60	female	strategy3	44	282	193
41	65	female	strategy3	4	104	286
42	70	female	strategy3	0	23	164

```r
n_t <- 10   # time horizon, number of cycles
v_names_states <- c("S1", "S2", "S3", "S4") # S1: live; S2: cvd; S3: cvdth; S4: oth_death
n_states    <- length(v_names_states)   # number of health states
v_names_str <- c("Strategy0","Strategy1", "Strategy2", "Strategy3") # store the strategy names
n_str       <- length(v_names_str)      # number of strategies

# Health utilities
out_cvd_free <- 1   # utility when being S1
out_cvd <- 0.9   # utility when being S2
out_dth <-  0   # utility when being S3 and S4 together
out_trans_to_cvd <- -0.038    # TODO

uti_values <- c(out_cvd_free, out_cvd, out_dth, out_dth)

HR_cvdhistory_cvd <-    1.37
HR_cvdhistory_cvdth <- 3.12
HR_high_live_cvdth <-   1.17

p_live_oth_death <- rate_to_prob(r=rate_data$death_nonCVD,t = 1)
p_live_cvd <- rate_to_prob(r=rate_data$incidence, t=1)
p_live_cvdth <- rate_to_prob(r=rate_data$death_CVD, t=1)
# transition probability from S2 to S3
p_ccvd_acvd <- rate_to_prob(rate_data$incidence*HR_cvdhistory_cvd, t=1)
p_ccvd_cvdth <- rate_to_prob(rate_data$death_CVD*HR_cvdhistory_cvdth,t=1)
set.seed(100)
p_acvd_cvdth <- rep(runif(1,min=0.02,max=0.1),length=length(p_live_cvd))

# half-cycle correction could be added
```

A transition probability matrix P_t



状态转换概率矩阵

状态	未患心血管病	患有心血管病	死于心血管病	死于非心血管病
未患心血管病	P4	P1	P2	P3
患有心血管病		P6	P5	P3

$$P_t = \begin{Bmatrix} p_{[1,1,t]} & p_{[1,2,t]} & p_{[1,3,t]} & p_{[1,4,t]} \\ p_{[2,1,t]} & p_{[2,2,t]} & p_{[2,3,t]} & p_{[2,4,t]} \\ p_{[3,1,t]} & p_{[3,2,t]} & p_{[3,3,t]} & p_{[3,4,t]} \\ p_{[4,1,t]} & p_{[4,2,t]} & p_{[4,3,t]} & p_{[4,4,t]} \end{Bmatrix}$$

Thus,

$P4 = 1 - P1 - P2 - P3$

$P1 = p\_live\_cvd * (1 - p\_acvd\_cvdth)$

$P2 = p\_live\_cvdth + p\_live\_cvd * p\_acvd\_cvdth$

$P3 = p\_live\_oth\_death$

$P6 = 1 - (p\_ccvd\_cvdth + p\_ccvd\_acvd * p\_acvd\_cvdth) - p\_live\_oth\_death$

$P5 = p\_ccvd\_cvdth + p\_ccvd\_acvd * p\_acvd\_cvdth$

Strategy 0

```
###################### Construct state-transition models for Strategy1 ######################
patient_group_name <- c("m40","m45","m50","m55","m60","m65","m70",
                        "f40","f45","f50","f55","f60","f65","f70")
result_m_M <- array(0, dim = c(10, 4, 14),
               dimnames = list(paste0("t",0:9), v_names_states, patient_group_name))

for(i in 1:14){
  if(i != 7 && i != 14){
    a_P <- array(0, dim = c(n_states, n_states, 10),
                 dimnames = list(v_names_states, v_names_states, 1:10))
    a_P["S1", "S1", 1:5] <- 1-(p_live_cvd[i]*(1-p_acvd_cvdth[i]) +
                                 p_live_cvdth[i]*p_live_cvd[i]*p_acvd_cvdth[i] +
                                 p_live_oth_death[i])
    a_P["S1", "S2", 1:5] <- p_live_cvd[i]*(1-p_acvd_cvdth[i])
    a_P["S1", "S3", 1:5] <- p_live_cvdth[i]*p_live_cvd[i]*p_acvd_cvdth[i]
    a_P["S1", "S4", 1:5] <- p_live_oth_death[i]
    a_P["S2", "S1", 1:5] <- 0
    a_P["S2", "S2", 1:5] <- 1-p_live_oth_death[i]-
      (p_ccvd_cvdth[i]+p_ccvd_acvd[i]*p_acvd_cvdth[i])
    a_P["S2", "S3", 1:5] <- p_ccvd_cvdth[i]+
      p_ccvd_acvd[i]*p_acvd_cvdth[i]
    a_P["S2", "S4", 1:5] <- p_live_oth_death[i]
    a_P["S3", "S3", 1:5] <- 1
    a_P["S4", "S4", 1:5] <- 1

    a_P["S1", "S1", 6:10] <-  1-(p_live_cvd[i+1]*(1-p_acvd_cvdth[i+1])+
                               p_live_cvdth[i+1]*p_live_cvd[i+1]*p_acvd_cvdth[i+1]
                               +p_live_oth_death[i+1])
    a_P["S1", "S2", 6:10] <- p_live_cvd[i+1]*(1-p_acvd_cvdth[i+1])
    a_P["S1", "S3", 6:10] <- p_live_cvdth[i+1]*p_live_cvd[i+1]*p_acvd_cvdth[i+1]
    a_P["S1", "S4", 6:10] <- p_live_oth_death[i+1]
    a_P["S2", "S1", 6:10] <- 0
    a_P["S2", "S2", 6:10] <- 1-p_live_oth_death[i+1]-
       (p_ccvd_cvdth[i+1]+p_ccvd_acvd[i+1]*p_acvd_cvdth[i+1])
    a_P["S2", "S3", 6:10] <- p_ccvd_cvdth[i+1]+p_ccvd_acvd[i+1]*p_acvd_cvdth[i+1]
    a_P["S2", "S4", 6:10] <-  p_live_oth_death[i+1]
    a_P["S3", "S3", 6:10] <- 1
    a_P["S4", "S4", 6:10] <- 1

    v_s_init <- c(state0 = 1, state1 = 0, state2 = 0, state3 = 0)
    m_M <- matrix(0,nrow     = (n_t), ncol = n_states,
                  dimnames = list(0:(n_t-1), v_names_states))
    m_M[1, ] <- v_s_init
    for(t in 1:9){
      m_M[t + 1, ] <- m_M[t, ] %*% a_P[, , t]
    }
    result_m_M[,,i] <- m_M
  }
    if(i == 7 | i == 14){
    a_P <- array(0, dim = c(n_states, n_states, 10),
                 dimnames = list(v_names_states, v_names_states, 1:10))
```

```
    a_P["S1", "S1", 1:10] <- 1-(p_live_cvd[i]*(1-p_acvd_cvdth[i]) +
                               p_live_cvdth[i]*p_live_cvd[i]*p_acvd_cvdth[i] +
                               p_live_oth_death[i])
    a_P["S1", "S2", 1:10] <- p_live_cvd[i]*(1-p_acvd_cvdth[i])
    a_P["S1", "S3", 1:10] <- p_live_cvdth[i]*p_live_cvd[i]*p_acvd_cvdth[i]
    a_P["S1", "S4", 1:10] <- p_live_oth_death[i]
    a_P["S2", "S1", 1:10] <- 0
    a_P["S2", "S2", 1:10] <- 1-p_live_oth_death[i]-
      (p_ccvd_cvdth[i]+p_ccvd_acvd[i]*p_acvd_cvdth[i])
    a_P["S2", "S3", 1:10] <- p_ccvd_cvdth[i]+
      p_ccvd_acvd[i]*p_acvd_cvdth[i]
    a_P["S2", "S4", 1:10] <- p_live_oth_death[i]
    a_P["S3", "S3", 1:10] <- 1
    a_P["S4", "S4", 1:10] <- 1

    v_s_init <- c(state0 = 1, state1 = 0, state2 = 0, state3 = 0)
    m_M <- matrix(0,nrow     = (n_t), ncol = n_states,
                  dimnames = list(0:(n_t-1), v_names_states))
    m_M[1, ] <- v_s_init
    for(t in 1:9){
      m_M[t + 1, ] <- m_M[t, ] %*% a_P[, , t]
    }
    result_m_M[,,i] <- m_M
  }
}
result_m_M[ , ,1] # an example for the patient group 40-45, male
```

```
##           S1          S2           S3          S4
## t0 1.0000000 0.000000000 0.000000e+00 0.000000000
## t1 0.9938017 0.003707301 1.417524e-07 0.002490893
## t2 0.9876417 0.007372048 1.062253e-05 0.004975580
## t3 0.9815200 0.010994609 3.132364e-05 0.007454053
## t4 0.9754362 0.014575348 6.212744e-05 0.009926300
## t5 0.9693901 0.018114626 1.029173e-04 0.012392312
## t6 0.9598894 0.024181206 1.862985e-04 0.015743143
## t7 0.9504817 0.030138534 2.974702e-04 0.019082321
## t8 0.9411662 0.035988076 4.359318e-04 0.022409791
## t9 0.9319420 0.041731284 6.011895e-04 0.025725500
```

```
prob_group0 <- matrix(0, ncol=14, nrow=10,
                      dimnames=list(paste0("t",0:9),patient_group_name))
for (i in 1:14){
  prob_group0[,i] <- result_m_M[, 1, i]* p_live_cvd[i]
}
patient_group <- matrix(noStrategy_data$num,ncol=1,dimnames=list(patient_group_name))
result_CVD <- matrix(0,ncol = 1, nrow = 14,
                      dimnames=list(patient_group_name,""))
for(i in 1:14){
  result_CVD[i] <- sum(prob_group0[,i]*patient_group[i])
}
result_CVD_stg0 <- sum(result_CVD)
print(xtable(data.frame(rbind(result_CVD,"sum" = result_CVD_stg0)),
      caption = "CVD events for patients under Strategy0"),
```

```
      caption.placement="top",comment=FALSE)
```

Table 4: CVD events for patients under Strategy0

	V1
m40	8.61
m45	28.35
m50	41.20
m55	55.93
m60	60.24
m65	39.14
m70	36.98
f40	21.97
f45	58.07
f50	78.15
f55	105.93
f60	84.11
f65	79.30
f70	50.75
sum	748.73

```
HR_l_stg1   <- 0.63
HR_m_stg1   <- 1.56
HR_h_stg1   <- 1.6

HR_l_stg2   <- 0.43
HR_m_stg2   <- 0.97
HR_h_stg2   <- 2.06

HR_l_stg3   <- 0.45
HR_m_stg3   <- 1.09
HR_h_stg3   <- 2.11
# lifestyle intervention for medium risk and above
HR_smk_cvd  <-  0.85
HR_smk_cvdth    <-  0.72
HR_salt_cvd <-  0.81
HR_salt_cvdth   <-  0.66
HR_wtc_cvd  <-  0.93
HR_wtc_dth  <-  0.93
# treatment intervention for high risk (additional)
HR_hpt_lip_cvd  <-  0.7
HR_hpt_lip_cvdth <- 0.82
```

Strategy 1

```
p_live_cvd_l <- ProbFactor(p_live_cvd,HR_l_stg1)
p_live_cvd_m <- ProbFactor(p_live_cvd,HR_m_stg1*
```

Table 5: Incidence rate

Item		CVD incidence(HR)	CVD cause-specific mortality (HR)
Strategy 1	Low risk	0.63	1
	Medium risk	1.56	1
	High risk	1.6	1.7
Strategy 2	Low risk	0.43	1
	Medium risk	0.97	1
	High risk	2.06	1.7
Strategy 3	Low risk	0.45	1
	Medium risk	1.09	1
	High risk	2.11	1.7
Intervention	Weight control	0.93	0.93
	Smoke cession	0.85	0.72
	Salt reduction	0.81	0.66
Medication	Statin and antihypertensive	0.7	0.82

```
                              HR_smk_cvd*HR_salt_cvd*HR_wtc_cvd)  # lifestyle intervention
p_live_cvd_h <- ProbFactor(p_live_cvd,HR_h_stg1*
                              HR_smk_cvdth*HR_salt_cvdth*HR_wtc_dth*    # lifestyle intervention
                              HR_hpt_lip_cvdth)   # treatment intervention

# transition probability to death
p_live_cvdth_l <- ProbFactor(p_live_cvdth,1)    # equal
p_live_cvdth_m <- ProbFactor(p_live_cvdth,1*
                               HR_smk_cvd*HR_salt_cvd*HR_wtc_cvd)  # lifestyle intervention
p_live_cvdth_h <- ProbFactor(p_live_cvdth,1.7*
                               HR_smk_cvdth*HR_salt_cvdth*HR_wtc_dth* # lifestyle intervention
                               HR_hpt_lip_cvdth) # treatment intervention
```

```
risk_levels <- c("low","medium","high")
result_CVD_lmh <- matrix(0,  nrow = 14,ncol = 3,
                         dimnames = list(patient_group_name, risk_levels))
p_live_cvd_lmh <- matrix(cbind(p_live_cvd_l,p_live_cvd_m,p_live_cvd_h), ncol=3,
                         dimnames = list(patient_group_name,risk_levels))
p_live_cvdth_lmh <- matrix(cbind(p_live_cvdth_l,p_live_cvdth_m,p_live_cvdth_h), ncol=3,
                           dimnames = list(patient_group_name,risk_levels))
for(r in 1:3){  # three rish groups
  for(i in 1:14){
  if(i != 7 && i != 14){
    a_P <- array(0, dim = c(n_states, n_states, 10),
                 dimnames = list(v_names_states, v_names_states, 1:10))
    a_P["S1", "S1", 1:5] <- 1-(p_live_cvd_lmh[i,r]*(1-p_acvd_cvdth[i]) +
                               p_live_cvdth_lmh[i,r]*p_live_cvd_lmh[i,r]*p_acvd_cvdth[i] +
                               p_live_oth_death[i])
    a_P["S1", "S2", 1:5] <- p_live_cvd_lmh[i,r]*(1-p_acvd_cvdth[i])
    a_P["S1", "S3", 1:5] <- p_live_cvdth_lmh[i,r]*p_live_cvd_lmh[i,r]*p_acvd_cvdth[i]
    a_P["S1", "S4", 1:5] <- p_live_oth_death[i]
    a_P["S2", "S1", 1:5] <- 0
    a_P["S2", "S2", 1:5] <- 1-p_live_oth_death[i]-
      (p_ccvd_cvdth[i]+p_ccvd_acvd[i]*p_acvd_cvdth[i])
    a_P["S2", "S3", 1:5] <- p_ccvd_cvdth[i]+
      p_ccvd_acvd[i]*p_acvd_cvdth[i]
```

```
  a_P["S2", "S4", 1:5] <- p_live_oth_death[i]
  a_P["S3", "S3", 1:5] <- 1
  a_P["S4", "S4", 1:5] <- 1

  a_P["S1", "S1", 6:10] <-  1-(p_live_cvd_lmh[i+1]*(1-p_acvd_cvdth[i+1]))+
                            p_live_cvdth_lmh[i+1]*p_live_cvd_lmh[i+1]*p_acvd_cvdth[i+1]
                            +p_live_oth_death[i+1])
  a_P["S1", "S2", 6:10] <- p_live_cvd_lmh[i+1]*(1-p_acvd_cvdth[i+1])
  a_P["S1", "S3", 6:10] <- p_live_cvdth_lmh[i+1]*p_live_cvd_lmh[i+1]*p_acvd_cvdth[i+1]
  a_P["S1", "S4", 6:10] <- p_live_oth_death[i+1]
  a_P["S2", "S1", 6:10] <- 0
  a_P["S2", "S2", 6:10] <- 1-p_live_oth_death[i+1]-
     (p_ccvd_cvdth[i+1]+p_ccvd_acvd[i+1]*p_acvd_cvdth[i+1])
  a_P["S2", "S3", 6:10] <- p_ccvd_cvdth[i+1]+p_ccvd_acvd[i+1]*p_acvd_cvdth[i+1]
  a_P["S2", "S4", 6:10] <-  p_live_oth_death[i+1]
  a_P["S3", "S3", 6:10] <- 1
  a_P["S4", "S4", 6:10] <- 1

  v_s_init <- c(state0 = 1, state1 = 0, state2 = 0, state3 = 0)
  m_M <- matrix(0,nrow     = (n_t), ncol = n_states,
                dimnames = list(0:(n_t-1), v_names_states))
  m_M[1, ] <- v_s_init
  for(t in 1:9){
    m_M[t + 1, ] <- m_M[t, ] %*% a_P[, , t]
  }
  result_m_M[,,i] <- m_M
}
  if(i == 7 | i == 14){
  a_P <- array(0, dim = c(n_states, n_states, 10),
               dimnames = list(v_names_states, v_names_states, 1:10))
  a_P["S1", "S1", 1:10] <- 1-(p_live_cvd[i]*(1-p_acvd_cvdth[i]) +
                              p_live_cvdth[i]*p_live_cvd[i]*p_acvd_cvdth[i] +
                              p_live_oth_death[i])
  a_P["S1", "S2", 1:10] <- p_live_cvd[i]*(1-p_acvd_cvdth[i])
  a_P["S1", "S3", 1:10] <- p_live_cvdth[i]*p_live_cvd[i]*p_acvd_cvdth[i]
  a_P["S1", "S4", 1:10] <- p_live_oth_death[i]
  a_P["S2", "S1", 1:10] <- 0
  a_P["S2", "S2", 1:10] <- 1-p_live_oth_death[i]-
    (p_ccvd_cvdth[i]+p_ccvd_acvd[i]*p_acvd_cvdth[i])
  a_P["S2", "S3", 1:10] <- p_ccvd_cvdth[i]+
    p_ccvd_acvd[i]*p_acvd_cvdth[i]
  a_P["S2", "S4", 1:10] <- p_live_oth_death[i]
  a_P["S3", "S3", 1:10] <- 1
  a_P["S4", "S4", 1:10] <- 1

  v_s_init <- c(state0 = 1, state1 = 0, state2 = 0, state3 = 0)
  m_M <- matrix(0,nrow     = (n_t), ncol = n_states,
                dimnames = list(0:(n_t-1), v_names_states))
  m_M[1, ] <- v_s_init
  for(t in 1:9){
    m_M[t + 1, ] <- m_M[t, ] %*% a_P[, , t]
  }
  result_m_M[,,i] <- m_M
```

```
  }
}

prob_group1 <- matrix(0, ncol=14, nrow=10,
                      dimnames=list(paste0("t",0:9),patient_group_name))
for (i in 1:14){
  prob_group1[,i] <- result_m_M[, 1, i]* p_live_cvd_lmh[i,r]
}
patient_group <- matrix(cbind(population_data[1:14,]$low,
                              population_data[1:14,]$medium,
                              population_data[1:14,]$high),
       ncol = 3, nrow=14,dimnames = list(patient_group_name,risk_levels))
for(j in 1:14){
  result_CVD_lmh[j,r] <- sum(prob_group1[,j]*patient_group[j,r])
}
}
```

```
print(xtable((rbind(result_CVD_lmh, "sum" = colSums(result_CVD_lmh))),
      caption = "CVD events for patients under Strategy1"),
      caption.placement="top",comment=FALSE)
```

Table 6: CVD events for patients under Strategy1

	low	medium	high
m40	3.80	0.30	1.36
m45	7.06	4.10	7.79
m50	11.82	6.18	9.92
m55	17.73	12.21	9.91
m60	15.89	16.79	11.84
m65	11.62	10.40	7.13
m70	9.79	8.92	7.53
f40	12.46	0.27	1.24
f45	32.01	1.22	4.00
f50	41.40	1.91	7.05
f55	35.85	27.44	13.92
f60	22.87	26.75	13.60
f65	17.02	27.63	15.99
f70	11.25	14.91	10.69
sum	250.58	159.03	121.96

```
result_CVD_stg1 <- sum(result_CVD_lmh)
result_CVD_stg1
```

```
[1] 531.5617
```

Strategy 2

```
p_live_cvd_l <- ProbFactor(p_live_cvd,HR_l_stg2)
p_live_cvd_m <- ProbFactor(p_live_cvd,HR_m_stg2*
```

```
                              HR_smk_cvd*HR_salt_cvd*HR_wtc_cvd)  # lifestyle intervention
p_live_cvd_h <- ProbFactor(p_live_cvd,HR_h_stg2*
                              HR_smk_cvdth*HR_salt_cvdth*HR_wtc_dth*    # lifestyle intervention
                              HR_hpt_lip_cvdth)   # treatment intervention

# transition probability to death
p_live_cvdth_l <- ProbFactor(p_live_cvdth,1)    # equal
p_live_cvdth_m <- ProbFactor(p_live_cvdth,1*
                               HR_smk_cvd*HR_salt_cvd*HR_wtc_cvd)  # lifestyle intervention
p_live_cvdth_h <- ProbFactor(p_live_cvdth,1.7*
                               HR_smk_cvdth*HR_salt_cvdth*HR_wtc_dth* # lifestyle intervention
                               HR_hpt_lip_cvdth) # treatment intervention
```

```
risk_levels <- c("low","medium","high")
result_CVD_lmh <- matrix(0,  nrow = 14,ncol = 3,
                         dimnames = list(patient_group_name, risk_levels))
p_live_cvd_lmh <- matrix(cbind(p_live_cvd_l,p_live_cvd_m,p_live_cvd_h), ncol=3,
                         dimnames = list(patient_group_name,risk_levels))
p_live_cvdth_lmh <- matrix(cbind(p_live_cvdth_l,p_live_cvdth_m,p_live_cvdth_h), ncol=3,
                           dimnames = list(patient_group_name,risk_levels))
for(r in 1:3){  # three rish groups
  for(i in 1:14){
  if(i != 7 && i != 14){
    a_P <- array(0, dim = c(n_states, n_states, 10),
                 dimnames = list(v_names_states, v_names_states, 1:10))
    a_P["S1", "S1", 1:5] <- 1-(p_live_cvd_lmh[i,r]*(1-p_acvd_cvdth[i]) +
                               p_live_cvdth_lmh[i,r]*p_live_cvd_lmh[i,r]*p_acvd_cvdth[i] +
                               p_live_oth_death[i])
    a_P["S1", "S2", 1:5] <- p_live_cvd_lmh[i,r]*(1-p_acvd_cvdth[i])
    a_P["S1", "S3", 1:5] <- p_live_cvdth_lmh[i,r]*p_live_cvd_lmh[i,r]*p_acvd_cvdth[i]
    a_P["S1", "S4", 1:5] <- p_live_oth_death[i]
    a_P["S2", "S1", 1:5] <- 0
    a_P["S2", "S2", 1:5] <- 1-p_live_oth_death[i]-
      (p_ccvd_cvdth[i]+p_ccvd_acvd[i]*p_acvd_cvdth[i])
    a_P["S2", "S3", 1:5] <- p_ccvd_cvdth[i]+
      p_ccvd_acvd[i]*p_acvd_cvdth[i]
    a_P["S2", "S4", 1:5] <- p_live_oth_death[i]
    a_P["S3", "S3", 1:5] <- 1
    a_P["S4", "S4", 1:5] <- 1

    a_P["S1", "S1", 6:10] <-  1-(p_live_cvd_lmh[i+1]*(1-p_acvd_cvdth[i+1])+
                               p_live_cvdth_lmh[i+1]*p_live_cvd_lmh[i+1]*p_acvd_cvdth[i+1]
                               +p_live_oth_death[i+1])
    a_P["S1", "S2", 6:10] <- p_live_cvd_lmh[i+1]*(1-p_acvd_cvdth[i+1])
    a_P["S1", "S3", 6:10] <- p_live_cvdth_lmh[i+1]*p_live_cvd_lmh[i+1]*p_acvd_cvdth[i+1]
    a_P["S1", "S4", 6:10] <- p_live_oth_death[i+1]
    a_P["S2", "S1", 6:10] <- 0
    a_P["S2", "S2", 6:10] <- 1-p_live_oth_death[i+1]-
       (p_ccvd_cvdth[i+1]+p_ccvd_acvd[i+1]*p_acvd_cvdth[i+1])
    a_P["S2", "S3", 6:10] <- p_ccvd_cvdth[i+1]+p_ccvd_acvd[i+1]*p_acvd_cvdth[i+1]
    a_P["S2", "S4", 6:10] <-  p_live_oth_death[i+1]
    a_P["S3", "S3", 6:10] <- 1
    a_P["S4", "S4", 6:10] <- 1
```

```
    v_s_init <- c(state0 = 1, state1 = 0, state2 = 0, state3 = 0)
    m_M <- matrix(0,nrow     = (n_t), ncol = n_states,
                  dimnames = list(0:(n_t-1), v_names_states))
    m_M[1, ] <- v_s_init
    for(t in 1:9){
      m_M[t + 1, ] <- m_M[t, ] %*% a_P[, , t]
    }
    result_m_M[,,i] <- m_M
  }
    if(i == 7 | i == 14){
    a_P <- array(0, dim = c(n_states, n_states, 10),
                 dimnames = list(v_names_states, v_names_states, 1:10))
    a_P["S1", "S1", 1:10] <- 1-(p_live_cvd[i]*(1-p_acvd_cvdth[i]) +
                                p_live_cvdth[i]*p_live_cvd[i]*p_acvd_cvdth[i] +
                                p_live_oth_death[i])
    a_P["S1", "S2", 1:10] <- p_live_cvd[i]*(1-p_acvd_cvdth[i])
    a_P["S1", "S3", 1:10] <- p_live_cvdth[i]*p_live_cvd[i]*p_acvd_cvdth[i]
    a_P["S1", "S4", 1:10] <- p_live_oth_death[i]
    a_P["S2", "S1", 1:10] <- 0
    a_P["S2", "S2", 1:10] <- 1-p_live_oth_death[i]-
      (p_ccvd_cvdth[i]+p_ccvd_acvd[i]*p_acvd_cvdth[i])
    a_P["S2", "S3", 1:10] <- p_ccvd_cvdth[i]+
      p_ccvd_acvd[i]*p_acvd_cvdth[i]
    a_P["S2", "S4", 1:10] <- p_live_oth_death[i]
    a_P["S3", "S3", 1:10] <- 1
    a_P["S4", "S4", 1:10] <- 1

    v_s_init <- c(state0 = 1, state1 = 0, state2 = 0, state3 = 0)
    m_M <- matrix(0,nrow     = (n_t), ncol = n_states,
                  dimnames = list(0:(n_t-1), v_names_states))
    m_M[1, ] <- v_s_init
    for(t in 1:9){
      m_M[t + 1, ] <- m_M[t, ] %*% a_P[, , t]
    }
    result_m_M[,,i] <- m_M
  }
}

prob_group2 <- matrix(0, ncol=14, nrow=10,
                      dimnames=list(paste0("t",0:9),patient_group_name))
for (i in 1:14){
  prob_group2[,i] <- result_m_M[, 1, i]* p_live_cvd_lmh[i,r]
}
patient_group <- matrix(cbind(population_data[15:28,]$low,
                              population_data[15:28,]$medium,
                              population_data[15:28,]$high),
       ncol = 3, nrow=14,dimnames = list(patient_group_name,risk_levels))
result_CVD <- matrix(NA)
for(j in 1:14){
  result_CVD_lmh[j,r] <- sum(prob_group2[,j]*patient_group[j,r])
}
}
```

```
print(xtable((rbind(result_CVD_lmh, "sum" = colSums(result_CVD_lmh))),
      caption = "CVD events for patients under Strategy2"),
      caption.placement="top",comment=FALSE)
```

Table 7: CVD events for patients under Strategy2

	low	medium	high
m40	2.67	1.18	0.45
m45	5.95	6.77	3.09
m50	4.60	14.36	6.32
m55	2.15	18.44	17.27
m60	0.43	9.90	34.25
m65	0.12	2.44	27.71
m70	0.00	0.60	27.18
f40	9.21	0.47	0.10
f45	21.90	4.63	0.72
f50	22.67	14.39	3.40
f55	15.64	34.92	12.70
f60	3.24	29.58	24.10
f65	0.37	13.73	44.80
f70	0.00	3.93	33.51
sum	88.96	155.34	235.60

```
result_CVD_stg2 <- sum(result_CVD_lmh)
result_CVD_stg2
```

[1] 479.9045

Strategy 3

```
p_live_cvd_l <- ProbFactor(p_live_cvd,HR_l_stg3)
p_live_cvd_m <- ProbFactor(p_live_cvd,HR_m_stg3*
                           HR_smk_cvd*HR_salt_cvd*HR_wtc_cvd)  # lifestyle intervention
p_live_cvd_h <- ProbFactor(p_live_cvd,HR_h_stg3*
                           HR_smk_cvdth*HR_salt_cvdth*HR_wtc_dth*    # lifestyle intervention
                           HR_hpt_lip_cvdth)   # treatment intervention

# transition probability to death
p_live_cvdth_l <- ProbFactor(p_live_cvdth,1)    # equal
p_live_cvdth_m <- ProbFactor(p_live_cvdth,1*
                             HR_smk_cvd*HR_salt_cvd*HR_wtc_cvd)  # lifestyle intervention
p_live_cvdth_h <- ProbFactor(p_live_cvdth,1.7*
                             HR_smk_cvdth*HR_salt_cvdth*HR_wtc_dth* # lifestyle intervention
                             HR_hpt_lip_cvdth) # treatment intervention
```

```
risk_levels <- c("low","medium","high")
result_CVD_lmh <- matrix(0,  nrow = 14,ncol = 3,
                         dimnames = list(patient_group_name, risk_levels))
p_live_cvd_lmh <- matrix(cbind(p_live_cvd_l,p_live_cvd_m,p_live_cvd_h), ncol=3,
```

```
                          dimnames = list(patient_group_name,risk_levels))
p_live_cvdth_lmh <- matrix(cbind(p_live_cvdth_l,p_live_cvdth_m,p_live_cvdth_h), ncol=3,
                           dimnames = list(patient_group_name,risk_levels))
for(r in 1:3){  # three rish groups
  for(i in 1:14){
  if(i != 7 && i != 14){
    a_P <- array(0, dim = c(n_states, n_states, 10),
                 dimnames = list(v_names_states, v_names_states, 1:10))
    a_P["S1", "S1", 1:5] <- 1-(p_live_cvd_lmh[i,r]*(1-p_acvd_cvdth[i]) +
                                 p_live_cvdth_lmh[i,r]*p_live_cvd_lmh[i,r]*p_acvd_cvdth[i] +
                                 p_live_oth_death[i])
    a_P["S1", "S2", 1:5] <- p_live_cvd_lmh[i,r]*(1-p_acvd_cvdth[i])
    a_P["S1", "S3", 1:5] <- p_live_cvdth_lmh[i,r]*p_live_cvd_lmh[i,r]*p_acvd_cvdth[i]
    a_P["S1", "S4", 1:5] <- p_live_oth_death[i]
    a_P["S2", "S1", 1:5] <- 0
    a_P["S2", "S2", 1:5] <- 1-p_live_oth_death[i]-
      (p_ccvd_cvdth[i]+p_ccvd_acvd[i]*p_acvd_cvdth[i])
    a_P["S2", "S3", 1:5] <- p_ccvd_cvdth[i]+
      p_ccvd_acvd[i]*p_acvd_cvdth[i]
    a_P["S2", "S4", 1:5] <- p_live_oth_death[i]
    a_P["S3", "S3", 1:5] <- 1
    a_P["S4", "S4", 1:5] <- 1

    a_P["S1", "S1", 6:10] <-  1-(p_live_cvd_lmh[i+1]*(1-p_acvd_cvdth[i+1])+
                               p_live_cvdth_lmh[i+1]*p_live_cvd_lmh[i+1]*p_acvd_cvdth[i+1]
                               +p_live_oth_death[i+1])
    a_P["S1", "S2", 6:10] <- p_live_cvd_lmh[i+1]*(1-p_acvd_cvdth[i+1])
    a_P["S1", "S3", 6:10] <- p_live_cvdth_lmh[i+1]*p_live_cvd_lmh[i+1]*p_acvd_cvdth[i+1]
    a_P["S1", "S4", 6:10] <- p_live_oth_death[i+1]
    a_P["S2", "S1", 6:10] <- 0
    a_P["S2", "S2", 6:10] <- 1-p_live_oth_death[i+1]-
       (p_ccvd_cvdth[i+1]+p_ccvd_acvd[i+1]*p_acvd_cvdth[i+1])
    a_P["S2", "S3", 6:10] <- p_ccvd_cvdth[i+1]+p_ccvd_acvd[i+1]*p_acvd_cvdth[i+1]
    a_P["S2", "S4", 6:10] <-  p_live_oth_death[i+1]
    a_P["S3", "S3", 6:10] <- 1
    a_P["S4", "S4", 6:10] <- 1

    v_s_init <- c(state0 = 1, state1 = 0, state2 = 0, state3 = 0)
    m_M <- matrix(0,nrow     = (n_t), ncol = n_states,
                  dimnames = list(0:(n_t-1), v_names_states))
    m_M[1, ] <- v_s_init
    for(t in 1:9){
      m_M[t + 1, ] <- m_M[t, ] %*% a_P[, , t]
    }
    result_m_M[,,i] <- m_M
  }
    if(i == 7 | i == 14){
    a_P <- array(0, dim = c(n_states, n_states, 10),
                 dimnames = list(v_names_states, v_names_states, 1:10))
    a_P["S1", "S1", 1:10] <- 1-(p_live_cvd[i]*(1-p_acvd_cvdth[i]) +
                                 p_live_cvdth[i]*p_live_cvd[i]*p_acvd_cvdth[i] +
                                 p_live_oth_death[i])
    a_P["S1", "S2", 1:10] <- p_live_cvd[i]*(1-p_acvd_cvdth[i])
```

```
    a_P["S1", "S3", 1:10] <- p_live_cvdth[i]*p_live_cvd[i]*p_acvd_cvdth[i]
    a_P["S1", "S4", 1:10] <- p_live_oth_death[i]
    a_P["S2", "S1", 1:10] <- 0
    a_P["S2", "S2", 1:10] <- 1-p_live_oth_death[i]-
      (p_ccvd_cvdth[i]+p_ccvd_acvd[i]*p_acvd_cvdth[i])
    a_P["S2", "S3", 1:10] <- p_ccvd_cvdth[i]+
      p_ccvd_acvd[i]*p_acvd_cvdth[i]
    a_P["S2", "S4", 1:10] <- p_live_oth_death[i]
    a_P["S3", "S3", 1:10] <- 1
    a_P["S4", "S4", 1:10] <- 1

    v_s_init <- c(state0 = 1, state1 = 0, state2 = 0, state3 = 0)
    m_M <- matrix(0,nrow     = (n_t), ncol = n_states,
                  dimnames = list(0:(n_t-1), v_names_states))
    m_M[1, ] <- v_s_init
    for(t in 1:9){
      m_M[t + 1, ] <- m_M[t, ] %*% a_P[, , t]
    }
    result_m_M[,,i] <- m_M
  }
}

prob_group3 <- matrix(0, ncol=14, nrow=10,
                      dimnames=list(paste0("t",0:9),patient_group_name))
for (i in 1:14){
  prob_group3[,i] <- result_m_M[, 1, i]* p_live_cvd_lmh[i,r]
}

patient_group <- matrix(cbind(population_data[29:42,]$low,
                              population_data[29:42,]$medium,
                              population_data[29:42,]$high),
       ncol = 3, nrow=14,dimnames = list(patient_group_name,risk_levels))
result_CVD <- matrix(NA)
for(j in 1:14){
  result_CVD_lmh[j,r] <- sum(prob_group3[,j]*patient_group[j,r])
}
}
```

```
print(xtable((rbind(result_CVD_lmh, "sum" = colSums(result_CVD_lmh))),
      caption = "CVD events for patients under Strategy3"),
      caption.placement="top",comment=FALSE)
```

```
result_CVD_stg3 <- sum(result_CVD_lmh)
result_CVD_stg3
```

[1] 446.8817

Conclusion

Table 8: CVD events for patients under Strategy3

	low	medium	high
m40	0.00	0.00	0.00
m45	0.00	0.00	0.00
m50	4.81	16.08	6.46
m55	2.25	20.61	17.66
m60	0.45	11.04	35.01
m65	0.12	2.71	28.30
m70	0.00	0.68	27.82
f40	0.00	0.00	0.00
f45	0.00	0.00	0.00
f50	23.69	16.11	3.48
f55	16.34	39.05	12.99
f60	3.39	33.03	24.64
f65	0.39	15.30	45.77
f70	0.00	4.40	34.30
sum	51.45	159.00	236.44

```
print(xtable((matrix(cbind(result_CVD_stg0,result_CVD_stg1,
      result_CVD_stg2,result_CVD_stg3),nrow = 1, ncol = 4,
      dimnames = list("",v_names_str))),
      caption = "CVD events for patients under 3 strategies"),
      caption.placement="top",comment=FALSE)
```

Table 9: CVD events for patients under 3 strategies

	Strategy0	Strategy1	Strategy2	Strategy3
1	748.73	531.56	479.90	446.88